Paul D. Dayton
Editor

Evidence-Based Bunion Surgery

A Critical Examination of Current and Emerging Concepts and Techniques

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Preface

Balas and Boren [1] studied the diffusion of discovery in the medical professions and found that the average lag time for adoption of new ideas and practices in medicine, based on the best current evidence available, is 17 years. There are many reasons that a surgeon may be slow or even resistant to adopt new information; certainly, the sheer volume of information that is presented in the health sciences every year makes it difficult for physicians to capture and incorporate all new ideas. In a landmark philosophical analysis of medical errors, Gorovitz and Macintyre [2] proposed that there are two fundamental reasons for medical errors. The first is ignorance, or the fact that the answer to a question has not been discovered. This mode of failure is forgivable, because we do not yet have the answer. The second reason is ineptitude, which they defined as failure to acknowledge or put into practice information that does exist due to internal or external bias. The evidence-based medicine triad—which always includes the patient's goals, the physician's clinical experience, and the best evidence we have available to us at the time—must be the basis for quality care. This, however, requires extensive time and energy to investigate and understand the wealth of data. The goal of this book is to consolidate the information available to us for the treatment of bunions, with a focus on critically analyzing the successes and failures of the most common procedures and provide this capture of information for providers.

I have no doubt that every one of us has had a bunion procedure that we performed on a patient that we wish we could have a "mulligan" on, perhaps even several of them. We wonder: Why did the bunion recur? Why does the toe still not look clinically "normal" to the patient or surgeon? Was it the fixation, the patient characteristics, or just a "bad" bunion? We struggle to identify the root cause of the failure because we feel we did everything correctly: We chose the right procedure based on the algorithm we were given, we performed it technically correctly, we educated the patient on the postoperative expectations and recovery, yet we don't get an ideal outcome every time. The "why" may not be the execution, but rather a failure of the algorithms themselves. It has been my experience with practice and research of bunion surgery that we spend a great deal of time and energy modifying existing techniques and algorithms, which in fact does not lead to innovation and true discovery in many cases. Continual minor modifications of a technique without consistently measurable improvements might suggest a flaw in the very basis of our understanding of the problem. Innovation almost always comes from the willingness to reject the status quo and a complete departure from convention. It is all too common for us, myself included, to justify what we do by the statement "this is what works in my hands." This statement is very common and is about as far from evidence-based medicine as can be due to the following biases, which are inherent in our human nature: We remember our good results with priority; we rationalize our bad results; we avoid the evidence if it questions our autonomy; we avoid the evidence if it affects our financial position; and we demonize those that seek to change the current cultural norms. This will seem to some readers to be hypercritical; however, to truly grow and improve, we need to recognize our internal and external biases and make every attempt to distance ourselves.

The patient is why we ultimately decided to write this book. As a foot and ankle specialist, patients come to us expecting the best treatment that is based on the best science and knowledge available to us at the time. This book is different than many surgical texts, in that it is not focused narrowly on technique; rather, the priority is examination of the current evidence and how it applies to the patient and the procedure. As the reader will note, there are extensive citations, not just supporting a particular procedure or viewpoint but also examining the failures and shortcomings. In fact, some readers may find many of the chapters to have a negative perspective on a popular procedure that we have all practiced for many years, while other techniques and procedures that are not currently as popular are supported by the preponderance of the evidence. Certainly, many of the ideas, along with the current available evidence, are incomplete and may be flawed based on our current understandings, and these ideas will need to be continually examined further through additional research. We hope to spark the imagination and passion of young scientists and surgeons to fill in the gaps that exist.

There are many people to thank for their help with this project. I am indebted to the authors and contributors for their hard work, past surgeons and scientists for their contributions to our knowledge, and the publisher for their willingness to take on this project. I also want to acknowledge the countless mentors whom I have learned from and many students whom I have learned with over my career. I am also thankful for Alexander, Andrew, Weston, and Mindi, who all helped with this text through their support of my career.

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Overview of the Condition

1

Paul D. Dayton, Dixon Xu, and James Mahoney

Definition

The common deformity of the first ray known as a "bunion" is a progressive positional deformity which leads to pain from shoe pressure and biomechanical malfunction of the first metatarsal phalangeal joint. While the medial bump is widely considered the etiology of pain, malalignment results in progressive joint adaptation and degeneration. The exact biomechanical fault and the etiology of the progression of the deformity remain unclear. The origin of the terminologies describing this first ray deformity deserves specific attention due to the common historical misapplications of terms used to describe disorders of the first metatarsophalangeal joint (MTPJ). Bunion is derived from the Latin term *bunio*, meaning turnip. This term has been applied to describe any enlargement of the first MTPJ and therefore poorly defines the deformity [7, 22]. It was not until 1870, when Carl Hueter, a German surgeon, coined the term hallux valgus to more accurately describe the condition [28]. Hueter defined this first ray deformity as a subluxation of the first MTPJ in the transverse plane with lateral deviation of the great toe and medial deviation of the first metatarsal. However, the term hallux valgus raised questions on whether the laterally deviated hallux should be the primary focus of the deformity. Therefore, half a century later, Truslow [66] proposed the term metatarsus primus varus to replace hallux valgus in the belief that the medially deviated first metatarsal is the primary level of deformity. This is in fact the first time the primary level of deformity is considered to be located at the first metatarsal cuneiform joint.

It is important to note that valgus and varus are used to describe transverse plane deviations in the aforementioned studies. A later term hallux abducto valgus was developed to incorporate the frontal plane eversion of the great toe in defining this deformity. The term valgus when used in this text describes frontal plane rotation and therefore differs from that used by Hueter who used it to describe the transverse plane position. Likewise, the term varus used by Truslow to describe the transverse plane deviation of the metatarsal is also used to describe frontal plane inversions in the foot. Confusion over the correct terminology to describe this first ray deformity still exists, and a uniformly accepted term is needed to accurately capture the nature of the deformity and to

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facilitate effective communication among providers. In an effort of achieving this, Dayton and colleagues [18] proposed the term hallux abducto valgus with metatarsus primus adducto valgus to address the multiplanar components of this deformity evident by previous cadaveric and clinical studies [16, 17, 54]. A more detailed description of the anatomy and clarification of the terminology of this first ray deformity will be discussed in Chap. 5.

Epidemiology

The true prevalence of HAV in the general population has never been uniformly established in the literature, although a wide range of estimates were presented in multiple reports ranging from 0.9% to 74% [2, 44, 61]. Previous studies demonstrate that HAV may more commonly correlate with the female gender and elderly individuals [51]. A systematic review conducted in 2010 [52] determined the prevalence of HAV to be 23% in adults aged 18–65 years and 35.7% in individuals over 65 years of age. The study also found a higher prevalence rate in females (30%) compared to males (13%), supporting the predilection of HAV in the female population as observed by other studies.

Many attribute this higher prevalence to the high-fashion yet less physiologic footwear worn by the females [14, 34]. It has been long established that HAV is associated with a habitually shod population as the incidence of HAV is very low in unshod people [55, 65]. Therefore, the ill-fitting and constricting footwear may further predispose individuals to the development of HAV deformity [12]. However, what may be more important are the hereditary factors as suggested by more recent literature [11, 58]. Studies report adult males and females have a positive family history with a pattern of maternal transmission. There may be a greater genetic predisposition for HAV in the female population [11, 12, 50]; however, whether this trait is associated with X-linked dominant transmission, autosomal dominant transmission, or polygenic transmission cannot be determined at this time.

The age of onset for HAV is still a topic of debate. In Piggott's original series of adult patients, 95% of patients recalled the onset of deformity before 20 years of age [57]. A study conducted by Hardy and Clapham proposes an early age of onset of the deformity with 46% of HAV deformities occurring before age 20 [25]. Other studies have suggested the mean onset of deformity to be in the third through fifth decades with an equal incidence rate in the second through fifth decades [13, 14]. A later study suggested that while the mean age of onset may vary, very few HAV deformities developed in the first decade, and therefore most HAV deformities develop and progress after skeletal maturity [12]. The exact age of onset is not agreed upon, and there does not seem to be a correlation between the age of onset and severity of the deformity. This may be because the recognition of the deformity by the patient is in many cases subjective and dependent on the onset of symptoms and not the awareness of the deformity.

HAV deformity has commonly been associated with other global foot deformities and dysfunction. A contracted Achilles tendon can theoretically contribute to the development of HAV deformity due to the repetitive medial stress to the hallux when the foot rolls on the medial aspect and externally rotates during gait. The ankle equinus deformity is typically defined as less than 10 degrees of ankle dorsiflexion [20]. Recent studies show no correlation between ankle dorsiflexion and the magnitude of HAV [12, 13]. In fact, according to one study by Grebing and Coughlin, 81% of individuals without the deformity demonstrate less than 10 degrees of ankle dorsiflexion, whereas this limited ankle dorsiflexion is found in only 67% of those with the deformity, further suggesting that ankle equinus may not be a contributory factor of HAV [24]. Similarly, the literature on the association of pes planus and HAV is unclear. While some authors believe that HAV tends to occur in pronated foot types [30, 67], no data are available to quantify this relationship. In addition, no increased incidence of HAV in patients with pes planus was observed in multiple studies [35, 59, 62], suggesting pes planus may not be a significant factor in the development of HAV. Nonetheless, patients with pes planus may have a more rapid progression of the deformity due to the altered biomechanics [33].

HAV deformity has also been discussed as associated or even caused by first ray hypermobility. This concept is first introduced by Morton [48] and later popularized by Lapidus [38]. However, whether this truly exists is still controversial as the level of the hypermobility, the proper diagnostic exam, and clinical imaging modality to assess the hypermobility cannot be agreed upon among providers [27, 36, 39, 49]. It is beyond the scope of this chapter to discuss the existing schools of thoughts and evidence in the current literature regarding the association of first ray hypermobility and HAV deformity. A more detailed review of the mechanical theories will be presented in Chap. 4. Other associated diseases in HAV include ligamentous laxity such as Ehlers-Danlos and Marfan syndrome, generalized neuromuscular diseases, cystic degeneration of the medial capsule of the first MTPJ, neuroma, and previous amputation of the second metatarsal. Discussion of the many possible etiologies of the bunion deformity is discussed in Chap. 3.

Quality of Life

As the most common deformity affecting the hallux, multiple studies have shown that HAV is strongly associated with impaired health-related quality of life (HRQOL) [1, 10, 40, 70]. Pain is the most common and significant chief complaint in patients with HAV deformity, with 70–75% of pain located over the medial eminence and 40–48% of pain caused by intractable plantar keratosis and metatarsalgia [12, 42]. In addition, HAV is associated with impaired balance, altered gait patterns, and increased risk of falls particularly in the elderly population [45, 46].

Whether the severity of HAV deformity is correlated with pain intensity and reduced quality of life is still unclear at this time. Pain intensity may be influenced by lifestyle, demographic, and cognitive factors [1, 29]. It has been reported that increased HAV deformity leads to increased foot pain and progressive reduction in functional scores of both the general health (SF-36) and foot-specific (FPDI) surveys [46]. In addition, an increasing severity of HAV directly corresponds to a reduction in both general health and foot health among the older adults [40]. However, Hurn et al. [29] found that foot pain associated with HAV was not determined by severity of the structural deformity or first MTPJ osteoarthritis, but rather by a patient's general health status, educational attainment, and level of physical activity. The authors also concluded that altered foot and ankle biomechanics such as weakness with hallux plantarflexion significantly contributed to increasing foot pain [29]. This flexor weakness of the hallux is also observed in the elderly population with disabling foot pain and reduced HRQOL [47], suggesting the importance of assessing dynamic foot and ankle biomechanics rather than focusing on a static structural deformity. A recent study by Yamamoto et al. [70] found that although quality of life was lower in patients with untreated HAV deformities, this reduction in quality of life was not correlated with severity of the hallux deformity, degree of dislocation of the second MTPJ, age, or BMI. Interestingly, pain severity and impaired foot function are directly correlated with increased HAV angle in the nondominant foot according to one study in the female population [10], further elucidating the need to assess the dynamic biomechanics of the lower extremities.

The impact of HAV is not just limited to pain and alteration of physical function. It has also been shown to affect the mental health and cognitive perception and may lead to detrimental effects on self-esteem [46]. Patients with untreated HAV exhibit significant concerns over foot appearance and difficulty with footwear [53]. In fact, free choice of footwear is significantly associated with improved HRQOL in one study [63], suggesting the importance of evaluating patients' footwear concerns when treating this deformity. A holistic approach should be employed in the treatment of HAV rather than an isolated correction of the structural deformity. A patient's chief complaint must be evaluated in the context of occupation, level of physical activity, preferences of footwear, health history, goals, and expectations of seeking the treatment to determine the optimal treatment option and physical rehabilitation for the patient.

Treatment Economics

A timely question in today's healthcare reform environment is this: how many corrective surgeries are performed and what is the cost of surgical and nonsurgical care? Hallux abducto valgus surgery is an extremely common occurrence, with reports that more than 200,000 patients have been estimated to undergo hallux valgus surgery in the United States every year [14]. Recent unpublished survey of billing records indicates that there was between 300,000 and 330,000 bunion operations in the United States in 2013 excluding isolated soft tissue corrections (personal investigation). The diversity of insurance products and billing codes for correction as well as the variability in the coding of the deformity and the corrective procedure or procedures makes accurate assessment difficult. Similarly, this diversity of insurance products and nontransparency of billing and coding insulate most patients from the true costs of the healthcare services they consume. Patients are frequently unaware of the overall cost of bunion surgery. A study conducted by Wiley et al. quotes the overall mean bundled price with hospital fees included at $18,332, ranging from $3,542 to 52,207, while the overall mean physician fee quoted was $2,487 and ranges from $800 to 7,934, suggesting an extremely high price variability and a low price transparency for bunion surgeries currently performed in the United States [69]. When reviewing data for Medicare patients, a total of 23,446 procedures for bunion corrections were identified in 2011 with an estimated combined cost of $59.5 million including professional fees and hospital charges and an overall estimated $325.1 million economic burden to the system when indirect factors such as disabilities and workdays lost were considered [6].

There are multiple recent papers identifying recurrence rates of between 25% and 73% based on radiographic evaluation with reported revision rates ranging from 5.56% to 8.19%, thus calling into question our common corrective techniques [21, 32, 56]. The costs of revision or repeat surgeries are not quantifiable with current data, but second or third surgeries certainly increase the overall cost of caring for patients with the deformity. Additionally, there are indirect costs of loss of productivity associated with not only the index procedure but subsequent surgeries as well. It is worth noting that no statistically difference is identified in revision rates among different surgical methods employed for hallux abducto valgus, prompting the necessity to further examine our current practice algorithm for this common deformity [60]. Because complications such as recurrence are common, the cost of bunion surgery has potential to add up for the patient, surgeon, and healthcare system. A more complete understanding of the pathological and normal anatomy will provide a basis for surgeons to design procedures and techniques that will theoretically provide more accurate and durable correction.

Effect of Variability on Quality of Outcomes

Well over 100 procedures have been described for correcting bunions. This variability is based in large part on individual surgeon preference and not necessarily supported by high-level evidence. We have come to accept a very high degree of variability in treating HAV, with surgeons rarely agreeing on the best treatment approach. In fact, differences in the approach to bunion surgery are noted to occur regionally and locally with no semblance of consistency in procedure selection or execution. This extreme variability and lack of consensus calls into question our basic understanding of the problem. As with any problem, we should strive to find the single most efficient and reliable solution, and in situations in which many solutions are perceived to be needed, we should reevaluate the very basis of our thought process. Multiple and repeated minor modifications to any existing technique or system can be defined as a failure of the basic paradigm. Bunion surgery is one area that has such extreme variability that it would suggest that we may indeed need to change our entire foundation for evaluation and management. Using a variety of radiographic algorithms, we attempt to define each bunion as a unique entity based on the degree of positional change, and it is this practice that drives the continued practice of selecting different variations of corrective surgeries.

Treatment variability is one of the factors that has been identified as a potential cause of lower healthcare quality. In fact, much of medicine in the United States remains empirical today as the decision-making process relies more on the medical opinions of the providers and local supply of resources rather than evidence from clinical sciences, thus leading to wide practice variations and healthcare outcomes [68]. One study investigating the quality of care in the United States found that Americans on average received only half of recommended medical care processes [5]. The gap between clinical sciences and bedside medicine is quite substantial. This practice variation, which is characterized by variation in adopting established effective care, variation in choosing preference-sensitive care, and variation in supply-sensitive care, is known as unwarranted variation and has huge implications in both healthcare quality and financial burden to the healthcare system [8, 68]. The abundance of unwarranted variations can be partly attributed to practice algorithms that are not supported by the current medical evidence but rather provider preference [68]. Many providers are more apt to trust their personal experiences and instincts over medical literature. Contrary to popular belief that clinical experience leads to better patient care, a systematic review exploring the relationship between provider experience and quality of care found that providers who have been in practice for more years are less likely to adhere to appropriate standards of care and are correlated with poorer patient outcomes, suggesting the importance of adopting evidence-based medicine and quality assurance strategies in today's practice environment [9].

In order to improve quality of care, it is widely accepted that first step should be taken to reduce practice variations [8, 9, 68]. It is clear that our current levels of discrepancy in the treatment of HAV are simply too high. Inconsistency in healthcare can be costly and in many cases may compromise the patient's quality of life. Koenig and Bozic [37] discussed the concept of value-based care related to orthopedic care. They "make the case that standardization of care along evidence based guidelines is the most predictable pathway to enhancing value in healthcare." They conclude that care pathways can reduce process variation which will have the effect of increasing quality and reducing cost while at the same time reducing complications. There is well-known resistance by many providers to adopting evidence-based care planning and standardization of process citing the necessity for professional autonomy and the common misconception that evidence-based care planning is "cookbook medicine." However, there is a compelling body of literature that clearly indicates reduction in variation through consistency results in higher-quality product [19].

The old notion that "not all HAV deformities are equal" is unfounded based on our current understanding of the deformity. HAV is a singular tri-plane positional deformity and not an intrinsic metatarsal deformity regardless of the x-ray severity measures. It is interesting that despite the relatively clear definition of the deformity, we accept the notion that a multitude of different treatment options are needed to correct the deformity. As stated earlier, our current practice paradigm of HAV deformity correction needs to be reexamined and should incorporate evidence from current literature. We should aim to develop a deformity correction guideline for HAV that reflects these updates in our understanding of the deformity.

Limitations Present in Current Medical Literature

Surgeons treating HAV strive to provide the most up-to-date and effective solutions for the problems our patients face through evidence-based practice. The most common definition of evidence-based medicine is the intersection between patients' needs and expectations, systematic review of published clinical research, and surgeon experience. A challenge that exists in the practice of EBM is understanding the limitations of clinical research evidence. In an essay examining the state of the medical literature, Ioannidis [31] boldly claimed that most research findings are false. He argues that a premise of clinical research is replication of study results and that the high rate of non-replication of studies was due to the "ill-founded strategy" of basing conclusive evidence on a p-value less than 0.05. The "truth" of a study result depends upon a high pretest probability that it is true, the statistical power of the study, limited author bias, and a high post-study probability that it is true. He stated that studies should not rely on the p-value calculated alone to represent statistical significance. He provided the following example to illustrate his points. A randomized controlled trial (RCT) that is adequately powered with a 50% pretest probability that the intervention is effective, and which has 10% bias (proportion of studies reported that would not be research findings, but are reported as such), is true 85% of the time. Furthermore, he found that an underpowered but well-performed phase I/II RCT is true 23% of the time, and a meta-analysis of small, inconclusive studies is true 41% of the time.

Another example of a bias present in clinical studies is the practice of relying on the Oxford level of evidence that is assigned by an author and journal to represent the quality of the research product. This concept is highlighted in a review [15] of 54 prospective controlled randomized trials on lateral epicondylitis. They found that of the studies published as level II based on the Oxford Levels of Evidence, nearly 90% did not have appropriate methodology based on independent expert review. They were found to be unsatisfactory in the areas of descriptions of recruitment, power-level calculations, randomization, and blinding based on methodology assessment. When evaluating published studies, the first item that most readers turn to is the level of evidence. We rely on the editorial board and the peer reviewers to provide that guidance, because there can be significant disagreement. A further disparity was found between the level of evidence assigned by reviewers in the *Journal of Bone and Joint Surgery* (American Volume) that would be required to optimally answer the primary research question and the level of evidence that was actually used [3]. Of the 64 JBJS-Am manuscripts eligible for analysis by Baldwin, the average level of evidence was between levels II and III. The biggest discrepancies occurred in levels I and III, where the evaluators only found four papers that met level I criteria vs. 11 that were published as level 1 but determined to be level III after review. In another study Barske and Baumhauer [4] evaluated the level of evidence cited for papers in seven foot and ankle surgery journals published in North America and the level of evidence assigned by the journal. They found a poor level of agreement with *Journal of Foot and Ankle Surgery* (JFAS) and higher agreement with all other journals.

Reporting bias occurs when published research findings are "influenced by the nature and direction of results" (Cochrane 2016). Specifically, there is an obvious trend to publish only "positive" findings that show an intervention is successful, and as a result, these studies are more likely to be cited by others. This includes many studies funded by commercial interests that show studies with a positive outcome tend to be published more frequently. "Negative" findings tend not to see the light of day [23]. Reporting bias, specifically publication bias and selective outcome reporting, is a widespread phenomenon in the medical literature [43]. In many cases, there was withholding of study data by manufacturers or regulatory agencies or an active attempt by manufacturers to suppress publication. In analyzing over 16,000 original papers published in the fields of orthopedic and general surgery, 74% of the articles reported positive findings, 17% negative findings, and 9% were neutral. These percentages were similar for all years of publication (2000–2006) and in all the journals analyzed [43]. By publishing a majority of studies that show a positive result in surgery, patient safety will be compromised by the inability to review unpublished negative studies and the valuable data that is contained in these trials [26]. As a result, there is an increasing call for journals to publish all findings in order to present a complete and unbiased picture regarding interventions. The WHO has published a position regarding clinical trials, demanding that all positive and negative study findings submitted to peer review journals be published and that these findings be submitted within 1 year of study completion [23]. Furthermore, there are now journals dedicated to publishing negative results, including *Journal of Negative Results, Journal of Negative Results in BioMedicine, Journal of Pharmaceutical Negative Results, and the All Results Journals* [23]. Another group found that within JBJS (American Volume), papers with a positive result were no more likely to be published than were those with a negative result. The authors also found that studies with a negative result tended to be of higher quality. If the higher-quality studies are not more likely to be published, they speculated that this may lead to overestimation of the sizes of apparent treatment effects in meta-analyses [41].

So what should we do with the discrepancies as we have outlined? Shapiro [64] said it best in a paper in which he summarized studies that showed significant inaccuracies in abstracts, citations, and study designs – "Finally, until all of this inaccuracy changes, we need to be highly skeptical of what we read." As we look for better answers to provide our patients' value in their care, we must be critical of our own knowledge and skill and also read the literature with a critical eye. Many of the answers that we strive for regarding the treatment of the bunion deformity are not yet available. This work is an attempt to bring together experts and thought leaders to present our current published knowledge base and provide critical analysis of the problems we face and explore possible solutions. We hope that this text will spark thought and investigation of a more complete understanding of bunion deformity and enhance our approach to conservative and surgical intervention, thereby improving patient outcomes, decreasing complications, and decreasing the cost to the patient and healthcare system.

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2 Anatomy and Terminology

Merrell Kauwe

Osseous Segment Descriptions

The Medial Cuneiform

The medial cuneiform has five surfaces and articulates with the navicular, the intermediate cuneiform, the second metatarsal, and the first metatarsal. The posterior surface articulates with the navicular. It is triangular or pear shaped, as is the corresponding facet on the navicular. The lateral surface is concave with two articular facets. The facet located superior and anterior is small and oval and articulates with the base of the second metatarsal. The superior and posterior facet is in the shape of an inverted L with the long vertical portion posterior and the shorter arm superior. Two ligaments attach to the lateral surface, the lisfranc ligament and the intercuneiform ligament. The medial surface is roughly pentagonal. The anterior-inferior aspect has a small smooth oval surface covered by a bursa that interfaces between the bone and a cartilaginous sesamoid of the tibialis anterior tendon. The tendon attachment begins just posterior to this facet and continues to the base of the first metatarsal. The medial surface also provides attachment for the dorsal and medial cuneonavicular ligaments, the dorsal intercuneiform ligaments, and the dorsal cuneometatarsal ligaments to both the first and second metatarsals. The plantar surface is rectangular and convex medial to lateral. It provides attachment for the peroneus longus at the lateral half of the distal portion just anterior to a tubercle located on the plantar surface. Additional attachments at this surface include the plantar cuneonavicular ligament, plantar intercuneiform ligament, and plantar cuneometatarsal ligaments to both the first and the second metatarsals [31]. The anterior surface of the medial cuneiform articulates with the base of the first metatarsal. It is kidney or reniform in shape. The surface has an average height of 28.3 mm and an average width of 13.1 mm, and both continuous and bilobed facets are common anatomical variants [5]. See Fig. 2.1 for pictorial osteology. All osteology figures were 3D scanned and digitally reconstructed from human skeletal remains (Fig. 2.1).

The First Metatarsal

The first metatarsal is the shortest and strongest of the five metatarsal. It has two articular surfaces. Proximally it articulates with the medial cuneiform and distally with the base of the first proximal phalanx. It is best described using three anatomic segments, the base, the shaft, and the head. There are numerous ligamentous and tendinous attachments. The base is roughly triangular with an inferior, lateral, and medial boarder. The

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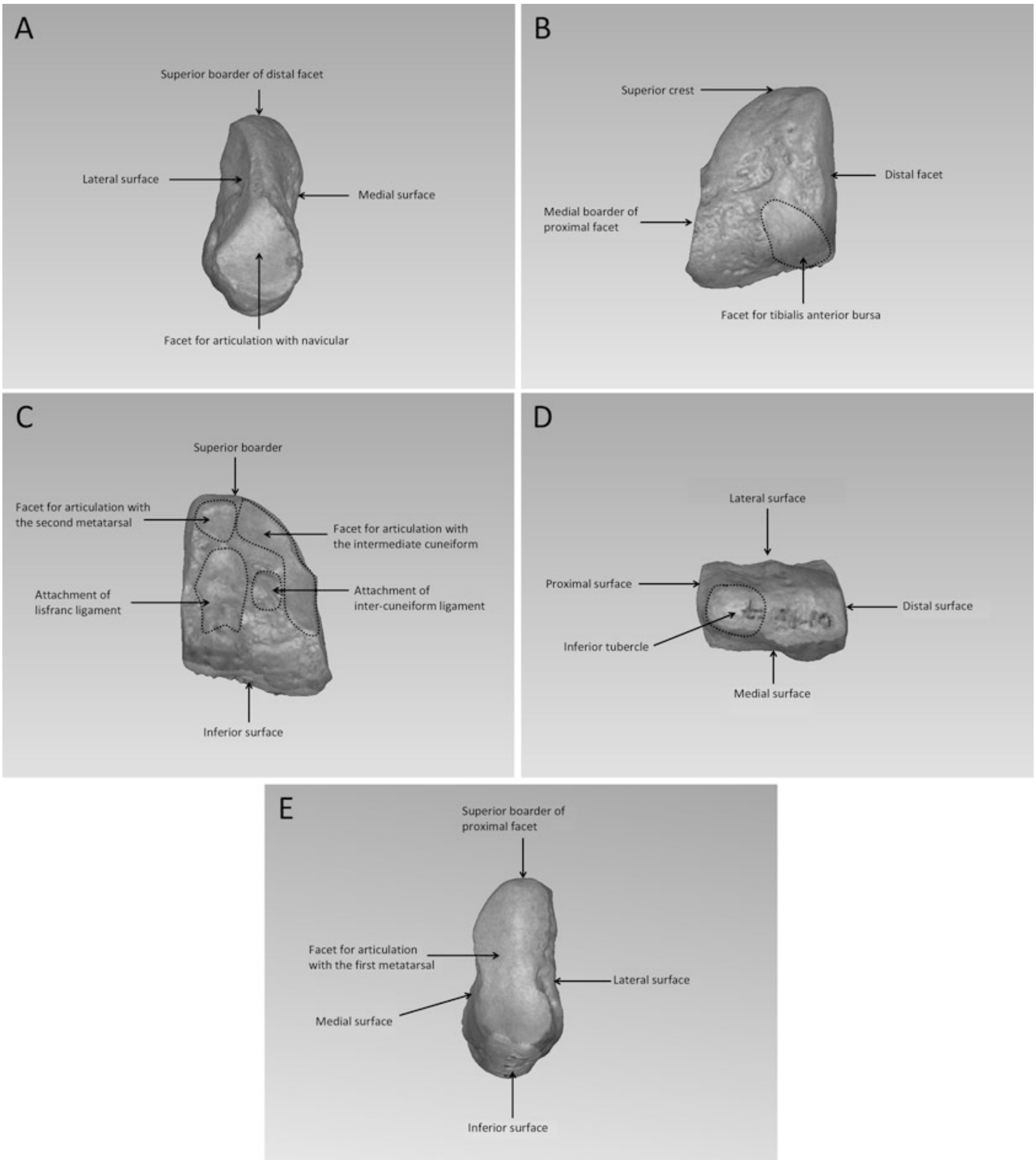

Fig. 2.1 Medial cuneiform. (**a**) Posterior surface. (**b**) Medial surface. (**c**) Lateral surface. (**d**) Inferior surface. (**e**) Superior surface

articular surface of the base is reniform with the hilum facing laterally and a transversely oriented concavity. The tibialis anterior tendon inserts at a tubercle present to the medial-inferior boarder junction. The peroneus longus inserts at a tuberosity present at the junction of the inferior and lateral surfaces. The dorsal and plantar cuneometatarsal ligaments attach to the medial and inferior surfaces, respectively. The lateral surface of the base has an inconsistent articulation with the second metatarsal [29, 33, 37]. The shaft of the first metatarsal has three surfaces: dorsal-medial, lateral, and inferior. The first dorsal interossei inserts into the lateral surface. The plantar surface is concave in a longitudinal direction and its concavity exaggerated by the inferior plantar tubercle. There are three boarders present, the superolateral, inferolateral, and the inferomedial.

The head of the first metatarsal is wider than it is tall, unlike the lesser metatarsals whose vertical diameter is greater than their transverse diameter. The distal surface is covered in cartilage that articulates with the first proximal phalanx. This distal surface is contiguous with the inferior surface that articulates with the sesamoid bones of the first metatarsal phalangeal joint. There are two facets on this surface separated by a ridge or crest called the media crista (Fig. 2.2).

The Great Toe

The proximal phalanx has two articular surfaces. Proximally it articulates with the first metatarsal

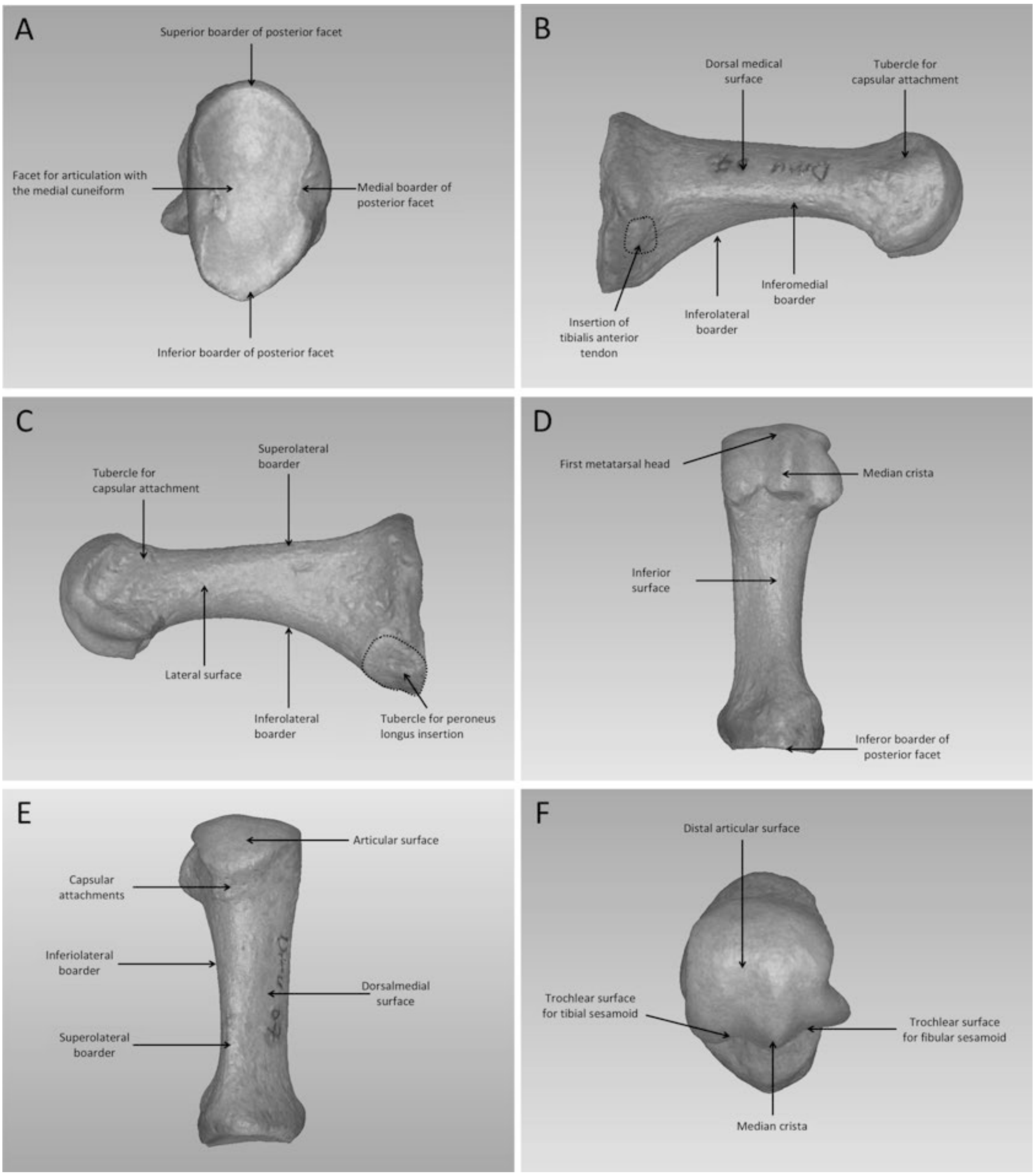

Fig. 2.2 First metatarsal. (**a**) Posterior surface. (**b**) Medial surface. (**c**) Lateral surface. (**d**) Inferior surface. (**e**) Anterior surface. (**f**) Anterior surface

head and distally with the distal phalanx. The base is oriented transversely with an oval posterior facet that is smaller than the metatarsal head it articulates with. This surface is called the glenoid cavity [31]. The dorsal surface provides attachment for the first metatarsal phalangeal joint capsule and the flexor hallucis brevis tendon at a ridge just distal to the proximal articular surface. The plantar surface provides attachments for the abductor hallucis and the adductor hallucis as well as the flexor hallucis brevis and the plantar plate. The shaft is flat plantar with a small groove for the flexor hallucis longus. The dorsal surface is convex. The head is flat with a trochlear articular surface extending more plantar than dorsal. It articulates with the first distal phalanx (Fig. 2.3).

The distal phalanx has a transversely oriented base. The dorsal transverse tubercle just distal to the articular surface serves for attachment of the joint capsule as well as the extensor hallucis longus. The plantar surface has an obliquely oriented ridge from the base to the distal tuberosity providing attachment for the flexor hallucis longus tendon. The distal phalanx deviates laterally approximately 15° from the proximal phalanx [38] (Fig. 2.4).

The Sesamoids of the First Metatarsal Phalangeal Joint

The non-articular surface is convex in both bones. These surfaces provide multiple attachments including medial and lateral attachments for the flexor hallucis brevis and medial and lateral suspensory metatarsosesamoid ligaments. Laterally there is attachment for the transvers and oblique portions of the adductor hallucis and the deep transverse intermetatarsal ligament. Medially there is attachment for the abductor hallucis tendon. The sesamoids are

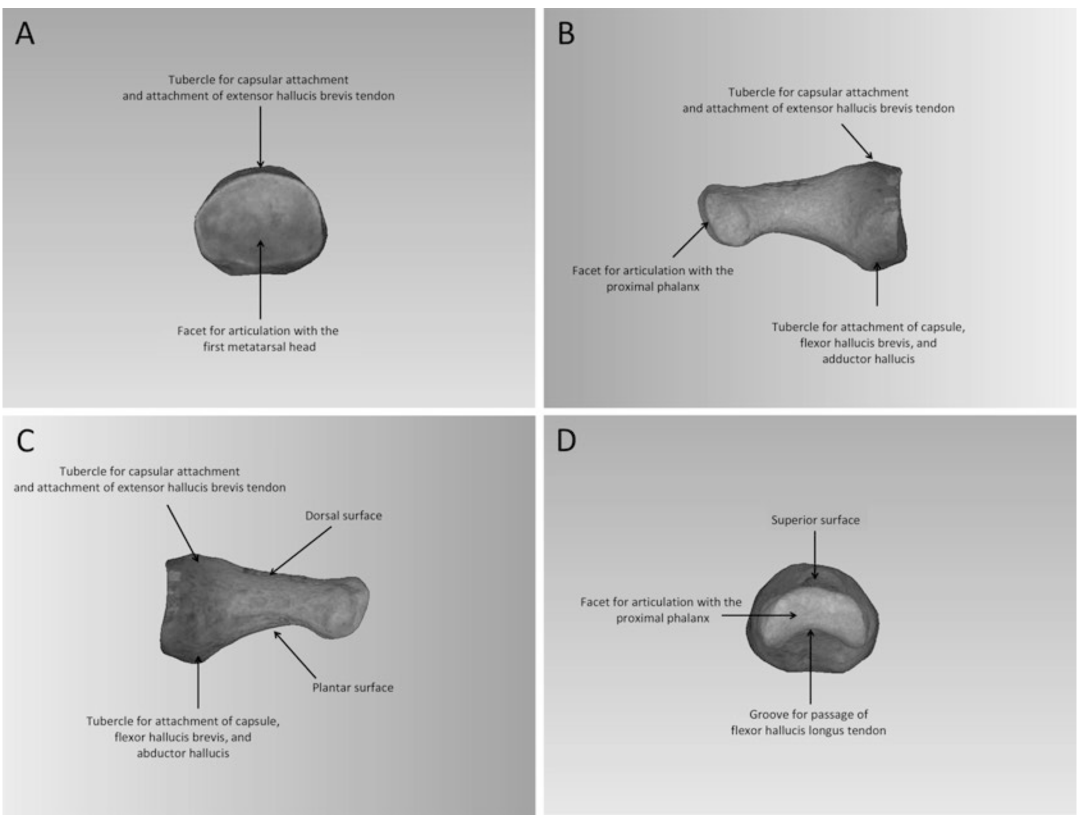

Fig. 2.3 Proximal phalanx. (**a**) Posterior surface. (**b**) Medial surface. (**c**) Lateral surface. (**d**) Anterior surface

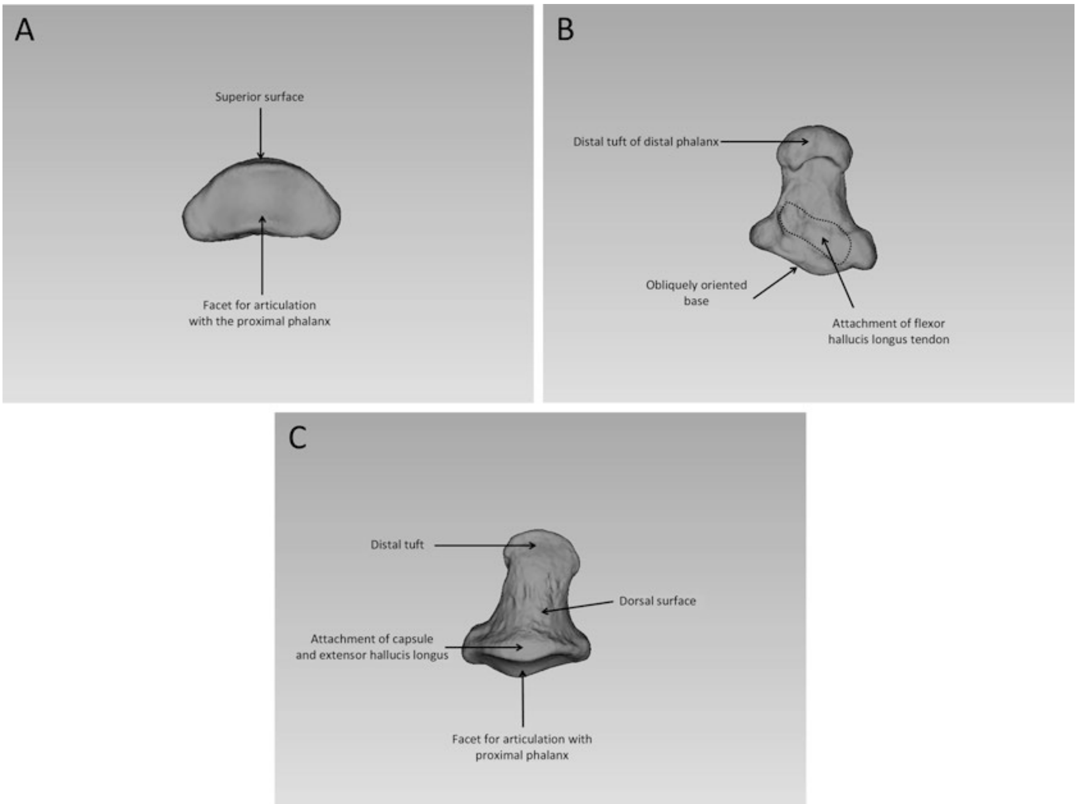

Fig. 2.4 Distal phalanx. (**a**) Posterior surface. (**b**) Inferior surface. (**c**) Superior surface

embedded into the thick plantar plate and within the flexor hallucis brevis tendon. There are two surfaces, articular and non-articular. The shape and size of these are variable [31], though the medial or tibial sesamoid is consistently larger than the lateral or fibular sesamoid. The articular surface interfaces with the inferior portion of the first metatarsal head. The sesamoids are concave longitudinally and slightly convex transversely. The sesamoids are primarily connected to each other via the plantar plate, but there is a thin fibrous band also noted termed the intersesamoidal ligament. They have intracapsular connections to the base of the proximal phalanx at the plantar tubercles and attachment to the metatarsal head via the metatarsosesamoidal ligaments. The sesamoids normally move with the phalanx relative to the first metatarsal head.

Orientation and Motion of the First Tarsal Metatarsal Joint

The first tarsometatarsal joint has been identified as the apex or center of rotational angulation (CORA) of a bunion [20, 25, 27, 35, 39] with the shape of the distal aspect of the cuneiform described as one of the predisposing features in the development of the deformity. Some have argued that the oblique shape of the cuneiform in bunion-affected feet is an inherited atavistic or ancestral trait. A similar obliquity is noted in human fetal development that decreases as the fetus progresses but is retained in other primates. This ancestral trait remains expressed in individuals with bunions. Others argue that the biomechanical flaws cause stress and strain and the obliquity observed is a result of the Wolf and Davis law as the bone remodels in response

[1, 8, 24]. One investigator found that the appearance of an atavistic cuneiform was a function of radiographic projection rather than actual intrinsic deformity and x-ray tube angle, foot position, and metatarsal declination angle affected the relative appearance of atavism [40]. They concluded that radiographic measurement of obliquity did not indicate true anatomic structure and that one should look to a source besides cuneiform shape in understanding bunion development. This finding is corroborated by Dayton et al. [4] in a study on the effect of a first metatarsal phalangeal joint fusion on cuneiform obliquity. They found that the one-to-two intermetatarsal angle decreased with the fusion as did the measureable cuneiform obliquity on standard anterior posterior radiograph. Not only did they both decrease, but they did so with a linear relationship. They suggested the metatarsal and cuneiform moved together in multiple planes as the deformity was reduced to change the perspective of the cuneiform, thereby altering what is observed on radiograph. The problem two-dimensional imaging poses to a three-dimensional deformity is a recurring conversation in the discussion of bunion evaluation and treatment.

The findings discussed above suggest the first ray, defined as both the first metatarsal and medial cuneiform, is moving as a unit; that motion or position applied to the first metatarsal is translated to movement of the cuneiform and in a linear fashion. For this to happen there would need to be very little motion available at the first metatarsal cuneiform joint. Just how much motion takes place at the first metatarsal cuneiform joint (TMTJ1) is debatable, and while there have been multiple studies that attempt to answer this question, many questions remain. First, there is poor reproducibility and validity with subjective evaluations. Second, measurements of mobility with assistive devices are unable to effectively isolate the metatarsocuneiform joint from the first ray as a whole. An extensive review of the literature on first ray mobility was performed by Roukis in 2003 highlighting an additional problem when finding and answer to how much motion takes place at the first tarsometatarsal joint: the fact that no clear consensus exists regarding direction and range of motion [30]. Additional inquiries into the question of hypermobility have been performed since Roukis' review. One such study, performed by Martin et al. [23], used dynamic fluoroscopic assessment of the foot through gait with full weight bearing. They observed 14 healthy feet and compared these to 8 ft that demonstrated clinical hypermobility and were scheduled for surgical correction of their bunion. The investigators found that maximum dorsal displacement of the first ray was 13.63 mm and 13.06 mm in the normal and bunion-affected patients, respectively, with a mean of 5.27° and 5.56°in the same groups. These values did not show statistical difference in the first ray motion. They also looked at relative translations of the osseous segments and found an average of only 2.61° of sagittal motion at the first metatarsal cuneiform articulation. An average of 5.63 and 4.83° of sagittal motion were observed at the cuneonavicular (CN) articulation and the talonavicular (TN) articulation, respectively. Maximum sagittal plane motion was found at the CN and TN articulations with comparatively little TMT1 motion observed.

Proximal motion may be the reason that persistent instability in multiple planes is retained at the first ray following first tarsal metatarsal joint arthrodesis. Galli et al. [11] performed a cadaveric study in which sagittal plane motion of the first ray was assessed before and after TMTJ1 joint fixation. They found the sagittal motion of the first ray was 7.45 mm prior to fixation and 4.41 mm following fixation. It was only after addition of intermediate cuneiform fixation from the base of the first metatarsal that they found significantly enhanced sagittal plane stability of the first ray. Fleming et al. noted intraoperative transverse plane instability of the first ray as evidenced by their hook test following TMTJ1 fusion. They showed transverse deviation of the first metatarsal with widening of the one-to-two IMA as they transversely stressed the fixated first ray and hypothesized that intercuneiform instability was the cause of retained instability. They proposed routing "spot welding" of the bases of the first two metatarsals to combat this instability [10]. Feilmeier et al. performed a cadaveric study to assess instability following TMTJ1 fusion [42].

After fixating the TMTJ1, they placed screws from the first ray into lateral osseous structures with in varying configurations and measured changes to the common hallux valgus measurements with transverse and frontal plane forces applied. Fixation of the TMTJ1 did not stabilize the first ray in the transverse or frontal plane. They also found that neither a screw from the medial to the intermediate cuneiform nor a screw from the base of the first metatarsal to the intermediate cuneiform stabilized the transverse or frontal plane to a significant degree. Only a screw from the base of the first to the base of the second metatarsal was able to significantly diminish multiplanar motion of the first ray. In all of these studies, it is clear that instability in multiple planes continues following TMTJ1 fusion indicating that motion of the first ray is not primarily at the TMTJ but comes from other intertarsal joints.

Geng et al. [12] performed an in vivo 3D CT study to assess the first ray hypermobility. Ten control and ten bunion-affected patients with a total of 20 ft in each group were observed. They found that during weight-bearing conditions of the foot, the first ray was pronated or everted from its non-weight-bearing position in all patients with the medial cuneiform more pronated than the first metatarsal. The degree of pronation was significantly larger in the bunion-affected feet. The TMTJ1 did show increased motion in bunion-affected feet in both the sagittal and frontal planes with 1.2° more sagittal motion and 1.19° more of frontal plane motion than the control feet. And, while the TMTJ1 joint did invert when compared to the medial cuneiform, the whole first ray was pronated. The findings are consistent with multiple other investigations that very little motion is present at TMTJ1 and that instability of the first ray in multiple planes exists at a proximal level. Their findings also confirm multiple observations of an everted or pronated first ray in a bunion-deformed foot compared with non-affected feet.

First Metatarsal Position

Despite findings such as Xiang's regarding pronation of the first ray in bunion-affected feet, evaluation of normal vs abnormal position of the first ray and first metatarsal has traditionally focused on the transverse plane aspect of the deformity. In 1951 Hardy and Clapham attempted to describe normal and abnormal positions of the various osseous segments involved in bunion-affected feet. The first metatarsal, hallux, and tibial sesamoid position were included in the assessment. They took weight-bearing anteroposterior (AP) radiographs of 252 control feet and 177 affected feet and performed angular evaluations of the various joint segments. They concluded that the transverse plane angular position of the first metatarsal relative to the second metatarsal in a normal foot averaged 8.5° and 13.0° in affected feet [14]. This deviation of the first metatarsal toward the midline of the body is a universally acknowledge component of a bunion, and the angle's severity is often used to define procedure selection. The position of the first metatarsal in a bunion is reflected in the term *metatarsus primus varus* coined by Truslow in 1925. The term as used by Truslow refers to the angulation of the first metatarsal toward the midline of the body in the transverse plane. He felt this term was more reflective of the deformity and intended to move the mind away from the lateral deviated hallux toward what he felt was the primary level of the deformity, the medially deviated first metatarsal.

While the transverse plane position of the metatarsal is easy to clinically and radiographically observe, the frontal plane position of the metatarsal is not. Because of the difficulty in observation of this position, Hick's axis of first ray motion has been used to presume the frontal plane position of the metatarsal in a bunion without actual observation. As described by Hicks [15] the orientation of the axis of the first ray produces a motion of dorsiflexion with concurrent inversion. Application of the Hick's normal range of motion of the first ray leads to the assumption that in a bunion, the first ray is dorsiflexed and inverted [15]; however, in investigations to date, the first ray has been shown to be everted in a bunion deformity. In 1980, Scranton and Rutkowski used axial radiographs of the first metatarsal phalangeal joint to observe the frontal plane position of the first metatarsal head in normal and bunion feet. They found that while normal feet had an average of 3.1° of pronation, feet with bunions had 14.5° of first metatarsal pronation with the conclusion that three structural components (the laterally deviated hallux, the medially deviated and pronated hallux) must be addressed when surgically addressing bunions [32]. Mortier et al. in 2012 also utilized axial radiographs to assess rotational position of the first metatarsal. They found that significant pronation occurred with 12.7° of metatarsal pronation in feet with bunion deformities. Their study conclude that it was not a structural torsion of the first metatarsal that produced pronation at the head, rather pronation of the entire metatarsal was responsible [25]. Grode and McCarthy in 1980 also observed an axial view, but rather than a radiographic image they viewed frozen frontal plane sections. They describe an everted position of the first metatarsal head in bunion feet as well as the observation that in a bunion, the medial eminence observed on radiograph represents the dorsal-medial surface of the first metatarsal head brought into prominence through rotational, not an actual medial structure. The term eversion used by Grode and McCarthy is synonymous with pronation [13]. A discussion of terminology is treated later in this chapter. Eustace et al., in 1993 [9], used AP radiographs to assess first metatarsal pronation. They observed the translocation of the inferior proximal tuberosity of the base of the first metatarsal. Lateral translocation of the tuberosity occurs with metatarsal pronation. After establishing the amount of translocation that occurs with specific degrees of pronation in a cadaveric model, they applied these quantified amounts to bunion and normal feet. They found significantly more metatarsal pronation in bunion feet than normal feet and concluded additional investigation should be performed regarding de-rotation of the frontal plane position during surgical correction (9).

In 2015 Kim et al. performed a partial weight-bearing CT examination of bunion and normal feet. Nineteen normal feet and 166 bunion-affected feet were studied. They found the transverse deviation of the metatarsal to be very consistent with what was reported by Hardy and Clapham, with normal feet exhibiting a mean 8.6° one-to-two IMA with bunion feet exhibiting a mean 15.0°. They found a mean of 13.8° of first metatarsal pronation in normal feet with bunion feet exhibiting a mean 21.9° of pronation. In total 87.3% of bunion-affected feet had pronated metatarsals. The Kim study also observed the metatarsal phalangeal joint, specifically the sesamoid/first metatarsal articulation. They found that the AP radiographic position of the sesamoids on a seven grade scale did not correlate to true sesamoid subluxation visualized on the CT scan [19]. This again illustrates the difficulty of assessing three-dimensional deformities with two-dimensional images. AP radiographic findings associated with a pronated metatarsal include the transposition of the inferior tuberosity as described by Eustace [9], increased lateral curvature of the first metatarsal as the plantar convexity is brought into view described by D'Amico [41], lateral rounding of the first metatarsal head described by Okuda [26], and an increased appearance of a medial eminence described by Grode and McCarthy [13]. Figure 2.5 highlights two-dimensional findings characteristic of the first metatarsal when it is pronated.

The First Metatarsal Phalangeal Joint and Hallux Position

The first metatarsal phalangeal joint (MTPJ1) is composed of the first metatarsal head, the proximal phalangeal base, the two sesamoid bones, and the joint capsule and ligaments. Normal motion is reported up to 65° of dorsiflexion and 10° of plantarflexion when using the first metatarsal shaft as a reference point (Valmassy). The normal transverse plane alignment of this joint is lateral deviation of the hallux from the first metatarsal by 12–13° [14, 19]. The sesamoids should be aligned under the first metatarsal head on their respective sides of the medial crista. The motion is roughly in the sagittal plane of the foot. Dorsiflexion of MTPJ1 in the sagittal plane allows proper mechanical function of the first ray.

In bunion-deformed feet, these normal relationships are affected. The hallux is laterally deviated in the transverse plane at the level of the

Fig. 2.5 Weight-bearing AP radiograph. Changes observed indicative of frontal plane valgus of the first metatarsal include translocation of the proximal inferior tubercle laterally, increased lateral curvature of the shaft, and lateral rounding of the first metatarsal head, and increased prominence of the medial first metatarsal head. Changes to the first metatarsal phalangeal joint indicating frontal plane valgus include appearance of subluxation of the sesamoid apparatus laterally and increased proximal articular set angle

MTPJ a mean of 30–32.0°. The whole joint complex including the metatarsal, proximal phalanx, and sesamoids are rotated in the frontal plane. This causes abnormal forces at the first metatarsal with force vectors aligned to press the metatarsal medially [25]. This rotational position also causes problems with radiographic interpretation of the joint. The pronated or valgus position of the joint gives the appearance that the metatarsal head has migrated off a stationary sesamoid apparatus when that is not always the case. Multiple investigators have found that the appearance of the lateral deviation of the sesamoids from under the metatarsal head visualized with standard AP radiograph does not correlate to the true position of subluxation because the alteration in perspective is imparted by the pronated position of the joint [2, 4, 18, 19, 21, 34]. Correction of the pronated position of the metatarsal improves sesamoid position and correlates to reduced recurrance (27). Pronation of the MTPJ1 is also purported to be responsible for the radiographic appearance of the proximal articular set angle (PASA) also termed the distal metatarsal articulation angle (DMAA). These equivalent terms are used depending on one's educational and training background. AP radiographic findings associated with a pronated first metatarsal phalangeal joint include the appearance of sesamoid deviation laterally as described by Kim and increased PASA described by Robinson and Lee [28, 22] (Fig. 2.5).

Clarification of Terminology

In both the Hardy and Clapham and the Kim studies, the word valgus refers to the hallux deviation away from the midline of the body and is a transverse plane descriptor. Valgus as used by these authors is defined differently than it is in the term hallux abducto valgus (HAV). HAV refers to the clinically present transverse and frontal plane deviation of the hallux, with abducto referring to the transverse plane deviation and valgus in this instance referring to the frontal plane. This discrepancy in terminology is a consistent finding in descriptions of the first ray and hallux in the bunion-deformed foot and can lead to confusion. One reason that a variety of terms exist in the description of the anatomic segments of a bunion is that knowledge regarding the position of the deformed segments and the etiology of the deformity has evolved over time. This evolution of understanding has progressed in parallel across different disciplines and educational backgrounds. As the understanding of etiology and treatment evolved, the terms used to describe the bunion did as well, though not with unified clarity. Durlacher [7] reported the bunion to be an enlarged first metatarsal phalangeal joint. Heuter [16] reported that it was not an enlargement of the joint; rather it was a lateral deviation of the hallux. He used the term hallux valgus to describe the great toe deviating away from the midline of the body. The term valgus, used by Heuter, is the same definition used by Hardy and Clapham. It describes a transverse plane position. In 1925 Truslow proposed a change in terminology from hallux valgus to metatarsus primus varus. He no longer retained the position of the hallux in his anatomic description. This was because he believed the primary deformity was the first metatarsal deviated toward the midline of the body. The term varus used by Truslow was not a frontal plane descriptor; rather it described the metatarsal deviating toward the midline of the body (37).

These early descriptions only included a single cardinal plane of the body. And though bunions are most easily clinically and radiographically observed in the transverse plane, the deformity exists in all three body planes. Recognizing that no current terminology was in place to describe the current understanding of the multiplanar position of both the hallux and the metatarsal in the bunion-deformed foot, Dayton et al. [3] proposed new terminology. Their publication justifies the new terminology by appealing to work by Huson [17], Sarrafian [31], and Draves [6]; that is, if one uses the tri-axial orthogonal coordinate plane system and transposes the planes used in the leg to the foot with the change in designation due to the foot position following embryologic development, then varus and valgus are more appropriate as frontal plane rather than transverse plane descriptors. This new term, *hallux abducto valgus with metatarsus primus adducto valgus*, captures "the multiplanar nature of the deformity along the entire segment of the first ray and great toe." They also highlight Sarrafian's work on equivalent terms about the axes of the foot. These are depicted in Fig. 2.6. Equivalent terms for the metatarsal and hallux frontal plane rotational position in a bunion are shown in Fig. 2.7.

Summary

Bunions are multiplanar deformities. Over time, observation of position of the osseous segments involved has increased our understanding of the deformity. Clearly, transverse plane deviation of both the hallux and metatarsal takes place, and mounting evidence points to a significant frontal plane component of both the first metatarsal and the

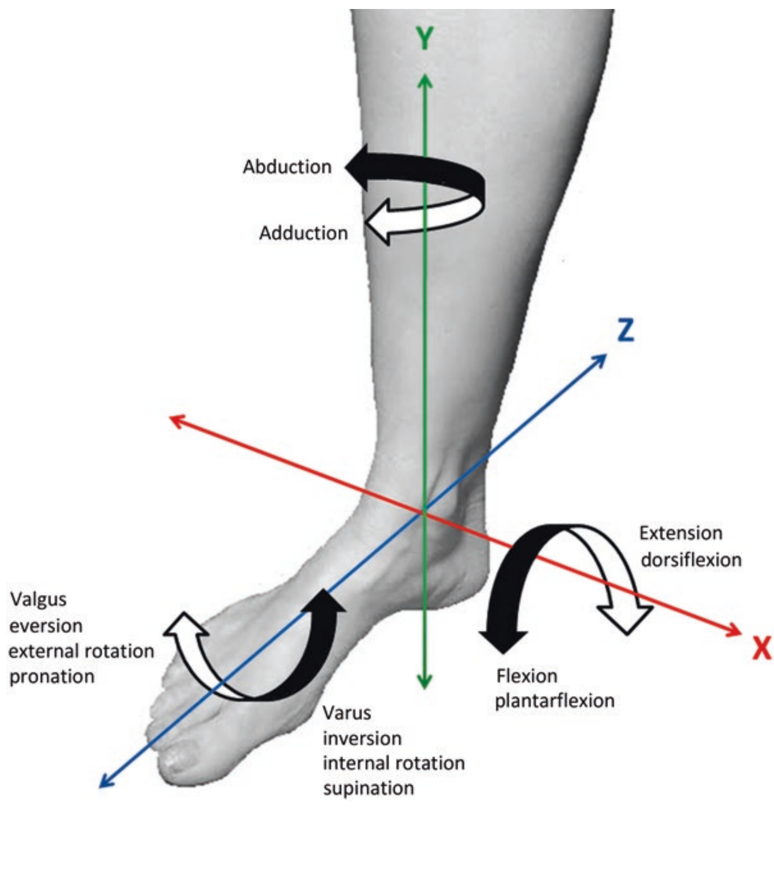

Fig. 2.6 Coordinate plane labeled with equivalent terminology for motion of the foot about each axis. The Y axis gives us motions of abduction and adduction in the foot. The X axis gives us motions of the foot known as flexion or plantarflexion in one direction and extension or dorsiflexion in the opposite. The Z axis gives us motions of the foot known as valgus, external rotation, eversion, or pronation in one direction and varus, inversion, internal rotation, or supination in the other

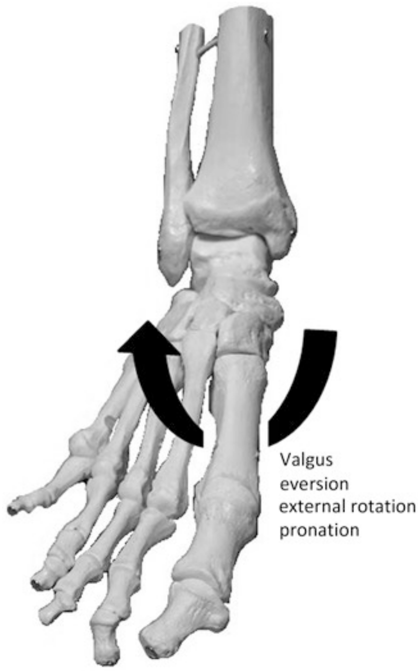

Fig. 2.7 Coordinate plane with Z axis motion about the first ray. The terms used to describe the position of the first metatarsal in a bunion deformity include valgus, eversion, external rotation, and pronation. Hallux abducto valgus with metatarsus primus adducto valgus should be used to describe the multiplanar deformity

hallux. By extension this frontal plane valgus position includes the first metatarsal phalangeal joints and its components, particularly the sesamoid apparatus. Our understanding of the deformity has evolved and accordingly the multiplanar position of the deformity should be reflected. Hallux abducto valgus with metatarsus primus adducto valgus is an appropriate and accurate anatomic term for the greater than 87% of bunion-affected feet that include a rotational component and should be used when a rotational component is present.

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3 The Etiology of Hallux Abductovalgus Described in Six Pieces

Andrew J. Meyr

Background

Any meaningful discussion into the etiology of a specific pathology should begin with an attempt to clarify an objective and broadly accepted definition. With respect to the hallux abductovalgus (HV) deformity, this represents a surprisingly qualitative and variable endeavor considering the amount of time, energy, resources, and scientific literature that have historically been dedicated to the complaint. While there is no doubt that subsequent chapters of this text will appropriately and comprehensively define the clinical examination techniques, plain film radiographic findings, intraoperative evaluation, and surgical correction of the HV deformity, one might respectfully propose to readers that these represent a relatively Cartesian view of first metatarsal-phalangeal joint pathology.

Although admittedly a bit tangential, this concept may be best understood by reviewing the history of science with respect to two of the great mysteries whose explanation evaded scientists well into the modern era: gravity and magnetism [1, 2]. Both of these observed phenomena appeared to demonstrate what Albert Einstein would later categorize as the insupportable scientific concept of "action at a distance." In other words, it is difficult to completely explain these ideas with physical, particulate, and tangibly material observations. Gravity, for example, is certainly a consistent and reliable observed finding, but a scientist is unable to put "gravity" into a test tube or examine it underneath a microscope. It has no mass, no physical structure, and no material form. Contrasting this idea, early physicist Rene Descartes, perhaps best known as a philosopher for his "cogito, ergo sum" or "I think, therefore I am," set forth the principle that all of science could be explained by the concept of "matter in motion." In opposition to the relatively intangible "action at a distance," his "matter in motion" theorem stated that all scientific observations could be explained by physical and tangible means.

This is relevant to a discussion of the HV deformity. Physicians, generally, and foot and ankle surgeons, specifically, have a tendency to adhere to this Cartesian "matter in motion" view of the world. When a patient presents with a complaint, their symptoms can typically be ascribed to a physical and tangible source. In the case of HV, the so-called bunion generally hurts because medial translation of the first metatarsal has resulted in a prominent metatarsal head which tends to painfully rub in shoes, and derangement of the normal anatomy and axes of motion within the first metatarsal-phalangeal joint result in the physical symptoms of arthropathy. Physicians are able to easily objectively define this deformity

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based on the physical position and kinematics of the first metatarsal, hallux proximal phalanx, and sesamoid complex and numerically describe radiographs based on the first intermetatarsal angle, hallux abductus angle, and tibial sesamoid position to name a few measurements.

But no patient has ever presented to a physician's office with a chief complaint of an "increased first intermetatarsal angle," just as no patient has ever specifically thanked a physician for surgically returning it to what we consider to be a normal range. Patients do not necessarily have this "Cartesian" view of the deformity and instead more simply report whether or not they are experiencing pain and other subjective symptoms in the medial forefoot. Indirect evidence of this finding is available if one looks for it. In a contemporary study which sought to examine the width of the first metatarsal head in the HV deformity, Lenz et al. interestingly found that of 100 patients presenting with bunion pain, only 43 met their radiographic definition of the deformity [3]. And in their control group of 100 patients without bunion pain, the majority (73%) were excluded from the study because they actually met the radiographic definition of deformity. Other studies have not demonstrated substantial correlation between objective measures of deformity severity and correction with patient symptoms [4–6]. Perhaps Laporta et al. commented on this potential dichotomy between relatively objective physicians and subjective patients best when in 1974 they stated that the "ideal" first intermetatarsal angle is "very simply, one which is not clinically significant" [7].

The science of etiology is the study of causation, so hereafter this discussion must include a critical evaluation of not only what could potentially "cause" the objective physical findings that physicians use to define HV and assess treatment interventions but also the subjective symptoms about which patients complain. As stated previously, this has been a topic that has seemingly been exhaustively researched by modern scientists. Table 3.1 attempts to summarize a general literature review of the theories traditionally associated with the development of structural first metatarsal-phalangeal joint deformity [7–59]. This is a long and at times apparently contradictory list. For example, both a short and a long first metatarsal have been described as contributing to the deformity!

Given this, instead of attempting to definitively describe an etiology which is likely multifactorial and variable, perhaps a more interesting way to undertake this chapter is by endeavoring to examine the evidence related to a series of six pieces previously related to and commonly associated with HV. These will admittedly tend to overlook congenital, inflammatory, traumatic, and neuromuscular causes and will instead focus on the more common progressive deformity seen in adults. This literary structure might also caution readers of the established scientific maxim that "correlation does not imply causation." In other words, it is likely that there are many findings that are associated with the HV deformity, but this does not necessarily mean that one causes the other or vice versa. A critical analysis of historical citations and generally accepted associations might do a better job of not only defining our current knowledge base but also identifying gaps which can be examined by future generations of foot and ankle surgeons.

What Role Does the Subjective "Bump" Play in the Pathogenesis of the Hallux Abductovalgus Deformity?

Perhaps the easiest way to relate HV to a Cartesian "matter in motion" model is by a subjective description of the deformity as a "bump" on the medial and/or dorsal-medial aspect of the first metatarsal-phalangeal joint. Although we generally lack extensive or definitive epidemiologic studies on the deformity, any physician with any degree of clinical experience can relate that this "bump" represents a common patient complaint. Even the term "bunion" itself derives from the Latin word "bunio" translating to turnip [8, 60], and admittedly it is not difficult to imagine an inflamed first metatarsal-phalangeal joint as the red and relatively bulbous vegetable.

However, most descriptions of the deformity simply as an abnormal "bump" of bone are historical. In 1856 Volkmann described the deformity as

Table 3.1 Described etiologies of the hallux abductovalgus deformity from a contemporary literature review [7–59]

Structural etiologies	Biomechanical etiologies	Systemic etiologies	Other etiologies
Short first metatarsal	Pronating pes plano valgus	Neuromuscular diseases	Hereditary factors
Long first metatarsal		Inflammatory arthritides	Shoegear
		Degenerative arthritides	Female gender
		Ligamentous laxity	Age
			Congenital abnormality
			Acute trauma
			Iatrogenic
			Idiopathic
			Occupation-related
			Handedness
Long second metatarsal	Periarticular muscle imbalance		
Long hallux phalanges	Ankle equinus		
Metatarsal head shape	Hypermobile medial column		
Metatarsus adductus	Functional hallux limitus		
Metatarsus primus varus			
Metatarsus primus elevatus			
Cavus foot structure			
Splayfoot structure			
Limb length discrepancy			

an "exostosis" on the first metatarsal head which in turn pushed the hallux into a lateral direction [61]. Mann and DuVries have presented the possibility of a congenitally wide first metatarsal head when considering etiology, which they proposed might lead to chronic inflammation, resultant capsular thickening, periosteal reaction, and further osseous enlargement [60]. Schoenhaus and Cohen specifically described a dorsal-medial "hypertrophy" of bone associated with the deformity [62]. The idea of the deformity as an abnormal hypertrophic bump is even propagated with some contemporary educational tools (Fig. 3.1). But relatively simple logic tells us that if HV was primarily an abnormal osseous growth on the first metatarsal head, then successful surgical correction of the deformity would merely involve resection of the exostosis. One might also assume that if this were indeed the case, then we would have no need for the dozens of described translational metatarsal osteotomies described for correction of the deformity or perhaps even for this entire textbook on the deformity!

A better description of HV might be relatively normal bone in an abnormal position, in this case the first metatarsal head. In other words, it is more likely that there is not a structural abnormality of the first metatarsal head in HV, but instead the natural progression of the deformity results in it being in a more prominent position because of medial translation/rotation of the first metatarsal as a whole. This concept of an abnormally positioned first metatarsal and hallux as opposed to abnormal new bone growth has been generally accepted for some time [54, 63–66]. Even Dr. David Silver, who somewhat ironically gave his name to the surgical procedure describing the removal of the hypertrophic osseous medial eminence from the first metatarsal, described HV as primarily being positional with very little "actual bone hypertrophy" in 1923 [66].

Two comparative clinical studies have attempted to provide evidence on this topic by quantifying the size of the first metatarsal head and any medial hypertrophy in the HV deformity [3, 67]. These studies objectified the so-called medial eminence by measuring the width of that portion of the first metatarsal head that protrudes

Fig. 3.1 What role does the subjective "bump" play in the pathogenesis of the hallux abductovalgus deformity? These three figures demonstrate a clinically symptomatic hallux abductovalgus deformity prior to surgical correction. The figure on the left demonstrates the clinical "bump" that patients will often complain of on the medial aspect of the first metatarsal-phalangeal joint. The central figure represents an onlay of a common commercial bone model used for surgical education incorrectly demonstrating the deformity as a hypertrophic exostosis on the medial first metatarsal. The figure on the right represents an onlay of the radiograph depicting a relatively normal first metatarsal medially translated and rotated with associated lateral deviation of the hallux. Note that very little bone protrudes medially at the head of the metatarsal relative to the medial aspect of the metatarsal shaft

out past the normal medial shaft of the first metatarsal. Thordarson and Krewer first measured the width of the entire first metatarsal head and then the width of the medial eminence in a group of 50 ft with HV and compared this to a group of age-matched controls without deformity [67]. They found a difference in the width of the medial eminence of only 0.2 mm between groups. Lenz et al. replicated this study design and found that a group complaining of bunion pain with radiographic HV deformity had both a larger medial eminence and wider first metatarsal head, but by only 1.12 mm and 2.81 mm respectfully [3].

These studies had several limitations that should be appreciated by critical readers, however. The precision of the utilized measuring instrument was unclear, and there was no attempt to correlate fractions of millimeters of deformity with clinical symptoms. Further, they relied on completely transverse plane radiographic evaluation which would not be expected to take into account frontal plane rotational positional changes. The frontal plane position of the first metatarsal has been demonstrated to contribute to perceived deformity on the dorsal-plantar radiographic projection [68].

All this is not to say that some morphological changes do not occur at the joint during the progression of the deformity. In 1887 a pathologist named Dr. W. Arbuthnot Lane provided a detailed description of the atrophic and degenerative changes that were likely to occur in the setting of long-standing HV as the hallux proximal phalanx base moved in a relative lateral direction on the head of the first metatarsal. Pertinent to our discussion on etiology, he cautioned that "the surgical pathologist has but too frequently mistaken the cause for the effect" [64], indicating that the visible and often symptomatic changes seen to the first metatarsal head in HV more likely represent the end result of the disease process and not necessarily the initiating cause.

Even if an accumulation of hypertrophic bone is not present on the first metatarsal as a primary cause of the deformity, some portion of the medial first metatarsal is typically excised and/or remodeled during surgical correction [9]. Thordarson and Krewer found that the width of the medial eminence decreased in size by a mean of 2.7 mm following HV surgical correction, for example [67]. Wen et al. performed hematoxylin and eosin stains of 123 resected medial eminences in patients undergoing HV surgery and noted consistent changes of "extensive chronic inflammation" [69]. In reviewing the pathology reports from 315 consecutive resected medial eminences from HV surgery, Oh et al. also found that the overwhelming majority (97.5%) were found to have degenerative changes and that it was not cost-effective to routinely send these specimens for specific histopathologic examination [70]. Similarly, Prasitdumrong et al. [71] and Uchiyama et al. [45] performed histologic analyses of the medial collateral ligament from feet with HV and found evidence of degenerative changes, abnormal mechanical properties, and collagen fiber differences. Bone cyst and bursa formation are also common at the first metatarsal-phalangeal joint. Further, Haas described a loss of trabeculation from the medial first metatarsal in the deformity consistent with long-standing disuse atrophy [65].

Degenerative arthritic findings have also been noted in the first metatarsal-phalangeal joint in the setting of HV deformity [72–76]. Mafart observed the presence of some minor osteophytic changes positively associated with age in a group of first metatarsals with HV deformity exhumed from a French necropolis [72]. Roukis et al. prospectively evaluated a series of 166 feet undergoing HV corrective surgery and found evidence of degenerative changes in a large majority, particularly along the inferior and medial aspects of the first metatarsal head [74]. Doty et al. similarly found intra-articular degenerative chondral changes on the first metatarsal head positively associated with HV severity [73]. And at least two studies have demonstrated an association between HV deformity and degenerative changes of the sesamoids [75, 76].

When this evidence is taken together, it seems reasonable to conclude that any "bump" associated with the HV deformity, both in terms of clinical appearance/symptomatology and morphological changes, represents the effect of the deformity and not the primary cause. The consistently observed changes to the joint structure, including articular cartilage remodeling, also likely represent mechanical adaptation, chronic inflammatory effects, and degenerative alterations.

What Is the Effect of Shoegear on Hallux Abductovalgus?

Although shoegear has been widely recognized as a potential cause for the development of HV, the evidence in support of this is often circumstantial and unfortunately more often seems to represent the result of recycled historical literature reviews rather than independent critical analyses. Some sources point to investigations which are reported to indicate the lack of HV in patient populations that do not regularly wear shoes; however, these conclusions do not hold up to a critical review of the original sources. Although Sim-Fook and Hodgson did report a hallux valgus rate of only 1.9% in a non-shoe wearing Chinese population, they also reported a rate of metatarsus primus varus of 24.3% and of metatarsus hypermobility of 13.1% [77]. Barnicott and Hardy noted "valgus deviation" of the hallux of barefooted Nigerians which "falls within the European symptomatic range" [78]. In a study of Solomon Islands natives in 1939, James reported that the hallux was "occasionally abducted" [79]. Kato and Watanabe concluded an association between HV and shoegear in part because they subjectively did not observe the presence of HV in a series of Japanese footprints believed to be over 2000 years old [57]. And Engle and Morton's study of natives in the Belgian Congo actually contains no specific mention whatsoever as to either the presence or absence of hallux deformity, although it does provide several figures indicating that it was observed [80]. These studies seem to indicate the presence of structural first metatarsal-phalangeal joint pathology in populations not exposed to regular shoegear or at the very least do not provide evidence to the contrary. In other words, it certainly seems possible to develop first metatarsal-phalangeal joint deformity in the complete absence of shoes.

It is perhaps more likely that shoegear has a tendency to exacerbate subjective patient symptoms and possibly even exaggerate the progression of the deformity rather than be an initiating cause of structural abnormality. From an evidence-based perspective, a prospective, long-term, longitudinal study rigidly controlling for shoegear and activity behaviors would be required to provide practical data on the effect of a certain type of shoe on deformity progression. This is simply not a practical investigational design, and so available evidence is somewhat indirect and at risk for bias. In 1965, Shine was able to provide data on a unique patient population on the island of St. Helena where regular shoe wear had only recently become commonplace [81]. He found that the percentage of the population with hallux deviation (defined clinically as lateral deviation of the hallux away from the medial border of the foot) steadily increased with the number of years that shoes were worn. However, this study was unable to account for participant age, and understandably those wearing shoes for a longer period of time would be expected to be older. More recently, Klein et al. drew an association between clinical abduction of the hallux with improperly sized shoes in a group of Austrian school children [82]. However, this study was not associated with any subjective symptoms, clinical outcome measures, or an evaluation of deformity progression. It might also be negatively biased as nearly 90% of children were judged to be in improperly fit shoes, somewhat limiting a “control” comparison.

Most of the data that is available on this topic is based only on patient-reported symptoms and surveys of previous behaviors. One might argue that this puts the information at risk for an error in logic exemplified by the Latin phrase “post hoc, ergo propter hoc” or “after it therefore because of it.” In other words, if a patient develops a symptomatic HV deformity, then they might be more likely to retrospectively associate it with an external variable such as shoegear. For example, Munteanu et al. completed a study on monozygotic and dizygotic twins and found patient perception of HV severity was associated with a reported history of consistently wearing constrictive toe box shoes [83]. Borchgrevink et al. noted an association between a reported history of wearing high-heeled shoes and patient symptoms, but did not identify any radiographic deformity differences in a limited controlled cohort investigation [84]. And Menz et al. found that women aged 50–89 years who self-reported hallux valgus pain were more likely to report a history of wearing constrictive footwear between the ages of 20 and 39 [85].

Although a critical analysis of the literature makes it difficult to draw definitive conclusions about the effect of specific shoegear behavior patterns on the development and progression of objective structural first metatarsal-phalangeal joint pathology, it is easier to conclude an association with subjective patient-reported symptoms. And while this is important to a discussion on the etiology of HV, it might arguably be more important to a discussion on patient expectations following HV surgical correction. Several studies have indicated that the ability of patients to comfortably wear their preferred shoegear postoperatively is strongly associated with their satisfaction of the procedure [4, 86, 87].

Does Hallux Abductovalgus Have a Hereditary Component?

It is not difficult to cite sources reporting a family history of foot deformity in a majority of patients presenting with HV [20, 56, 88–92]. Few, however, have attempted to determine a specific mode of inheritance. Ola Johnston is typically credited with the first description of HV as being transmitted with a pattern of autosomal dominance with incomplete penetrance, although this conclusion was based on the pedigree of a single male college student in Texas [93]. Perhaps the most detailed investigators were Piqué-Vidal et al. who had 350 participants with HV complete a family history questionnaire extending back three generations [94]. Ninety percent had a history of at least one affected family member, and the authors concurred with a pattern compatible with autosomal dominance with incomplete penetrance. Coughlin and others have further provided some evidence for the possibility of a high relative rate of maternal transmission [89, 90]. It seems reasonable to conclude that HV has a hereditary component.

Is Hallux Abductovalgus an Actual Pathologic Deformity or Simply a Compensatory By-Product of the Evolutionary Development of the Human Foot?

If there is evidence of a hereditary component to the HV deformity, then a reasonable follow-up question inquires what exactly is passed down. This relates to a potential irony associated with the theory of evolution in that there is a tendency within human nature to assume that the process has reached a stable apex. Although there is certainly evidence that the structure and function of the foot has changed substantially since human beings transitioned to consistent bipedal ambulation, it is in fact likely that this is still a relative work in progress [95–105]. Considering lower extremity structure and function as a dynamic, somewhat variable, and evolving process instead of one which is universal and static is an interesting way to approach the etiology and development of the HV deformity. And while much of what has been specifically described on this topic is owed to the work of Morton, Lapidus, and Hansen [15, 49, 106–108], one might also argue that the strong associations more recently described between both hypermobility and the flatfoot deformity with HV are at least indirectly if not directly related to this discussion as well.

Morton, Lapidus, and Hansen focused on several consistent findings involving the first metatarsal labeled as “atavistic” indicating a relation to ancestral function [15, 49, 106–108]. These include the obliquity of the first metatarsal-medial cuneiform articulation, length of the first metatarsal segment, and equinus of the Achilles complex. To discuss these topics, and really anything found more within the area of biomechanical theory, a divergence from reliance on high levels of clinical evidence and evidence-based critical analysis is required. Readers must also make several assumptions with respect to lower extremity function that admittedly cannot be definitively established and might be open to other interpretations. The most basic of these is that the human foot has generally evolved from more of a grasping function in an arboreal species to a propulsive function in an erect and bipedal species.

The First Metatarsal-Medial Cuneiform Articulation

First, the obliquity of the first metatarsal-medial cuneiform articulation should be considered a clear predisposing factor associated with HV (Fig. 3.2). The articular cartilage of the distal medial cuneiform is typically orientated in a distal, plantar, and medial direction, but readers should appreciate that any medial orientation of this facet whatsoever literally directs the first metatarsal away from the second metatarsal and the remainder of the foot [109]. This effectively increases the first intermetatarsal angle and

Fig. 3.2 Obliquity of the first metatarsal-medial cuneiform articulation. Although obliquity of the first metatarsal-medial cuneiform articulation is often thought of as a pathologic finding, some degree of obliquity should be considered normal when considering the morphologic lineage of the human foot. Studies have demonstrated considerable variation in this obliquity both between and within species of primates, with humans consistently having less obliquity than other species

would be expected to influence the kinematics and prehensile ability of the first metatarsal-phalangeal joint.

Lapidus' interest in this joint as the apex for surgical correction of the HV deformity eventually leads him to the work of anthropologists who had already identified that this was a relatively variable anatomic area between different species of primates, including humans [49]. Larger and more ambulatory primates generally have less obliquity to this articulation, and more recent ontogenetic investigations have even identified differences in ossification patterns of the medial cuneiform between primates which affect the shape and obliquity of the bone [98]. A more oblique orientation to this facet would be advantageous to a more arboreal and grasping species, but perhaps not as much to an erect and bipedal species.

It would not be difficult to imagine that these findings would provide a confirmation bias to Lapidus and other surgeons with respect to the validity of arthrodesis of this joint as a surgical option for HV. Indeed, arthrodesis of the first metatarsal-medial cuneiform articulation is widely recognized as a powerful corrective procedure. And it certainly seems reasonable to conclude based on available evidence that although humans might have less obliquity of this joint than other primate species, some obliquity remains and might contribute to the formation of HV. However, while it might be fair to consider it an atavistic finding based on the morphologic lineage, it might also be unfair to consider this a "deformity" given that it is a part of the natural history of the human species. And it would be potentially inappropriate to conclude that just because humans have less obliquity than other primate species, then we should have none whatsoever. In fact, one could make an argument that it would be "abnormal" to completely lack obliquity of this articulation! One study evaluated a group of 373 participants without a history of foot and ankle surgery and found that there was always some degree of intrinsic "deformity" about the medial forefoot [110]. For example, the lower limit of the range of observed first intermetatarsal angles was in fact 2 degrees and 0 degrees (Should be 0 degrees). This indicates that a first metatarsal which is completely parallel to the second metatarsal is not a finding that would be expected to naturally occur.

Further, although there might be clear variability between and within species with respect to the shape and obliquity of this articulation, it remains unclear exactly how this structure affects function. This probably most relates to a discussion about hypermobility of the medial column, another commonly debated etiologic factor with respect to HV. One problem with hypermobility within the scientific literature that has potentially limited our knowledge base is that it is often considered as a categorical variable. In other words, an investigation will often report that hypermobility is either present or it is not present. This is likely an inappropriate oversimplification of the matter; however, that understates the fact that it is normal for there to be a range of sagittal plane motion of this joint. It is generally accepted that the first metatarsal has an independent axis of motion through the first metatarsal-medial cuneiform articulation [33–35]. Although this is primarily in the sagittal plane, it involves triplanar motion. As the first metatarsal dorsiflexes, it also adducts toward the midline of the body and rotates into a valgus position. As the first metatarsal plantarflexes, it also abducts away from the midline of the body and rotates into a varus position.

Much has been made of this arc of motion! Whether as a cause or an effect, hypermobility of the first ray implies excessive relative sagittal plane dorsiflexion of the metatarsal during stance and gait. This has the consequence of generally moving the first metatarsal in a medial direction away from the remainder of the foot, leading to incongruity of the first metatarsal-phalangeal joint, and destabilizing the medial longitudinal arch proximally [33–35, 50, 51, 68, 111–117]. Once again though, caution should be exercised with respect to defining this as "abnormal" motion. Although in this circumstance one can appreciate how it would be considered potentially detrimental to an erect and bipedal species, excessive motion of this joint would likely be advantageous to an arboreal grasper and contribute to prehensile function.

The Length of the First Metatarsal Segment

The effect of the length of the first metatarsal segment on first ray function might be better explained by first reviewing the function of the lesser toes during gait. Hansen describes in his text that although the osseous, ligamentous, and tendinous anatomy of the fingers is similar to that of the toes, their functions differ dramatically [15]. Flexion of the metatarsal-phalangeal, proximal interphalangeal, and distal interphalangeal joints is helpful for grasping of the fingers certainly, but this flexion is also required for forefoot stabilization during gait. The toes need to efficiently flex against the ground in order to increase the effective weight-bearing surface area of the foot during the end of stance, aid in balance, and provide a stable platform for forward propulsion. Each digit therefore is a musculoskeletal chain that must act serially and in concert. The long flexor tendon stabilizes the distal phalanx against the ground, the short flexor tendon stabilizes the middle phalanx against the ground, and the lumbricals and plantar aponeurosis stabilize the proximal phalanx against the ground with interosseous muscles providing medial and lateral stabilization. One might also argue that the lumbrical tendons of the lesser digits, which are anatomically unopposed and insert medially on digits, help provide additional transverse plane stabilization against the relative abductory twisting force that results from the normal angle and base If these structures act in concert, then the fibrocartilaginous plantar plate can serve as a stable platform for the metatarsal head to roll onto in extension during propulsion.

If, however, there is any dysfunction or asymmetry within this chain, then the construct will have a tendency to "buckle" and destabilize. The most evident example of this is a hammertoe with flexor stabilization as a widely accepted theory to explain this common digital deformity [15, 118]. In this case, the long flexor tendon is proposed to fire earlier, harder, and longer than its norm in an effort to combat excessive rearfoot pronation. A detrimental consequence is that this strong extrinsic tendon subsequently overpowers the other intrinsic tendons of the digits and the chain "buckles" with relative dorsiflexion of the metatarsal-phalangeal joint and plantarflexion of the proximal interphalangeal joint.

A similar conceptual construct can be configured for the first ray. In order to provide a stable platform for the first metatarsal head to roll onto in extension during propulsion, the long flexor tendon must stabilize the distal phalanx of the hallux firmly against the ground and the short flexor tendon, abductor hallucis, adductor hallucis, and plantar aponeurosis must stabilize the proximal phalanx against the ground and stabilize the sesamoids as a stable platform for the first metatarsal head. Any instability or asymmetry within this chain would then be expected to cause the chain to "buckle." In this case the first metatarsal can buckle medially causing more of a hallux abductovalgus deformity or dorsally causing more of a hallux limitus deformity. Any abnormalities in the length of the metatarsal, whether long or short, would also be expected to destabilize this construct and prevent efficient metatarsal-phalangeal joint extension during propulsion. If the first metatarsal is relatively short, it might not effectively load into the stable platform created by the proximal phalanx base and sesamoids and subsequently buckle medially as the center of mass passes over the construct. The so-called Morton foot describes this process of a short metatarsal being insufficient to fully load and accept the weight of the body during propulsion [106, 107, 119]. Or if the first metatarsal is relatively long, then it might jam into the stable platform and buckle dorsally.

Relevantly, the same studies which have demonstrated joint obliquity differences between species of primates have also shown that humans have developed larger first metatarsals [49].

Equinus of the Achilles Complex

It is interesting to consider that quadruped species do not have a specific heel strike associated with their gait pattern. As a matter of fact, relative to bipeds, the calcaneus in quadrupeds is not even in close proximity to the ground, with a relatively plantarflexed ankle and shortened heel cord

(Fig. 3.3) [120–122]. Here again we see something that is often described as an abnormality which in fact likely just represents part of our evolutionary morphologic development. A standard maxim of bipedal biomechanics is that the foot must first act as a mobile pronating adaptor in order to initially accept the weight of the body and then subsequently transform into a supinating rigid lever arm through propulsion to effectively drive forward motion [33–35]. From a developmental perspective, the lower extremities of bipedal primates have a relatively lengthened Achilles complex with a calcaneus which is closer in contact with the ground to serve as this mobile pronating adaptor. Although few people would argue against equinus as a potentially deforming force in human biomechanics, in fact we have much less equinus than most other species!

Specific to our discussion on HV etiology, Achilles construct equinus negatively affects the first metatarsal-phalangeal joint through the mechanisms of rearfoot and midfoot pronation [8, 106, 107]. And although there are a number of theories on these effects, perhaps the most objective evidence has been provided by the Christensen group and their series of investigations on first ray function [50, 51, 114–117]. These biomechanical cadaveric studies have provided evidence of the effects and interactions of the equinus deformity, peroneus longus tendon, first metatarsal, and medial column. Specifically they described that the function of the peroneus longus tendon on the first metatarsal is primarily in the frontal plane and that this function is substantially reduced in the setting of equinus and rearfoot pronation. The normal action of the peroneus longus with respect to frontal plane motion has a stabilizing effect on the medial column of the foot as a whole and sagittal plane motion of the first metatarsal specifically. In other words, in the setting of rearfoot pronation, the peroneus longus tendon loses effect and directly decreases the stability of the first ray and stabilizing function of the medial column. Increased sagittal plane instability of the metatarsal was also observed in the setting of transverse plane deformity. This does provide some evidence with respect to the relationship between structure and function of the first metatarsal-medial cuneiform joint.

Fig. 3.3 Contribution of Achilles complex equinus to hallux abductovalgus. This figure demonstrates a representative example of quadruped lower extremity anatomy. This lower extremity structure is relatively apropulsive and does not utilize the mobile pronating adapter/supinating rigid lever arm function of the human foot. Note the plantarflexed orientation of the ankle and considerable physical distance between the calcaneus and the weight-bearing surface. Although few would argue against equinus as a potentially deforming force in human biomechanics, it is interesting to consider that we have less equinus than most other species

Further, just as the flexor stabilization theory proposes that the flexor digitorum longus tendon fires earlier, harder, and longer as a compensatory mechanism for excessive rearfoot pronation and results in lesser digital deformity, it is not unreasonable to expect the flexor hallucis longus muscle to do the same and potentially result in first metatarsal deformity. As a matter of fact, the original electromyographic studies on which the flexor stabilization theory is based provide more evidence of the flexor hallucis longus firing earlier, harder, and longer than the flexor digitorum longus [123–130]. If one was to draw an analogy between HV and hammertoes in the setting of a dynamic muscle imbalance secondary to rearfoot pronation, then HV could essentially be conceptualized as a hammertoe on its side (or in the transverse plane instead of the sagittal plane). The most distal joints (hallux interphalangeal joint and distal interphalangeal joint, respectively) remain relatively rectus, the second most distal joints (first metatarsal-phalangeal joint and proximal interphalangeal joint, respectively) are in a position of relative flexion, and the most proximal joints of the complex (first metatarsal-medial cuneiform joint and metatarsal-phalangeal joint, respectfully) are in a position of extension. At least one study has provided evidence of a substantial association of digital deformities with HV versus other forms of first metatarsal-phalangeal joint pathology, potentially indicating a common dynamic etiology [131].

Considered together, these three atavistic traits of human foot morphology speak to a potential structural and functional predisposition for HV in some individuals. To some degree, this evidence points to the first metatarsal-medial cuneiform articulation as the apex of the deformity, emphasizes frontal plane positional abnormalities of the first metatarsal over the transverse plane position in the pathogenesis, and links the function of the forefoot and rearfoot during human gait. But again, it may be inaccurate to classify these consistencies as "deformities" as they appear to be a fairly normal part of human evolutionary morphology. Interestingly, instead of a structure transitioning from "normal" to "abnormal" as is typically the case when discussing the pathogenesis of a condition, with a broad view, here the morphology seems to have considerably moved away from relatively "abnormal" to our current level of structure and function. And it is difficult to predict what changes might yet still occur. It would be fascinating to be able to see how the morphology of these structures changes over the next couple thousands of years of human history and development!

Is Hallux Abductovalgus a Progressive Deformity with a Consistent Natural Course?

Here again a lack of longitudinal studies limits definitive answers to a seemingly direct question. However, indirect evidence in the form of cross-sectional and other investigations tends to demonstrate an increasing prevalence of the deformity associated with age [8]. Further, clinical experience indicates that the HV deformity tends to progress with time and rarely, if ever, improves or becomes self-limiting. This is likely most accurate for the type of deformity which has formed the focus of this chapter thus far, a progressive adult-onset biomechanical HV, as opposed to those deformities arising from congenital, inflammatory, traumatic, and/or neuromuscular causes.

There is also relatively little data available on the natural history of the process of articular deformation. These biomechanical bunions likely initiate when something, whether structural or functional or a combination therein, in or around the first metatarsal-phalangeal joint leads to a relative imbalance in the direction of lateral deviation of the hallux (or medial deviation of the first metatarsal). This could originate proximally such as with an increased obliquity of the first metatarsal-medial cuneiform articulation, hypermobility/instability of the first ray and/or medial column producing an excessively dorsiflexed, adducted and valgus-positioned first metatarsal, angular cartilage malformation on the head of the first metatarsal, etc. Or this could originate distally such as from deformity within the phalanges of the hallux or from excessive lateral pull from extrinsic or intrinsic muscles like the flexor hallucis longus. Somewhat regardless of the initiating source of the imbalance, there are very few intrinsic compensatory mechanisms available to counteract it.

An analogy to this process could be drawn to the flatfoot deformity and Hansen's description of peritalar subluxation [132]. Although the talonavicular joint is certainly not a ball-and-socket joint from an anatomic perspective, conceptually it might help to think of it this way when considering rearfoot pronation/supination. In the rearfoot, the concave base of the navicular and flattened superior surface of the sustentaculum tali of the calcaneus forms a specialized pocket-like structure in which the convex head of the talus sits. These osseous structures are supported by strong surrounding soft tissues plantarly and laterally such as the fibrocartilaginous plantar calcaneonavicular ligament, bifurcate ligament, and intrinsic/extrinsic musculature. Although these all lie in close anatomic proximity to the head of the talus, very few of them actually have an insertion into it. Most of the soft tissue structures insert onto the calcaneus and navicular. During pronation, the distal foot can be visualized as swinging off of the talar head laterally in a triplanar manner resulting in a relatively unstable and radiographically decreased talar head coverage. During supination, the foot can be visualized as swinging back onto the talar head in a triplanar manner resulting in a relatively stable and radiographically increased talar head coverage. There is not an osseous support structure medially to block excessive pronation, and the posterior tibial tendon (the only substantial medial structure in the area) becomes pathologic in the setting of long-standing deformity.

A similar anatomic construct is found at the first metatarsal-phalangeal joint, at least conceptually. The concave base of the proximal phalanx and flattened superior surfaces of the sesamoids form a specialized pocket-like structure in which the convex head of the first metatarsal sits. These osseous structures are supported by strong surrounding soft tissues plantarly and laterally such as the components of the sesamoid apparatus, plantar aponeurosis, deep transverse metatarsal ligament, and intrinsic/extrinsic musculature. Although these all lie in close anatomic proximity to the head of the first metatarsal, very few of them actually have an insertion into it. Most soft tissue structures insert onto the sesamoids and base of the proximal phalanx. In the biomechanical bunion deformity, for whatever reason, the base of the proximal phalanx uncovers the head of the first metatarsal which exits the medial aspect of this construct. There is not an osseous support structure medially to block it, and the pathologic changes that often occur to the medial soft tissue structures in the setting of long-standing deformity have already been reviewed [45, 71].

Within this framework, the base of the proximal phalanx and sesamoids remain relatively stationary throughout the progression of the deformity while the first metatarsal is the relatively mobile structure. Evidence in support of this is provided by studies which have noted that the sesamoids remain immobile relative to the second metatarsal before and after surgical correction [133–135], and by a study which has shown that the center of the base of the proximal phalanx of the hallux also does not "move" relative to the remainder of the foot regardless of the severity of the HV deformity [136]. Although it sometimes appears as though the sesamoids have "subluxed" into the distal first interspace in severe HV deformities, this is probably a radiographic result of the first metatarsal translating medially and/or rotating into a valgus position [68, 134]. And while the deformity is traditionally primarily thought of in the transverse plane and assessed with the dorsal-plantar radiographic projection, other more recent investigations have also provided evidence that this might be more of a radiographic finding attributed to frontal plane rotation than transverse plane translation [68, 111–113, 137, 138]. Even further, a recent cross-sectional investigation has demonstrated statistically significant positive correlations between the transverse and frontal planes in the setting of HV deformity [139].

Once the hallux is laterally deviated (or first metatarsal medially deviated), the action of the extrinsic muscles (flexor hallucis longus and extensor hallucis longus) tends to exaggerate and exacerbate the deformity with no substantial static or dynamic antagonist present. This is sometimes referred to as a retrograde buckling effect [8, 17]. And as these relative motions progress into more severe stages of the deformity, the secondary consequences of these positional changes begin to take effect. This includes laxity and atrophic changes to the medial capsular structures, loss of trabeculation to the medial metatarsal head, contracture of the lateral capsular and tendinous structures, erosion of the crista, functional adaptation of the articular cartilage, etc. Once again, it is more likely that these findings represent the result of the process as opposed to the cause.

Recent evidence has indicated that this process occurs in a relatively consistent and predictable manner. Meyr et al. demonstrated that when the first intermetatarsal angle was less than 10 degrees, an approximate 1:1 positive relationship between the first intermetatarsal angle and hallux abductus angle was observed (Fig. 3.4) [110]. In other words, a one-degree increase in the first intermetatarsal angle is associated with a compensatory one-degree increase in the hallux abductus angle, or vice versa. But in situations of greater radiographic deformity, a more rapid acceleration of deformity progression is found. In other words, a one-degree increase in the first intermetatarsal angle was associated with a greater degree of hallux abductus angle increase. The authors went so far as to describe a specific possible "tipping point" of the HV deformity in which the deformity progression seemed to accelerate.

However, what might be less understood is what happens at the end of the natural course of the deformity. Although it is generally accepted that HV worsens over time, it is absolutely not common for it to progress to the point of complete subluxation where the hallux is at 90 degrees to the metatarsal and underlapping the lesser digits. In other words, at some point in most cases, the deformity must slow and essentially stop, indicating more of a "progression to a point" natural course. Predicting this point, or the maximum extent of deformity progression, could be valuable with respect to the timing of surgical intervention and procedural planning.

Although the author is not aware of any specific evidence to support or refute this theory, one possible explanation could be that first metatarsal-phalangeal joint deviation develops as a compensation for a dorsiflexion limitation of the joint during propulsion. As stated previously, there is some evidence that a degree of intrinsic deformity is a "normal" finding in a group without a history of previous foot surgery [110]. The mean observed hallux abductus angle in this group was approximately 18 degrees and the first intermetatarsal angle was approxi-

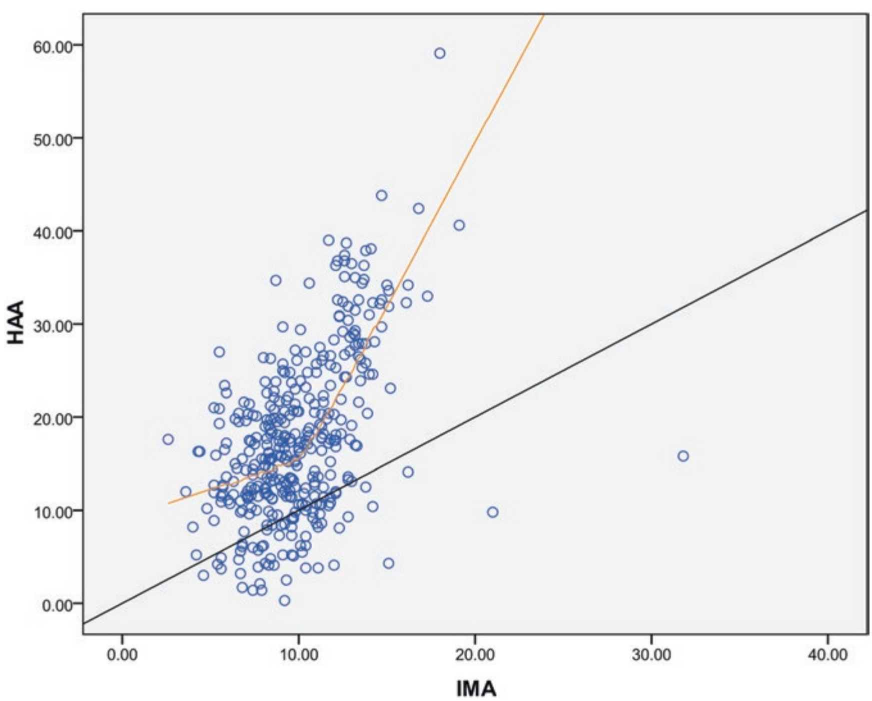

Fig. 3.4 Relationship between the first intermetatarsal angle (IMA) and hallux abductus angle (HAA). This frequency scatter plot with overlying Loess best fit lines demonstrates the relationship between the first intermetatarsal angle (IMA) and hallux abductus angle (HAA) in a large cohort of feet without a history of foot surgery. An approximate 1:1 positive relationship was observed when the IMA was less than approximately 10°, but an accelerated pattern of deformity progression was observed when the IMA was greater than 10° (Reproduced from Meyr et al. [110])

mately 10 degrees. As surgeons, during operative correction of the deformity, we tend to strive for creation of a perfectly rectus radiographic result. In other words we generally attempt to bring the first intermetatarsal angle and hallux abductus angle as close to 0 degrees as possible, but this might not be a "natural" outcome and does not take into account a relatively abducted angle and base of gait. Perhaps in order to help drive efficient and effective forward propulsion, the first metatarsal remains in a relatively medial orientation compared to the long axis of the remainder of the relatively abducted foot during gait.

The degree of medial orientation of the first metatarsal which is "normal" might be variable depending on the specific angle of gait and effective extension achieved at the first metatarsal-phalangeal joint. It is interesting to consider that hallux abductovalgus is not necessarily associated with a decrease in first metatarsal-phalangeal joint range of motion while in the "deformed" position. Intraspecies variations in the obliquity of the first metatarsal-medial cuneiform articulation, the variations seen in medial cuneiform ossification based on loading patterns which affect morphology, the relatively late ossification of the proximal first metatarsal physis, and the relatively increased range of the motion of the first metatarsal-medial cuneiform articulation might all provide circumstantial evidence that the human body allows for some dynamic adaptation of this anatomic area as skeletal maturity is reached. In other words, the first intermetatarsal angle and hallux abductus angle might be predisposed to an intrinsic ability to increase until a relative steady state in lower extremity biomechanics is achieved where there is an effective balance between rearfoot pronation/supination and between the angle and base of gait with first metatarsal-phalangeal joint extension. Once this balance has been met, the "deformity" anatomically stabilizes regardless of what relative pathoanatomy and subjective symptoms have developed.

What Are Patient Perceptions of the Deformity and Expectations of Treatment Intervention?

By way of conclusion, readers should appreciate that there is value to a discussion of deformity etiology if it results in a means to improve treatment intervention. And although a substantial portion of this chapter dealt with the objective ways by which surgeons define deformity and assess treatment outcomes, another intended general theme was to point out the potential disconnect between patient subjective symptoms and physician objective assessment. Several studies have demonstrated a seeming lack of concordance between objective deformity assessment and subjective patient symptoms [4–6]. And while there is not a preponderance of investigations detailing pre- and postoperative patient outcomes following surgical interventions for the HV deformity, those that have been published have demonstrated fairly consistent results [4–6, 86, 87, 140]. The most common postoperative patient expectations, and therefore possibly related to the most common preoperative patient complaints, are for a reduction of pain and the ability to comfortably wear shoes of their choice.

This might affect physician intervention in two ways. The first is the performance of patient interviews, physical examinations, and diagnostic testing with a specific aim to ascertain the source of patient pain. Is it simply positional and related to the external stresses of activity and shoegear, or is it intra-articular and as a result of degenerative arthrosis, for example? The second is with respect to shoegear. These studies provide evidence that although the association between shoegear and objective deformity progression might be questionable, the association between shoegear and subjective patient symptoms is strong. What are patient goals with respect to activity and shoegear, and will a recommended treatment intervention be expected to achieve these goals?

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4 Clinical Assessment

Naohiro Shibuya

Background

In a bunion, it is well recognized that the first metatarsal is adducted while the hallux is abducted in the transverse plane. However, it is a complex triplanar deformity that is variable in its etiology, amount and type of deformity. For example, juvenile versus adult onsets, neurological versus biomechanical origins, underlying pes cavus versus planus deformity can present in a bunion with very different characteristics. Some of these unique factors are known to affect the final outcomes of corrective surgeries [1, 2]. Therefore, evaluation of each component of the overall deformity is important to optimize the surgical results.

In all bunion deformities, neurovascular examination is essential. Especially in patients with underlying comorbidities and/or previous surgical procedures, neurovascular insufficiency may be present at a high frequency. A good history taking is necessary to avoid overlooking conditions that negatively affect surgical outcomes. Psychosocial issues such as depression, metal health issues and compliance should be also carefully evaluated. Perception of successful outcomes can greatly differ from a patient to patient depending on the mental status of the patient. It is also dependent on pre-surgical general physical condition. Frailty of a patient, especially in an elderly and less healthy/fit patient, should be evaluated and documented. A patient's ability to use an ambulation assistance device and to stay off-weight bearing, if necessary, should be assessed as well. In this group of patients, a physician should discuss the likelihood of potential deconditioning during postoperative period with the patient.

In this chapter, discussion is focused on biomechanical examinations of a patient with a bunion. Evaluation of components and associated conditions of a bunion is discussed.

First Ray

The first ray consists of the medial cuneiform and the first metatarsal. The ray is generally adducted, externally rotated and dorsiflexed in majority of the biomechanically-induced hallux valgus (HV) deformity. Adduction of the metatarsal along with lateral deviation of the hallux creates a medial prominence or a "bunion". This deviation is associated with insufficiency of static and dynamic stabilizers, resulting in instability or hypermobility. This may then result in attenuation of some of the plantar ligamentous structures; therefore, the ray pathologically elevates in the sagittal plane.

In the frontal plane, many of the first metatarsals in HV deformity is rotated in the valgus direction. This is evidenced by laterally rotated

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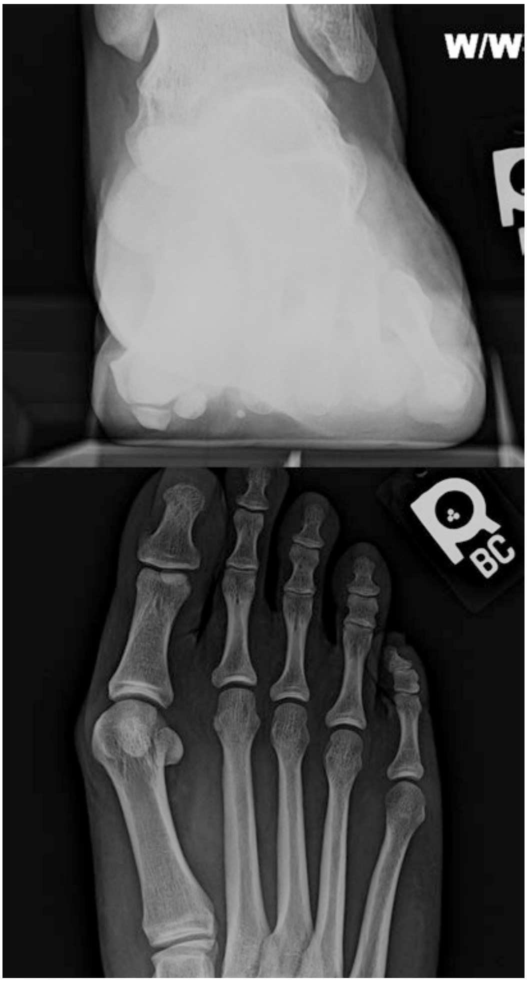

Fig. 4.1 In this sesamoid axial view, the crista is shown to be laterally rotated, indicating that the first metatarsal is externally rotated

crista of the first metatarsal head in the sesamoid axial view of a plane radiograph (Fig. 4.1). It has been shown in an observational study with computed tomography evaluation that this external rotation of the first ray occurs in almost 90% of HV [3].

While radiographic examination can show deviation of the first ray in these different planes, flexibility, reducibility and joint adaptation cannot be assessed effectively without a thorough clinical examination. Evaluating these parameters are important when selecting a surgical procedure that effectively reduces the deformity and maintains the correction. Reducibility of a medially deviated first metatarsal can be relatively easily assessed in a clinical examination. When a first intermetatarsal angle is manually reducible in a clinical examination, surgical correction of the deformity may be achievable without proximal osteotomy or arthrodesis. For example, soft tissue balancing, tethering or distal metatarsal osteotomy techniques may adequately reduce the overall deformity by negating the retrograding buckling force caused by the long extensor and flexor (Fig. 4.2). Conversely, a proximal osseous procedure may be necessary in those non-reducible deformities. For example, first metatarsophalangeal joint (MTPJ) arthrodesis for correction of HV would not improve the intermetatarsal (IM) angle unless the first ray is passively reducible in a preoperative clinical examination. Without a reducible intermetatarsal space, a significant gap between the hallux and the second digit may occur after correcting the hallux position on the metatarsal with this procedure.

On the other hand, excessive motion of the first ray can be problematic and warrants an extra attention. While most of the bunion deformities have some degree of first ray instability, magnitude of hyperflexibility should be assessed. This needs to be evaluated with a clinical examination since radiographic examination in this matter can be inaccurate [4, 5]. In order to assess the magnitude of mobility in the first ray, one can simply squeeze the forefoot from the medial to lateral direction (Fig. 4.3). Alternatively, one can squeeze the forefoot while the other hand stabilizes the second metatarsal to isolate the first IM space (Fig. 4.4). Also, it is beneficial to observe the location and angulation of the hallux while performing this squeeze test. It is important to note whether the hallux further deviates laterally or positions back to its original position. If it further abducts with lateralization of the first metatarsal, significant contracture of the lateral MTPJ can be present. Lateralization of the first metatarsal otherwise should place the long flexor and extensor over the first ray axis and help realign the hallux onto the first metatarsal head. The squeeze test can also be done simultaneously with reduction of the hallux at the MTPJ, as it

Fig. 4.2 These flexible deformities were corrected successfully without proximal osseous procedures. (**a**) Distal metatarsal osteotomy, (**b**) tethering bunionectomy and (**c**) first metatarsophalangeal joint arthrodesis reduced intermetatarsal and hallux valgus angles

Fig. 4.3 The first ray is manually and passively reduced. A reducible first ray will result in a narrower forefoot

Fig. 4.4 To prevent from other interspaces contributing in the narrowing of the forefoot, one can stabilize the second metatarsal while performing the squeeze test

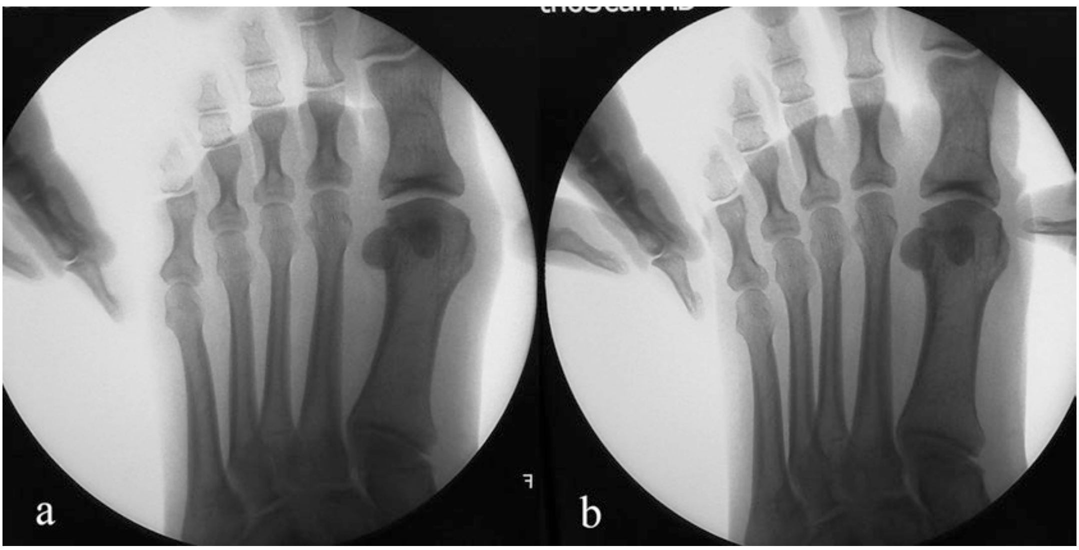

Fig. 4.5 A manual, passive reduction of the first ray is confirmed under fluoroscopy

negates the retrograde buckling force and may further reduce the IM angle. For more accurate assessment, this can be done under fluoroscopy if available (Fig. 4.5). Reducibility of the sesamoids can also be observed at the same time. Pain associated with these maneuvers should also be noted. A painful, forced reduction may result in a poor post-operative outcome if the area of pain is not addressed adequately. For example, HV correction with first MTPJ arthrodesis can result in painful the tarsometatarsal joint (TMTJ) or base of the first IM space post-operatively if the deformity had a non-reducible IM angle.

In the frontal plane, reducibility can be assessed by internally rotating the hallux, which in turn, internally rotates the first metatarsal (Fig. 4.6) [6]. This can also be done with reduction of the IM and HV angles to simulate the actual surgical reduction. Again, this is more helpful with an aid of fluoroscopy if available. Reduction of the sesamoids, change in curvature of the medial and lateral first metatarsal shaft cortex

Fig. 4.6 The hallux is internally rotated to assess the reducibility of the first metatarsal in the frontal plane

are the indications of a mobile first ray in the frontal plane. In surgery, reduction of the first ray in the frontal plane can be achievable with different techniques that de-rotate the first metatarsal or reduce underlying deformities, such as pes planus or metatarsus adductus deformities.

In the sagittal plane, excursion of the first ray relative to the lesser metatarsal should be evaluated. The excursion is often referred to as flexibility of the first ray. In a normal foot, the motion is mainly coming from the naviculocuneiform joint (NCJ) and minimal motion is coming from the TMTJ [7, 8] though more motion in the TMTJ is present in a foot with metatarsus primus varus (MPV). An increased motion at the TMTJ comes in a pathological foot with ligamentous attenuation [9] and/or weakening of the dynamic stabilizers, such as the peroneus longus. When unstable, one should gain a sense of how much instability is clinically appreciated. An unstable first ray can result in metatarsus primus elevatus and hallux limitus [10, 11].

Elevation of the first ray is often examined with a lateral x-ray view. However, it is as important to assess the position of the first ray in the open kinetic chain clinically as well. Many of the elevated first rays, viewed in the weight-bearing lateral x-ray, can be resulted from the ground reacting force applied to the first metatarsal head, that is otherwise plantarflexed in the open chain [12]. The falsely and radiographically elevated first ray in a forefoot valgus patient (the first ray is plantarflexed in the open kinetic chain) should not be further plantarflexed with surgery as it may cause sub-first metatarsal pain post-operatively. To assess the position of the first ray in the sagittal plane clinically, a patient's calcaneus is placed in the examiner's hand, in line with the long axis of the leg. The other hand is then used to grasp the fifth metatarsal head. The examiner's thumb (on the hand cupping the calcaneus) is then placed over the talonavicular joint while the subtalar joint (STJ) is manipulated using the other hand until the head of the talus is covered by the navicular. At this point, the STJ is considered to be in a neutral position and the forefoot is observed in the frontal plane (Fig. 4.7). If the patient's first ray is higher than the lesser metatarsals, it is considered elevatus or supinatus, and the examiner should be highly suspicious of unstable first ray and the ray may need to be surgically plantarflexed.

Anatomical structures that are responsible for stabilization of the first ray should also be examined. Dynamic stabilizers, such as long flexor and peroneus longus tendons can be evaluated by the regular muscular examination and with gait observation. Lack of re-supination, overly flexible or rigid medial column and

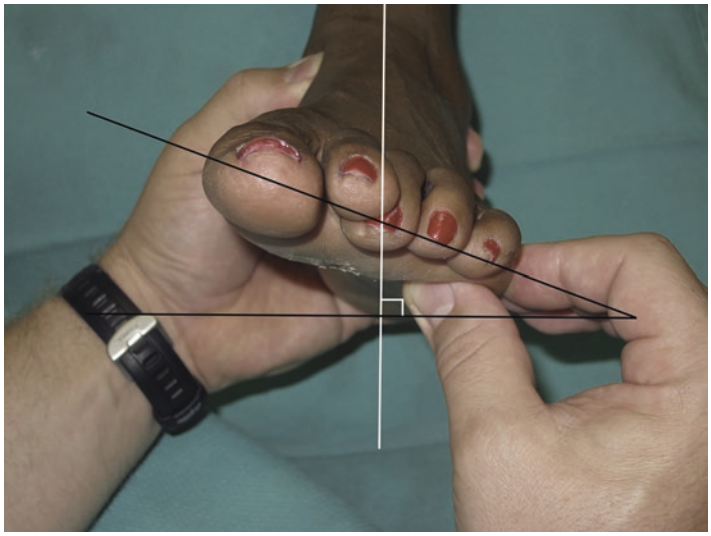

Fig. 4.7 Elevation of the first ray is evaluated with the subtalar joint in the neutral position

inefficient propulsion are indicative of attenuation or loss of biomechanical advantage of one or more of the first ray dynamic stabilizers. Damages to static stabilizers, such as plantar and inter cuneiform ligaments may be associated with pain on palpation and/or range of motion in the corresponding areas.

In open kinetic chain examination, one of the most popular methods of evaluating the instability of the first ray was described by Root and Merton [13]. Hypermobility was referred to as a total (dorsiflexion and plantarflexion) excursion of the first ray of more than 1 cm in the sagittal plane. Yet, no scientific rationale for this definition was originally provided. Reproducibility, accuracy, sensitivity and clinical significance of this examination is therefore uncertain. However, later studies conducted by other investigators, focusing mainly on identifying an average motion of the first ray between symptomatic bunions and a control without bunion deformity, showed a normal average range motion in the first ray to be similar to that of the range of motion described by Root and Merton [14–16].

Many advocate arthrodesis of the TMTJ for more hypermobile bunions, but some studies show good surgical outcomes with joint preservative procedures [5, 17]. Ambiguity of the definition of hypermobility however makes these findings difficult to interpret. Nevertheless, one can appreciate the difference in amount of excursion form a patient to patient using this evaluation technique. It has been shown that dorsiflexory resistance of the first ray is compromised when the first metatarsal, sesamoids and hallux are malaligned [18]; therefore, examination of the first ray instability also provides information on magnitude of the HV deformity. To perform this test, one can hold the first metatarsal with one hand while the other holds the lesser metatarsals. Having the ankle and subtalar joints in their neutral positions, the first ray is maximally dorsiflexed and plantar flexed (Fig. 4.8). The excursion in reference to the fingernails is recorded. Alternatively, to simulate a normal gait and to activate the windlass mechanism, the hallux is dorsiflexed before the first ray can be assessed for hypermobility [19, 20] (Fig. 4.9). Lack of stabilization with this maneuver indicates that his/her windlass mechanism may be already compromised and improvement of the first ray function after surgery may be challenging.

Generalized ligamentous laxity in a patient should be also examined. Ligamentous laxity results in instability of the first ray and may mean that it is more difficult to maintain the surgical correction. Namely, an instrument, such as Beighton Score, can be utilize to assess the degree of ligamentous laxity objectively by evaluating the metacarpophalangeal joints in the

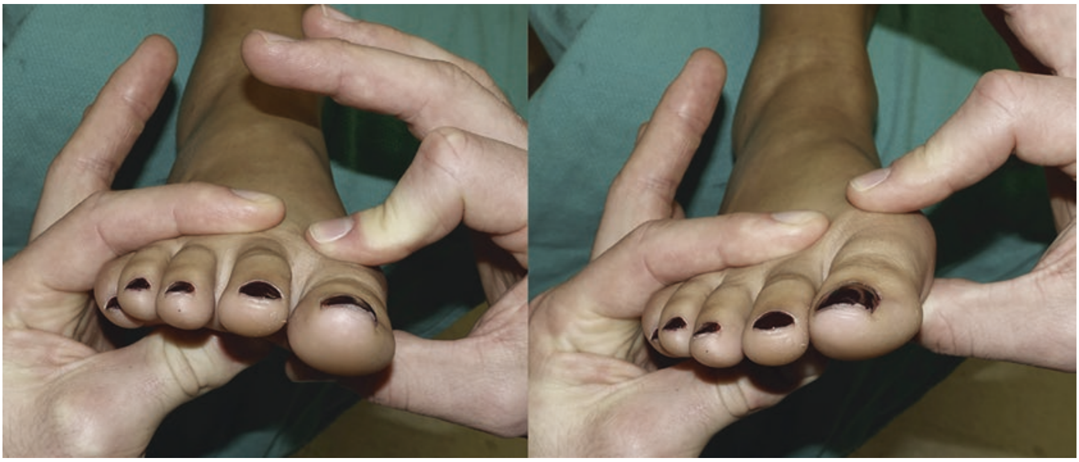

Fig. 4.8 Mobility of the first ray is examined in the sagittal plane while the lesser metatarsals are stabilized and the ankle and subtalar joints are placed in their neutral positions

Fig. 4.9 Dorsiflexion of the hallux mimics normal gait and activates windlass mechanism before mobility of the first ray is assessed

Fig. 4.10 Generalized ligamentous laxity in a patient can be evaluated by examining other parts of the body

hands, hyperextension of the elbows and knees and forward flexion of the trunk [21] (Fig. 4.10).

Other signs that may suggest instability of the first ray are found in the second ray. A patient may possess a sub-second metatarsal biomechanical hyperkeratotic lesion, plantar plate rupture/attenuation of the second MTPJ and hammer toe deformity (Fig. 4.11). A visual, dermatological examination to rule out the biomechanical lesion, a dorsal dislocation maneuver to stress the plantar plate to rule out the plantar plate pathology and thorough hammer toe evaluation are critical in a comprehensive bunion evaluation. It is also important to note that the relationship between the hallux and the second digit often changes with weightbearing. Crossover deformity, for example, can worsen with a loading of the forefoot (Fig. 4.12).

Fig. 4.11 A second submetatarsal lesion may indicate unstable first ray

First Metatarsophalangeal Joint

In the first MTPJ, reducibility, flexibility and degree of joint adaptation should be carefully assessed clinically in the similar manner to those of the first ray. Compared to the TMTJ and NCJ, the first MTPJ is far more complex due to more tendon attachments and presence of the sesamoid complex; therefore, understanding characteristics of hallux valgus deformity in association with these structures is imperative. The sesamoids rest in the grooves adjacent to the crista in a normal foot. In HV deformity, the sesamoids are deviated in the transverse plane when viewed in the dorsoplantar projection of a plane radiograph relative to the first metatarsal head [22, 23], while the relationship between the sesamoids and the second metatarsal remains consistent [24, 25]. These relationships suggest that the first metatarsal is the moving part that is dislocating from the sesamoids. Deviation and subluxation of the first metatarsal out of the sesamoids can then result in degenerative changes under the first metatarsal [26] and this

Fig. 4.12 Relationship between the hallux and the second digit is best evaluated in a weightbearing position. A degree of deformity often worsens when the forefoot is loaded in this manner

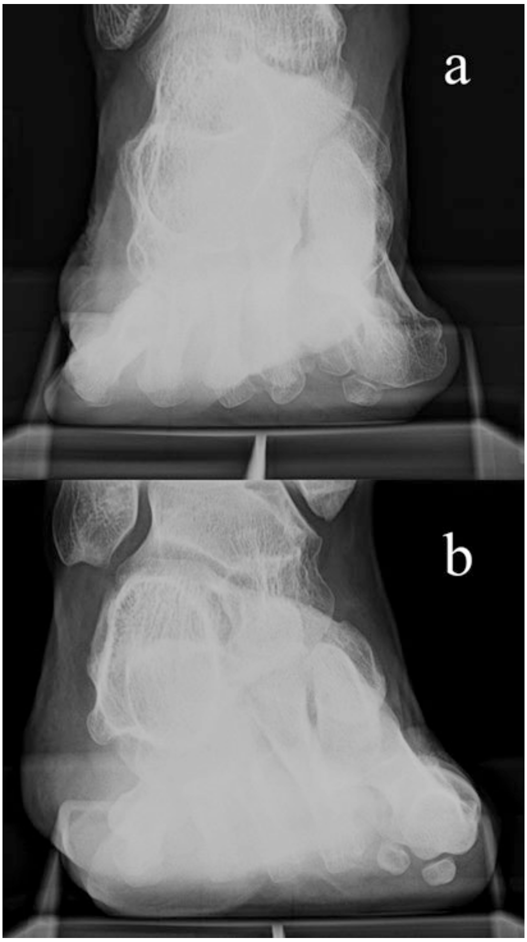

Fig. 4.13 The sesamoids can either (**a**) sublux or (**b**) remain congruous as the first metatarsal medially deviates

should be noted preoperatively to avoid unexpected residual pain after surgery. However, radiographic medial deviation of the first metatarsal does not always result in dislocation of the sesamoids out of their proper articular surfaces [27]. They can many times remain in the corresponding grooves, yet they "appear" to be laterally deviated in the dorsoplantar x-ray view. This phenomenon is due to simultaneous external rotation of both the first metatarsal and the sesamoids as these structures remain congruous (Fig. 4.13). In a cohort of 166 HV feet studied by Kim et al., 26% of HV presented with a congruent sesamoid complex despite the apparent radiographic subluxation [3]. This explains that both lateral translation of the head of the first metatarsal and de-rotation of the first metatarsal have been reported to be efficacious is achieving reduction of the sesamoid position [25, 28–31] (Fig. 4.14).

Range of motion examination at the first MTPJ in deformed and rectus positions of the hallux can provide information on the status of the sesamoid complex. When the first metatarsal is pronated but the sesamoid complex is congruous, a smooth, painless range of motion in the deformed position is not uncommon. On the other hand, subluxation of the sesamoids out of the corresponding grooves can result in a painful range of motion with or without manual reduction of the first MTPJ in the transverse plane. If available, live radiographic examination with fluoroscopy can provide the definitive answer to the relationship between the first metatarsal and the sesamoids throughout the range of motion (Fig. 4.15). During this test, reduction of the sesamoids in the dorsoplantar view and sesamoid axial view while the hallux is reduced in the transverse and frontal plane and also through the range of motion in deformed and corrected positions are evaluated. If an IM angle can be reduced manually at the same time, it can also assist in reduction of the sesamoid position. It should be noted that sesamoids may reduce into more congruous position with dorsiflexion of the hallux and the sesamoid axial view may underestimate the amount of subluxation [32]. Non-reducible sesamoids may warrant some type of osseous procedure. On the other hand, in a reducible deformity, when the range of motion is painful in the corrected position, surgical reduction of the deformity may result in an even more painful joint post-operatively. Therefore, these evaluations are important to determine what type of procedure is necessary not only to reduce the deformity but also to achieve a non-painful joint range of motion after surgery.

The standard evaluation for hallux limitus should also be employed while assessing the range of motion. As many HV deformities are associated with first metatarsal elevation, a decreased dorsiflexion at the MTPJ is not uncommon. The prominence many times appears more dorsally in these

Fig. 4.14 The sesamoid position was reduced with (**a**) lateral translation and (**b**) internal rotation of the first metatarsal

situations with a limited dorsiflexion (Fig. 4.16). They may also present with hallux extensus from hallux interphalangeal joint (IPJ) compensation. These findings should be well documented and a patient should be informed about it preoperatively, as some patients do not notice the limited range of motion until after the corrective procedure. Again, this clinical examination is conducted with the hallux in deformed and corrected positions. The patient should also be informed about the potential loss of range of motion after surgery, especially when the range of motion worsens when the hallux is reduced in a rectus position during the clinical examination. The range of motion at the hallux IPJ is also assessed at the same time. A painful range of motion in the IPJ will most likely be problematic if the MTPJ range of motion decreases post-operatively.

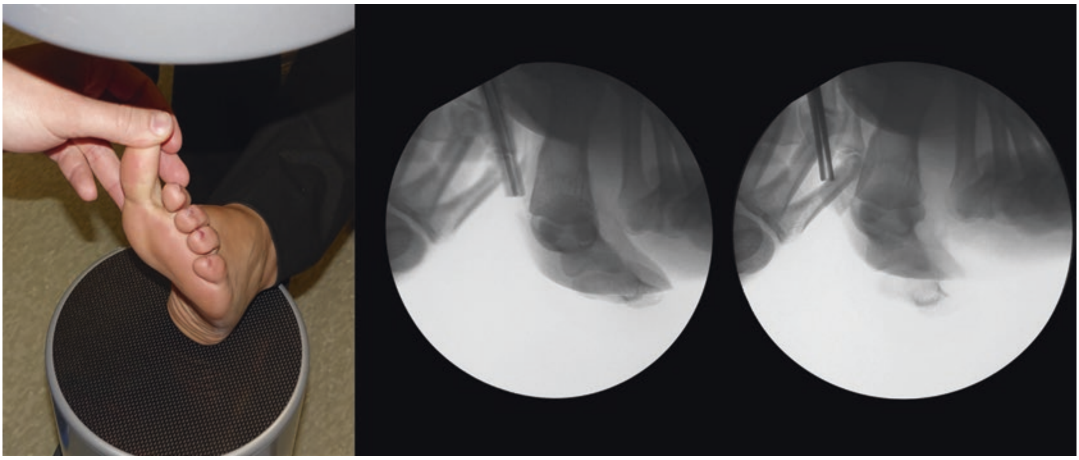

Fig. 4.15 A range of motion examination with live fluoroscopic guidance can show the relationship of the sesamoids with the first metatarsal and the dynamics of the sesamoid complex

Fig. 4.16 This pronated foot presents with a medial column collapse, unstable first ray and elevation of the first ray. This type of foot many times results in hallux limitus, evidenced by limited range of motion and more dorsally located prominence at the metatarsophalangeal joint

While assessing the range of motion, an amount of contracture of the lateral structures should also be assessed. A chronic HV deformity often results in contracture of the lateral capsule, adductor tendon and long flexor and extensor. Also, weakening of the antagonists, such as abductor hallucis, can be present [33] and should be noted. It has been shown that an older age and HV deformity are risk factors for reduction in size and change in morphology of the abductor hallucis muscle [34, 35]. As seen in other areas, such as the ankle joint, release of contracture, shortening of the segment and augmentation of insufficient structures may be necessary to reduce the chronic deformities. Contracture of these anatomical structures should also be assessed in weightbearing examination. Often, long extensor contracture is not appreciated until a patient bears weight. Bowstringing of the extensor tendon may be apparent only with weightbearing. Further, in many cases, lateral deviation of the hallux worsens with weightbearing. Lateral tracking of the hallux should be assessed in this position as well as in a slightly dorsiflexed position, as some intrinsic, extrinsic muscles and ligamentous structures become taut in this position. As mentioned earlier, relationship between the hallux with the second digit should also be observed in this position.

Crepitus associated with a range of motion of the MTPJ suggests arthritic changes. Often the joint can be without crepitus in a deformed position but it can present when the deformity is corrected manually into a rectus position as the joint is put through the range of motion. This suggests adaptation of the joint or a laterally deviated articular cartilage on the first metatarsal head. When the joint motion is smooth in the abductovalgus position, articular cartilage may no longer exist on the medial side. This is not always appreciated with radiographic examination.

Even without crepitus, pain felt with range of motion of the first MTPJ in different positions may suggest a chondral lesion of the articular surface as the prevalence of this condition is extremely high in HV [36–38]. This condition is often underestimated with radiographic examination; therefore, a careful clinical examination is critical [39]. It should be noted that the condition not only occurs in the anterior articular surface of the first metatarsal, but also frequently under the metatarsal head where it articulates with the sesamoids [36, 40]. Similarly, synovitis in the first metatarsophalangeal joint can be a cause of the patient's main complaint in HV [41]. In these intra-articular conditions, a diagnostic intra-articular block can differentiate the pain in the joint from the pain coming from the medial prominence. The hallux is slightly dorsiflexed and the needle can be introduced in the dorsal capsular pouch, and a small amount of short-acting anesthetic agent can be injected in the joint.

In a bunion with extensive frontal plane valgus rotation and with a congruent sesamoid complex, the apparent lateral deviation of the articular cartilage can be due to an externally rotated first metatarsal. Therefore, surgical de-rotation of the first metatarsal may centralized the articular cartilage without distal metatarsal osteotomy, such as Reverdin osteotomy. In this case, the "corrected" position may not necessarily be created by adduction of the hallux.

Over the medial prominence, a surgeon can evaluate for erythema, biomechanical hyperkeratotic lesion, neurological irritation and presence of a bursa. Pain associated with compression applied to the area from a shoegear should be differentiated from the pain coming from the joint. If the pain is purely coming from medial prominence irritation, then one should remember that deformity correction may improve the medial prominence complaint but can initiate a new pain in the joint by modifying the alignment of the non-symptomatic joint. Neurological pain evidenced by Tinel's or Valleix's signs should be documented as some of the pain may not improve after a surgical intervention if extent of the nerve damage is severe and irreversible. A fluctuance over the medial eminence may indicate presence of a bursal sac under the skin. If noted, it should be part of the surgical planning.

In the hallux itself, one should examine the amount of valgus rotation, presence of a biomechanical hyperkeratotic lesion, lateral deviation of fat pad and presence of ingrown nail. These findings are associated with hallux valgus deformity itself but also can be due to an increased angle of gait, underlying pes planus and delta-proximal phalanx. It is important to note that some of these conditions may not improve after bunion surgery unless the actual cause is corrected. Adjunctive proximal phalanx osteotomy may address some of these issues but effectiveness in correction of HV as an isolated procedure or with other osseous procedure is controversial [1, 42–47]. A valgus rotation of the hallux can also correspond to an externally rotated first metatarsal; therefore, a careful examination of the sesamoid complex, lateral plantar contracture of the MTPJ and reducibility of the first ray in the frontal plane, described earlier, should be emphasized.

Length of the hallux is also important to note. When the first ray is longer, it is more likely to be subject to a retrograde buckling and is more difficult to maintain correction. When too short, it is important to note which segment is short. If the first ray is short from a previous surgery at the metatarsal segment then stability of the metatarsophalangeal joint may be compromised, as intrinsics may no longer have the mechanical advantage to stabilize the joint. Weightbearing examination may show a floating hallux (Fig. 4.17), and gait analysis may show non-purchasing/non-propulsive hallux. Further shortening can result in further instability of the joint.

Associated Deformities

While most of the focus may be in the first ray and the first MTPJ, there are many other associated conditions that affect the long-term result of the HV deformity correction. These associated conditions are often causative factors of a bunion deformity; therefore, if not addressed, recurrence may occur.

Fig. 4.17 A previous unsuccessful surgery shortened the first ray significantly, and a non-purchasing hallux is apparent on weightbearing

Equinus

It has been shown that people with foot and ankle pathologies have a higher prevalence of isolated gastrocnemius tightness [48]. Within a group of people with equinus, the prevalence of hallux valgus, in particular juvenile bunion deformity, has been shown to be high. Many believe that a tight gastrocnemius is independently associated with hallux valgus deformity. Many also believe this to be one of the causative factors of HV deformity [49]. It has also been suggested that Achilles loading can make peroneus longus function less effective in stabilizing the first ray [50]. Therefore, addressing the equinus factor may be important for longevity of successful surgical outcomes in some situations. Yet, this association is not well identified in a controlled study [51]. Equinus can also be a confounder for pes planus and/or the result of first ray instability. Regardless of presence of the association, one should still assess the tightness of the posterior muscle group, as tight posterior muscles can theoretically tighten the plantar aponeurosis and increase forefoot pressure. Extra measures or adjunctive procedures may be necessary to negate this effect.

As many bunions have underlying pes planus, one has to make sure that the foot is in a neutral or slightly supinated position while assessing the ankle range of motion. Breaking down at the subtalar, midtarsal or tarsometatarsal joint can falsely increase the dorsiflexion. Equinus should be assessed with both the knee flexed and extended using Silverskoid test (Fig. 4.18). Presence of metatarsalgia should also alert an examiner as it can be associated with equinus deformity [52, 53].

Pronated Foot

A pronated foot has a strong association with medial column instability and HV deformity. Shibuya et al. showed an association of flatfoot deformity with bunion deformity after adjusting for clinically relevant covariates in both survey data analysis and an observational cohort study [54, 55]. Also, association of spring ligament attenuation with tibialis posterior dysfunction is well established [56]. A lower arch height also has been shown to be associated with first metatarsal pronation in HV deformity [57–59]. Pronation of a foot in many cases in pes planus patients results in pronation of the talonavicular and naviculocuneiform joints. This results in valgus rotation of the first ray. If the pronation is severe and coming from the rear- and/or midfoot, controlling the pronation with a bunion surgery in the first ray may not be adequate. It is therefore important to assess underlying pes planus

Fig. 4.18 Silverskoid test is utilized to assess equinus in both the knee flexed and extended positions

deformity, if present, when planning for surgical correction of HV deformity.

To assess underlying pes planus deformity in HV patients, one should identify the apex of deformity, assess the amount of pronation in the medial column, evaluate reducibility of the flatfoot deformity, identify structures that are attenuated or ruptured and recognize the location of long extensor and flexor tendons. In a typical tibialis posterior dysfunction patient, the navicular is everted in the frontal plane on the talus. In a severe case, the navicular is also often dorsiflexed on the talar head. Otherwise, most of the sagittal plane deformity comes from the NCJ [56]. Excessive surgical plantarflexion of the first ray distal to the joint can therefore further dorsiflex and stress proximally unless an adjunctive procedure or orthotic management is rendered.

Reducibility of a pronated foot can be examined by placing the STJ in a neutral position and plantarflexing the first ray to correct the forefoot supinatus deformity (Fig. 4.19). To identify structures that are attenuated or ruptured, one can palpate the areas of concern. Namely, tibialis posterior tendon, spring ligament and other plantar ligaments of the medial column are typically palpated. Also, the standard single/double heel raise test for tibialis posterior dysfunction can be employed to assess the status of the plantar ligamentous structures. Without a rigid medial column lever arm, heel raise is difficult in patients with pes planus. Inability to perform this test is indicative of plantar ligamentous attenuation or rupture resulting in chronic medial column instability, which also translates into instability of the first ray.

Fig. 4.19 A flatfoot is reduced by placing the subtalar joint in a neutral position and by plantarflexing the first ray

Fig. 4.20 Compensating metatarsus adductus deformity can result in medial column instability and hallux valgus deformity. Often the medial column faulting is found at the naviculocuneiform joint

In a pediatric patient, a surgeon should differentiate physiological pes planus, which is likely to be grown out, from pathological pes planus that is not likely to improve over time. Age of the patient should be noted as flatfeet can continue to improve up to around 12 years of age as femoral external torsion stops. Some pediatric pes planus deformities caused by reasons such as tarsal coalition, vertical talus, neurological and collagen disorders, will not improve over time. A good history taking, range of motion examination and radiographic evaluation are necessary to rule out these conditions.

Metatarsus Adductus

The prevalence of metatarsus adductus is known to be high in patients with HV deformity [60] and correlation between metatarsus adductus and hallux valgus angles have been observed in the past [61]. Underlying metatarsus adductus deformity is thought to make surgical procedures more difficult [62], and recurrence of HV can be more frequent in this group of patients [63]. A general belief is that metatarsus adductus deformity masks the bunion deformity; therefore, aggressive reduction of IM angle is necessary to avoid recurrence. Yet, this relationship has not been extensively studied.

There are many kinds of metatarsus adductus deformities. Broadly, the condition can be categorized into compensating and non-compensating types. Non-compensating metatarsus adductus deformity is generally more rigid and lacks midfoot breakdown. Therefore, the first ray is often more stable and provides more predictable results after surgical correction. More commonly HV deformity is associated with the compensating type. Compensating metatarsus adductus deformity often presents with a medial column faulting with plantarflexion of the navicular and dorsiflexion of the cuneiform (Fig. 4.20). This results in instability of the first ray not only at the NCJ but also at the intercuneiform joints. Range of motion examination is therefore important to rule out arthritic

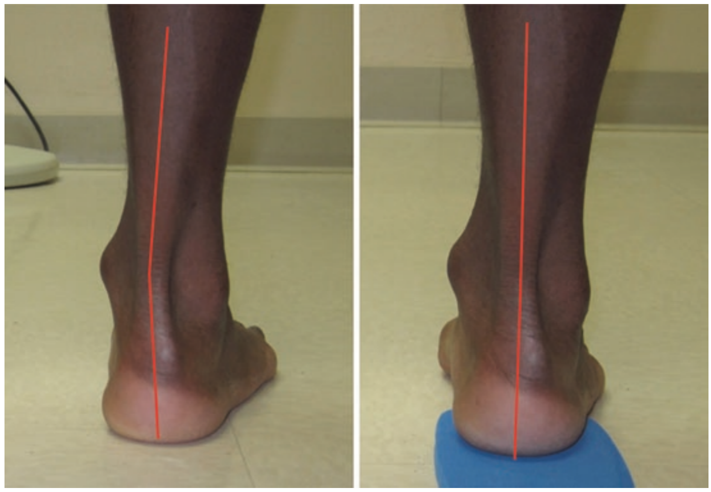

Fig. 4.21 A block is placed under the heel to negate the effect of metatarsus adductus in the forefoot on the overall deformity. In the picture, the calcaneal eversion is corrected by negating the forefoot deformity

changes not only in the first ray but also in the adjacent joints. Lesser tarsometatarsal joints are also common places for arthritic changes in patients with compensating metatarsus adductus. The compensating deformity often presents with forefoot supinatus while the non-compensating one may have forefoot valgus with a plantarflexed first ray relative to the lesser metatarsals. Examination of the forefoot relative to the rearfoot in an open chain in the frontal plane, described earlier, is therefore valuable here. This finding may influence the surgical decision to what type of sagittal plane correction of the first ray is needed. To differentiate compensating versus non-compensating metatarsus adductus deformity, weightbearing examination is also essential. Compensated metatarsus adductus deformity results in pes planus. Lack of medial arch, everted calcaneal stance position, associated symptoms, such as pain along the tibialis posterior, medial arch and sinus tarsi are indicative of the compensating type.

Also, reducibility of the compensated metatarsus adductus is to be assessed. One useful technique is to hang the forefoot while having a patient stand on a block under his/her heels to negate the effect of the forefoot on the overall deformity (Fig. 4.21). If the rearfoot reduces to a neutral position, without the forefoot influence, the deformity is considered to be reducible. This may mean that a forefoot procedure alone may improve the overall deformity without addressing the rearfoot.

Locally in the first ray, the squeeze test described earlier is also employed here. Because of the medially angulated lesser metatarsals, the first ray is often not reducible unless rest of the metatarsals are addressed at the same time. If the IM space is narrow and the first metatarsal has no room to improve in the sagittal plane, this should be observed in both clinical and radiographic examinations prior to surgery.

Conclusions

There are many important findings that can only be provided by clinical examinations. Dermatological, neurovascular and biomechanical examinations are all important for comprehensive evaluation of a bunion deformity. As variability exists among bunion deformities, each deformity needs a specialized clinical examination dependent on its etiology, flexibility, chronicity, joint adaptive changes, underlying deformity and other patient demographic characteristics and psychosocial status. A thorough clinical examination, accompanied by a careful radiographic examination, is critical for selecting optimal procedures for addressing bunion complaints.

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5 Radiographic Assessment

Daniel J. Hatch

Background

There has been a gradual evolution in the radiographic assessment of hallux abducto valgus from purely two-dimensional interpretations to analysis of the deformity in three dimensions. This change to a more complete description of the planar components of the hallux abducto valgus HAV deformity is starting to provide a better understanding of foot anatomy and pathologic deformation. Despite an evolving understanding of the triplane positions and kinematic relationships, the predominant means for evaluation of HAV is the anterior posterior (AP) radiographic view, with the vast majority of measurements and subsequent decisions made based on transverse plane representations. These two-dimensional measurements will be discussed and contrasted with multiplane radiographs which provide a triplane perspective. Also newer methods such as computed tomography techniques will be discussed.

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Two-Dimensional Evaluations

Evaluation of hallux valgus throughout the twentieth century has relied principally on transverse plane angular relationships of the hallux, first metatarsal, second metatarsal, and to a lesser extent the cuneiforms and proximal structures. Using this traditional thought process, the degree of severity is associated with a magnitude of angular measurements. Despite the universality of making these measurements, there is little agreement among surgeons as to the best procedure for optimal correction based on radiographic algorithms. It is interesting to note that despite a wide variety of recommendations for the definition of normal and abnormal and proposals for procedure selection, the majority of these transverse plane radiographic measurements have not been validated. LaPorta et al. [1] discussed the traditional aspects of metatarsus primus adductus angle, hallux valgus angle and distal articular set angle (DASA), proximal articular set angle (PASA), hallux interphalangeal angle, tibial sesamoid position, and joint congruency (Fig. 5.1a, b). Bryant et al. [2] also concluded that HAV was associated with increased metatarsus primus adductus, increased metatarsal width (distance from medial first metatarsal to lateral aspect of fifth metatarsal), and first metatarsal protrusion distance. Condon et al. in 2002 [3] described classic considerations of hallux abducto valgus referencing the intermetatarsal angle as normal (<9°), mild (9–11°),

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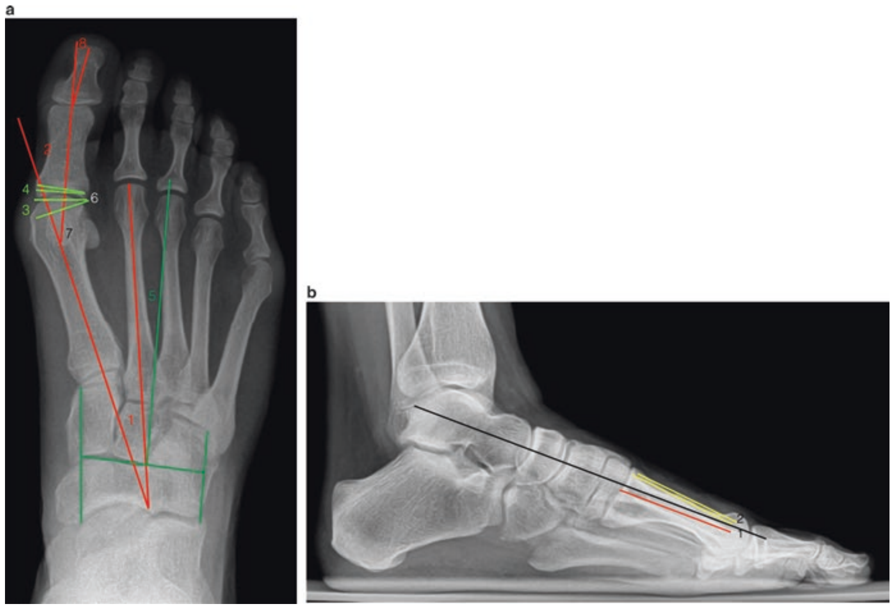

Fig. 5.1 (**a**) Classic AP angles: *1* metatarsal 1–2 angle(IM angle), *2* hallux valgus angle, *3* distal metatarsal angle (proximal articular set angle), *4* distal articular set angle, *5* metatarsus adductus angle, *6* joint congruency, *7* tibial sesamoid position [7], *8* hallux interphalangeus. (**b**) Lateral projection angles: *1* Meary's angle, bisection of talus and first metatarsal; *2* Seiberg index, lines parallel to dorsum of first and second metatarsals

moderate (11–16°), and severe (>16°). Based upon degrees of angle severity, various surgical procedures would be recommended from distal first metatarsal, midshaft, and proximal first metatarsal. Observations such as these have been published repetitively in classic textbooks on hallux valgus [4–8]. The recommendations have taken on an air of truth through repetition and republication. AP radiograph angular relationships are almost universally accepted in foot and ankle surgery despite the lack of evidence to support their role in defining the deformity and choosing the procedure. Taking a more analytical approach, transverse plane radiographic measurements were analyzed by Meyr et al. [9] who set out to look at what we consider as normal and abnormal for transverse plane measurements of intermetatarsal angle (IMA), hallux abductus angle (HAA), and medial sesamoid position (MSP). They concluded that our current definition of normal values for these parameters may not be entirely accurate. The authors proposed well thought out challenges to what we traditionally consider as normal radiographic measurements. Unfortunately, there has been only circumstantial evidence and an abundance of opinion to support the ubiquitous radiographic analysis and subsequent surgical recommendations for HAV, leaving us with a gap in our understanding. The key may be in the multiplane evaluation which we discuss throughout this chapter.

Distal metatarsal articular angle (DMAA) or proximal articular set angle (PASA) is commonly discussed in association with HAV. There is a growing body of data suggesting that this measurement may be a radiographic artifact rather than a true deformity of the distal metatarsal surface. Coughlin and Freund [10] analyzed the intraobserver and interobserver reliability of radiographic assessments of hallux valgus. Their study validated the reliability of the hallux valgus angle and metatarsal 1–2 angles; however, they questioned the reliability of the distal metatarsal angle (DMAA). The common radiographic findings in hallux valgus was found to be the hallux valgus angle, metatarsal 1–2 angle, and sesamoid subluxation in the literature review by Coughlin and Jones [11]. This was later supported by Lee et al. in 2012 [12] who concluded that the hallux valgus angle had the highest reliability and the DMAA, the lowest among intraobserver and intraobserver reliability. However, they did observe that the DMAA did correlate with sesamoid rotation angle. Coughlin and Carlson [13] described angular osteotomies for hallux abducto valgus associated with increased metatarsal 1–2 angle, distal metatarsal angle, and proximal phalangeal articular angle. This at times incorporated a "triple" osteotomy of the first metatarsal base, first metatarsal head, and proximal phalanx.

Richardson et al. [14] described the DMAA (PASA) anatomically and how it varies with hallux valgus deformities. Vittletoe et al. [15] stated that the PASA measurement was unreliable. In 1993, Martin [16] found that the preoperative PASA observe rarely correlated with intraoperative findings. In 2002, Chi et al. [17] questioned the relevance of the DMA and offered that the rotation of the hallux may influence the measurement. Robison et al. [18] found that the linear correlation the DMAA correlated with the amount of frontal plane rotation of the first metatarsal. Dayton et al. [19] found that a reduction of PASA of 18.7° occurred after a tarsometatarsal arthrodesis was performed with frontal plane correction also correlating the measured PASA changes to frontal plane rotation. Jastifer et al. [20] compared radiographic DMAA versus anatomic and found only a 66% correlation. They believed that it was an important factor as it correlated with severity of hallux valgus. As a point of clarification on terminology, the distal metatarsal angle (DMAA) and proximal articular set angle (PASA) are indeed the same measurement and have been used interchangeably to define the metatarsal articular surface angulation. It is clear from analysis of the available literature that the reliability and clinical importance of the distal metatarsal angle is suspect. This is likely because radiographic DMAA/PASA assessment is a two-dimensional observation and is seen to change with the three-dimensional position of the first ray. Additionally, the presence of articular surface angular deformity has not been confirmed by intraoperative observation. The concept of joint congruency was identified by Piggot in 1960 [21]. Joints were classified as either congruous, deviated, or subluxated depending where joint lines intersected from the first metatarsal head and base of the proximal phalanx. This has been associated with adaptation of the joint surfaces which has common sense appeal but has not been shown to occur. It is not clear what the true effect of congruency has on the HAV deformity, and it is interesting to consider the possible effect frontal plane rotation has on this transverse plane radiographic measurement. Taking into consideration the serious questions that exist regarding DMAA/PASA and the changes that are seen with multiplane position, this often quoted radiographic finding may very well be an artifact driven by planar orientation.

Multiple researchers have associated the medial cuneiform shape with the possible etiology and progression of metatarsus primus adductus. In 1960 Lapidus [22] described an angular deviation of the medial cuneiform that has been call "atavistic." This cuneiform shape finding was associated as a possible cause for development of hallux valgus deformity [23]. Vyas et al. in 2010 [24] found that the medial cuneiform obliquity angle was not related to juvenile hallux valgus. Conversely, Burns and Mecham in 2014 [25] pointed out that many theories of hallux valgus have suggested pathology at the metatarsal cuneiform joint; however, not all joint types with hallux valgus had abnormal shaped joints. This was substantiated by Doty et al. [26] who found that the first metatarsal cuneiform mobility was not related to joint shape or medial inclination angle. Saragas and Becker also confirmed that there was no relationship with the first metatarsal cuneiform angle and hallux valgus [27]. Additionally, Hatch et al. [28] found an inverse relationship to the joint obliquity and severity of hallux valgus and concluded that the joint obliquity was a poor indicator of the hallux abducto valgus deformity.

Sagittal Plane Evaluations

Over the past five decades, there has been substantial controversy regarding sagittal plane malalignment and instability of the first ray. Dietze et al. [29] described that in eight patients with "instability," there was a correlation of increased intermetatarsal angle and increased dorsiflexion of the first ray. King et al. [30] described the metatarsal medial cuneiform angle (MMCA) and identified a correlation of increased angle associated with hallux valgus. Roukis and Landsman in 2003 [31] summarized in their literature review that there was no consensus for first ray range of motion. Standard sagittal plane assessment is usually performed by evaluation of Meary's and the Seiberg index and indicated in Fig. 5.1b. This has correlation to sagittal plane range of motion as described by Samimi et al. [32]. Any plantar gapping at the first metatarsal cuneiform joint is also noted (metatarsal medial cuneiform angle) as described by King et al. [30]. They concluded that the pathology of HAV be evaluated by biplanar radiographs evaluating the entire foot complex and not just the forefoot deformities. With regards to clarity, sagittal plane instability is one of the most controversial topics with regard to evaluation and management of HAV.

Sesamoid Position

Another common radiographic measurement recommended for staging of HAV deformity and selecting corrective procedures is the transverse plane tibial sesamoid position (TSP). Like other radiographic measurements discussed, the evidence describing the role sesamoid position plays in the development and correction of HAV has undergone an evolution. While a majority of authors state that sesamoid realignment is critical to overall hallux abducto valgus repair success, the challenge has been in the understanding of the mechanics [7, 33, 34]. In 1951 Hardy and Clapham [35] described the tibial sesamoid position from one to seven with seven being the most severe deformity of hallux valgus (Fig. 5.2).

Fig. 5.2 Hardy and Clapham's seven position tibial sesamoid location on AP radiograph [35]

Early studies focus more on the AP radiographic view. Saragas and Becker [27] pointed out that the sesamoids are fixed and the metatarsal is the component that moves with increased severity. Additionally, Woo et al. in 2015 [36] substantiated that the lateral sesamoid release in surgical repair of hallux abducto valgus alone did not affect sesamoid position. Geng et al. [37] pointed out that the lateral sesamoid doesn't change position relative to the second metatarsal confirming Saragas and Becker's earlier study. Meyer [9] noted that a TSP of one was not observed in their "normal" population calling into question what we define as normal with regard to sesamoid station. A major concern with assessing TSP is whether what we see on the AP radiograph and use to define sesamoid subluxation is indeed accurate. Talbot and Saltzman [38] stated the AP radiographic view doesn't correlate with the axial views. Similar to the medial sesamoid parameters of observed lateral sesamoid position has also been discussed [39, 40]. The effect of metatarsal eversion on the perceived sesamoid subluxation has been widely discussed in the past several years and cannot be discounted.

Kuwano [41] identified sesamoid rotation on axial views and described a sesamoid rotation angle. Further studies have elucidated the importance of frontal plane rotation of the metatarsal and subsequent sesamoid rotation. Dayton et al. [42] observed in their cadaveric study that frontal plane rotation correlated with changes in tibial sesamoid position (TSP) and IM angle. This was also corroborated by DiDomenico et al. in 2014 [43]. The identification of frontal plane rotation of the first metatarsal dates back to DJ Morton [44] and Mizuno et al. [45]. Authors have stressed the importance of getting axial radiographs to assess rotation of the sesamoids [46, 47]. The axial view in conjunction with the AP and LAT radiographic views provide a 3D representation of the first metatarsal and first ray position. Standardization of this view is important as there are many variables. Yildirim et al. [48] illustrated that the amount of dorsiflexion of the first metatarsal-phalangeal joint can affect the sesamoid position. They found that the more dorsiflexion of the joint, the greater tendency to have the sesamoids reduce under the metatarsal head. This was agreed upon by other researchers utilizing computerized tomography (CT) studies [48, 49]. The study by Lamo-Espinosa et al. advocated that the best position to evaluate the sesamoids would be at neutral position with no induced dorsiflexion by CT imaging. Kim et al. in 2015 [50] studied with a semi weight-bearing CT 19 ft without hallux valgus and 166 with hallux valgus. They identified rotation of the metatarsal as the alpha angle (Fig. 5.3). Based upon their findings, they categorized four different groups with hallux valgus sesamoid positions. This incorporated either plus or minus rotation of the first metatarsal (P+, P-) and plus or minus subluxation of the sesamoids (S+ S−) (Fig. 5.4). The class of P-S- was found in 2.4% of the hallux valgus group. P− S+ was present in 12.7%. P + S− was found in 25.9% and P + S+ was found in 61.4%. Total pronation was found in 87.3% and sesamoid subluxation was exhibited in 71.7%. Ideally neutral position CT studies should be evaluated in all patients with hallux abductovalgus. At the very least the evaluation of the sesamoid complex should be done with axial (coronal) radiographic views. Because of the variability discussed, further standardization of this method needs to be performed in the future.

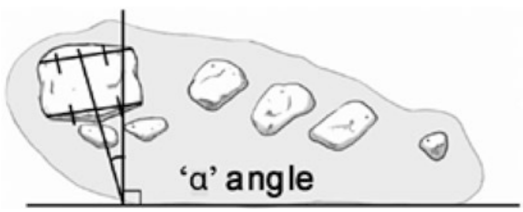

Fig. 5.3 Kim et al. [50] alpha angle

Critique of Standard Assessments

As can be seen by review of the studies presented, traditional radiographic assessments of hallux abducto valgus have been frequently criticized in literature and have little scientific validation. Of all

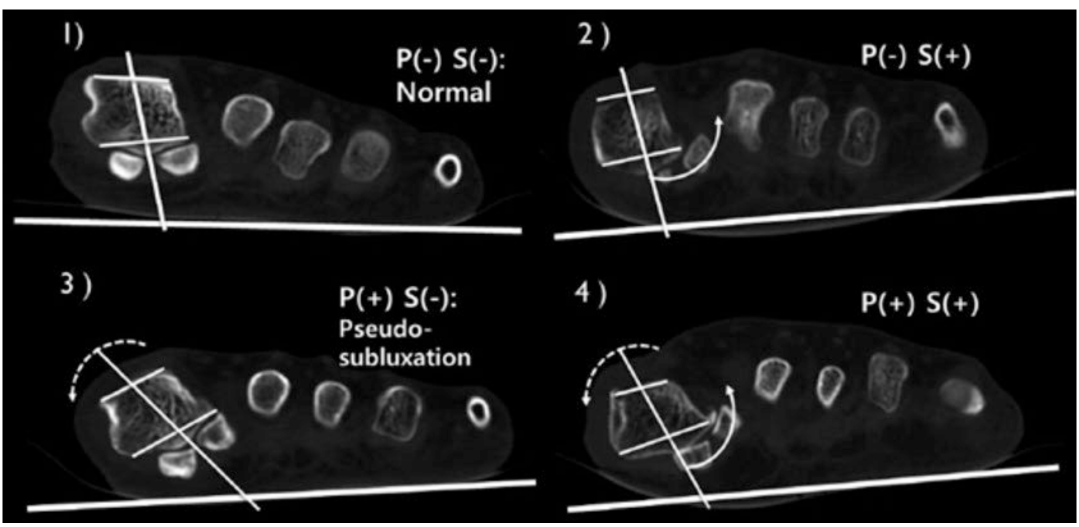

Fig. 5.4 The four classifications of Kim et al. [50] regarding rotation and sesamoid subluxation

the angular measurements that have traditionally evolved, the only ones that have held up to critical analysis in recent literature and have proven reliable are the hallux valgus angle, metatarsal 1–2 angle (also known as intermetatarsal angle (IMA), and the sesamoid position. Even attempts at augmentation with computerized assessments have failed. Various authors have questioned the intra- and interobserver reliability of standard manual radiographic assessment [51–53]. Computerized augmentation of measurements has been advocated as more reliable than manual methods [54–56]. Panchbhavi and Trevino [57] recommended computer-assisted radiographs measuring the width of the forefoot pre- and postsurgery. Ege et al. [58] advocated the use of iphone® software for evaluation of the HVA, IMA, and DMAA. Whatever the method, there is still a lack of interobserver reliability of these measurements. Certainly, more studies are needed to further delineate the pathomechanics of HAV.

The Effect of CORA on Our Understanding of the Deformity

The center of rotation angulation (CORA) as described by Paley [59] identifies the apex of the deformity. This may be done by means of the anatomic axis or mechanical axis. The anatomic axis is the bisection of the mid-diaphyseal osseous segments. This traditionally is the way the intermetatarsal angle (metatarsal 1–2 angle) is evaluated. Ortiz et al. [60] described an "angle to be corrected" utilizing the anatomic axis of the first metatarsal and the "predicted" anatomic axis. The mechanical axis is the line connecting the midpoint of the joint articular surfaces of the segment. Dayton et al. [61] identified the anatomic axis of the first ray to be the first metatarsal cuneiform joint (Fig. 5.5). The angular correction axis (ACA) is the chosen point of the surgical correction. If the ACA does not correlate with the CORA, then secondary deformities may occur. The anatomic CORA of the first ray is at the first metatarsal cuneiform joint. This was substantiated by Tanaka et al. [62] in their mapping study of hallux valgus.

The mechanical axis of the first ray may also be evaluated. This has range from the spherical midpoint (Mose Sphere) as advocated by Coughlin et al. [63] to the evaluation of hallux abducto valgus by the mechanical axis of the first ray by LaPorta et al. [64]. Even though that this evaluation hasn't yet been validated, they found that the normal mechanical axis of the medial column and the mechanical axis of the first ray to be 11°.

One major issue in the assessment of postoperative repair of hallux valgus is the inaccuracies of using dual measurements. Hardy and Clapham [35] described the angle formed by the axis of the first and second metatarsals as an indicator for hallux valgus severity. Even though this is frequently utilized and attempted, there are many

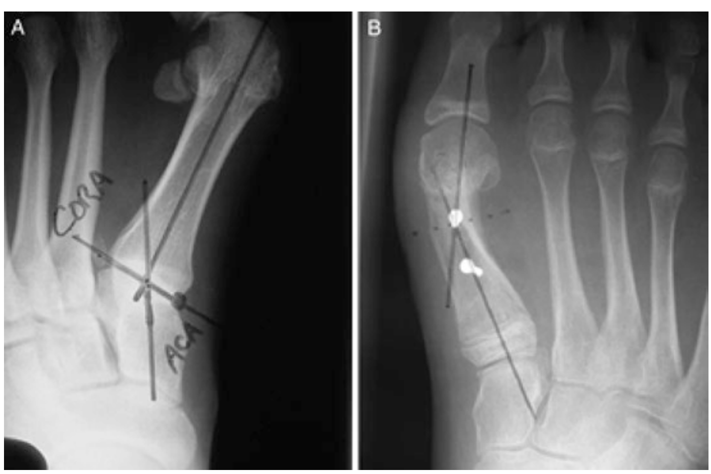

Fig. 5.5 (**a**) CORA of first ray. (**b**) New CORA if ACA is not at original CORA [61]

errors in this process [63]. One must keep in mind Paley's deformity of correction principles to assess pre- and postoperative results. A common error is to identify preoperative anatomic metatarsal 1–2 angles and compare result with postoperative mechanical axis angles (Fig. 5.6a, b, c). Smith et al. [65] reported that the postoperative IM angles didn't improve much after distal metatarsal procedures. With distal metatarsal procedures, Coughlin et al. recommended using a center of head technique with a Mose sphere [63]. The effect that this measurement technique has on postoperative results is discussed in further detail in chapter seven.

Weight-Bearing CT Scanning

Two-dimensional studies have provided some insight into the pathology of hallux abducto valgus [66–68]. We must further look into the three-dimensional structure and kinematics of the first ray and it's components. Historically we have gained some insight into the 3D nature of the deformity by comparing multiplane radiographic views. These relationships are being clarified with the advent of weight-bearing and semi-weight-bearing CT scanning. Scranton and Rutkowski's study utilized axial sesamoid views to observe the position of the metatarsal [66]. They found feet with bunions had a mean of 14.5° of metatarsal pronation (eversion) versus the normal group having 3.1° of eversion. Mortier et al. [67] also used the axial views and found an average of 12.7° eversion of the metatarsal in the hallux abducto valgus group. Further support for the presence of first metatarsal rotation was identified on two-dimensional radiographs by Okuda et al. [69]. They found that the rounding of the lateral head of the first metatarsal was indicative of first metatarsal pronation/eversion. This was later confirmed by the study of Yamaguchi et al. in 2015 [70]. Additionally, the lateral bowing of the first metatarsal was thought to be a radiographic artifact caused by eversion of the first metatarsal segment making it appear more curved and present with cortical thickening [71].

Three-dimensional computed tomography (CT) has evolved to provide more insight into the pathomechanics of hallux valgus. More recently with the aid of technologic advances, Collan et al. [72] reported on the use of weight-bearing 3-D CT evaluating patients with hallux valgus [10] to a control group [7]. While not found to be

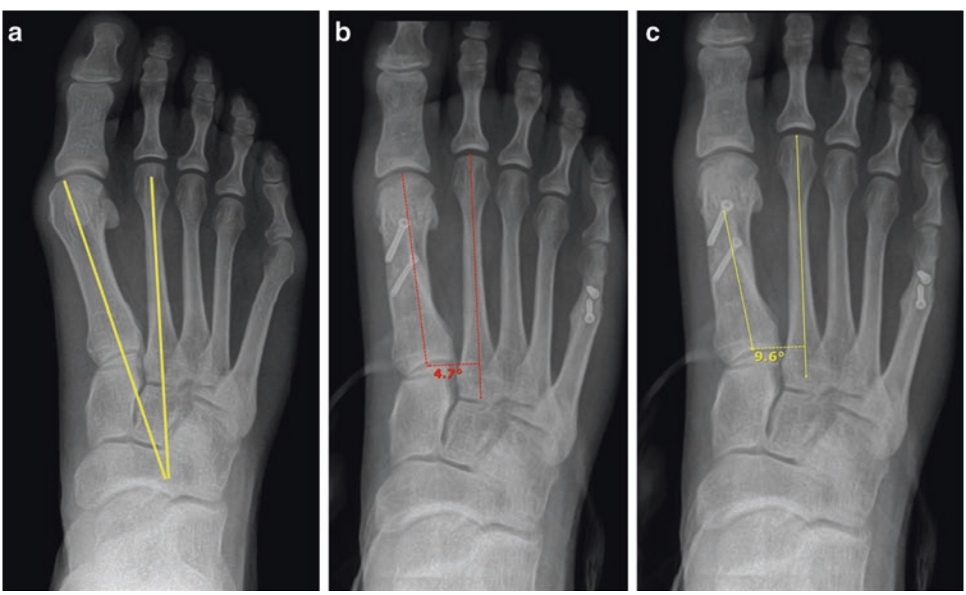

Fig. 5.6 (**a**) Preoperative AP assessment with IM angle of 17º. (**b**) Post operative AP assessment using the mechanical axis. IM angle is 4.7º. (**c**) Post operative AP assessment of anatomic axis of 9.6º. Clearly, the method utilized will change the perceived results of correction

statistically significant, they found that the amount of first metatarsal rotation of the hallux valgus group was 8° everted versus the control group of 2°. They found that the cuneiform was rotated into valgus to a greater degree than the first metatarsal although they were both rotated. One methodological issue that may confuse their findings is the fact that while the scans were taken weight bearing, the patient was in single-leg stance, not in functional angle and base of gait. This fact alters the overall kinematic relationships because in single-leg stance, the weight-bearing extremity is externally rotated inducing supination of the foot. Geng et al. [73] found that the medial cuneiform was more everted than the first metatarsal in the hallux valgus group. Their study utilized weight-bearing CT. Kim et al. in 2015 [50] utilized semi weight-bearing CT in their study of 19 control feet versus 166 ft with hallux valgus. They found a high incidence of first metatarsal pronation of 87.3% in the hallux valgus group. The amount of pronation averaged 15.8°. Their study also supported the findings by Smith et al. [65] regarding the amount sesamoid subluxation from the first metatarsal head stages 0–3. Lamo-Espinosa et al. [49] found in normal subjects (no HV deformity) that the CT appearance of the sesamoids was zero according to the classification of Yildirim et al. [48]. Katsui et al. [74] discussed a direct correlation of sesamoid displacement with increased severity of hallux valgus and arthritic changes. Kimura et al. [75] studied 10 ft with hallux valgus and ten normal feet with a simulated weight-bearing CT using 3-D computer analysis. They supported Geng et al. findings of increased valgus rotation of the medial cuneiform in hallux valgus patients. They also found that the navicular was more in a valgus position, while the first metatarsal relative to the cuneiform was slightly inverted in the hallux valgus group.

It is certain that the use of weight-bearing CT will provide more information on hallux abducto valgus. It is understood that the particular image only shows a certain osseous segment and not the entire foot. When we reference pronation/eversion of the metatarsal, it is in reference to the area of study and not the entire segment or ray. Care must be taken to realize that the genesis has yet to be fully identified and that the CORA and segment rotation may occur more proximally than at the metatarsal cuneiform articulation.

Future Radiographic Considerations

Historical classification systems for hallux abducto valgus have mainly been expert opinion and low levels of evidence. These have been well summarized in Deenik et al.'s [76] review in 2015 who summarized findings from common radiographic measurements and found the only reliable criteria was the hallux valgus angle (HVA). Garbuz et al. [77] stressed the importance of a valid classification system that has both intraobserver and interobserver reliability. Since 2013 we have seen an emergence of papers that have utilized WB CT studies. This has helped us understand the pathomechanics of hallux abducto valgus. These studies have reminded us to think in three dimensions and reminded us more of the frontal plane component of hallux abducto valgus. Further research using CT and magnetic radiographic imaging (MRI) in a dynamic fashion will help elucidate the pathogenesis of hallux abducto valgus. This will include joint anatomy, foot mechanics, and the influence of tendon vectors.

With the advent of three-dimensional technology and other anatomic research, a group of researchers have proposed a new classification system known as the PVB classification for hallux abducto valgus assessment [78] (Fig. 5.7). The uniqueness of this system is the lack of historical references to angular severity of the deformity. It is based upon surgical CORA and the correctional axis of the deformity. It also takes into account if pronation/eversion of the metatarsal segment (first ray) exists. Preoperative three-dimensional assessment is done utilizing at least AP, lateral, and axial projections. No metatarsal rotation is found in class one and is amenable to shaft and base procedures for repair. In class two rotation is apparent and may exist with or without sesamoid subluxation. Derotational procedures are performed with or without lateral sesamoid release. Class three identifies the unique attributes of metatarsal adductus that need to be addressed to achieve optimal results. Lastly, class

Triplane hallux valgus classification & treatment algorithm			
Class	**Anatomic findings**	**MTP joint status**	**Treatment recommendation**
1	Increased HVA and IMA **No first metatarsal pronation evident on AP and Sesamoid axial Radiograph** Sesamoids may be subluxed.	No clinical or radiographic evidence of DJD	Transverse plane corrective procedure +/-Distal soft tissue procedures
2A	Increased HVA and IMA **First metatarsal pronation evident on AP and Sesamoid Axial Radiograph** No sesamoid subluxation on Axial	No clinical or radiographic evidence of DJD	Triplane correction with first metatarsal supination/inversion
2B	Increased HVA and IMA **First metatarsal pronation evident on AP and Sesamoid Axial Radiograph** With sesamoid subluxation on Axial	No clinical or radiographic evidence of DJD	Triplane correction with first metatarsal supination/inversion + Distal soft tissue procedures
3	Increased HVA and IMA >15 degrees MTA	No clinical or radiographic evidence of DJD	Metatarsal 2 and 3 transverse plane correction. Followed by 1st metatarsal correction per class 1 & 2 recommendations
4	Increased HVA and IMA +/-First metatarsal pronation	**Clinical and or radiographic evidence of DJD**	First MTP arthrodesis

Fig. 5.7 Triplane hallux valgus classification and treatment algorithm

four incorporates arthrosis of the first metatarsal-phalangeal-sesamoid complex. Surgical procedures to address this condition are recommended. The goal in this system is to provide the three-dimensional aspects of hallux abducto valgus and to provide improved long-standing outcomes for repair considerations.

Further research is imperative for our understanding of the pathogenesis, pathomechanics, and imaging assessments of hallux abducto valgus. Continued use and teaching of radiographic measurements that may not provide reliable basis for diagnosis and procedure selection must be questioned by surgeons using all available tools and with the freedom to question current concepts ingrained through the process. We must not feel compelled to accept the status quo and traditional concepts. Only through more critical discussion of current ideas will we discover the best methods to evaluate this complex deformity and thereby provide optimal and reliable patient outcomes.

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6 Clinical and Surgical Implications of First Ray Triplane Deformity

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In a bunion deformity, the fundamental problem is a deviation of the hallux at the metatarsophalangeal joint (MTPJ) and deviation of the first metatarsal at the tarsometatarsal joint (TMTJ) from their normal positions. While one plane, namely, the transverse plane, may appear to dominate, there is typically at least some degree of movement in all three planes: the transverse, sagittal, and frontal. This observation is very important when one considers that the most prevalent methods recommended to correct the deformity (metatarsal osteotomy) are in fact altering a deviated but intrinsically straight metatarsal. The starting point for understanding hallux abducto valgus (HAV) deformity, like any bone deformity, is a definition of the point of misalignment of the bone segments, which has been described by many surgeons and researchers [5, 9, 26, 36, 39, 49, 51].

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The apex of the deformity can be defined using the center of rotation angulation (CORA) concept described by Paley [40]. Using this accepted deformity mapping concept, the level of deformity is determined to be at the first TMTJ, and we consider the TMTJ to be the starting point for understanding the pathomechanics of the deformity. Mapping the deformity at the anatomic CORA requires bisection of the mid diaphysis of the first and second metatarsals and comparison of these anatomic axes to the medial cuneiform and proximal phalanx of the hallux. Others [30] have suggested a mechanical axis for the deformity that can be mathematically mapped to a location proximal to the TMTJ. Whether the CORA is anatomically at the TMTJ or defined mechanically at a point proximal is currently a subject of study, however, it is clear that the deformity does not reside distally within the metatarsal (Fig. 6.1).

The next important consideration when describing the anatomy of the deformity is understanding the individual planar components of the deformity. Typically surgeons rely on an anterior-posterior (AP) radiograph almost entirely to define the deformity by measuring the intermetatarsal angle (IMA), hallux valgus angle (HVA), tibial sesamoid position (TSP), and the joint surface angle known both as distal metatarsal articular angle (DMAA) and proximal articular set angle (PASA). It must be pointed out that these are all two-dimensional observations which define only the transverse plane components of the deformity. To identify and characterize the

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Fig. 6.1 (**a**) Mapping of the *CORA* for first metatarsal transverse plane deviation component of HAV deformity. The metatarsal has no intrinsic angular deformity but is deviated from its normal orientation relative to other first ray components. Although this may not represent the true mechanical axis definition for the first ray, it represents the anatomic axis definition of the deformity and the site of correction to realign the first metatarsal. (**b**) The degree of IMA does not change the actual level of the deformity and in reality does not define the deformity despite the common convention of assigning procedure choice based on IMA

other planar components of the deformity (frontal and sagittal), we must look at different landmarks, and it is very helpful to look at the anatomy on axial radiographic projection as well as the lateral radiographic view. Though it's also important to understand that since the AP radiograph is a two-dimensional projection of the three-dimensional anatomy, an out-of-plane deformation, such as frontal plane rotation of the first metatarsal, can substantially change several visible cues on the AP radiograph, and we will discuss the effect rotation has on each of the common radiographic findings.

The practice of preferentially considering the transverse plane of the deformity by relying primarily on AP radiographic measurements gives an incomplete understanding of the deformity and in our opinion is one of the main factors driving poor outcomes and recurrence. If we analyze the majority of the most popular osteotomy procedures, it is clear that correction priority is in a single plane (transverse) with most procedures either angulating or sliding the first metatarsal in the transverse plane while failing to address either the frontal or sagittal planes to a meaningful degree. Despite the published description of the frontal plane component of the first ray deformity dating to the 1950s [35], it has not been common to address this component of the deformity in a bunion operation. Recently there is a renewed interest in the frontal plane position of the first metatarsal and sesamoid alignment, and there are many current publications illustrating the effect frontal plane rotation has on common paradigms of preoperative bunion evaluation and the selection of the corrective procedure. In these studies frontal plane rotation has consistently been observed to be in the direction of eversion (valgus or pronation are equivalent) and has a significant and dramatic effect on the alignment of the first MTPJ including the sesamoids (Fig. 6.2).

Scranton and Rutkowski [47] presented a series of sesamoid axial radiographs to observe the position of the metatarsal. They found feet with bunions had a mean of 14.5° of metatarsal pronation (valgus orientation), while normal feet had a mean of 3.1° of valgus metatarsal orientation. They concluded that the three structural deformities present in a bunion must be corrected: the abducted hallux, the adducted metatarsal, and the pronated or valgus metatarsal position. Mortier et al. [36] also used sesamoid axial radiographs to observe the position of the

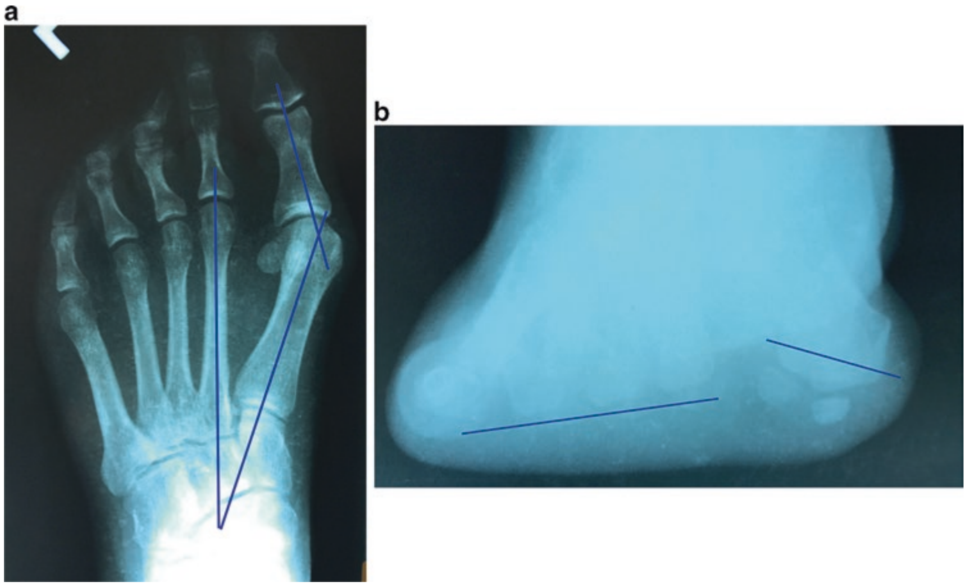

Fig. 6.2 (**a**) The AP radiograph shows typical transverse plane angular findings commonly used for decision-making regarding procedure choice (IMA, HVA, TSP). This view shows a TSP of V. (**b**) Semi-weight-bearing sesamoid axial view clearly showing the sesamoids in their normal anatomic location medial and lateral to the crista. Frontal plane eversion of the first metatarsal relative to the plane of the lesser metatarsals gives the appearance of sesamoid subluxation on the AP view when the sesamoids are in reality in normal alignment relative to the metatarsal head

metatarsal in a bunion deformity. Their novel method of both patient position and measurement showed a mean of 12.7° of metatarsal pronation in feet with bunion deformities. They concluded this rotation was due to metatarsal cuneiform instability rather than torsion of the metatarsal shaft and that valgus metatarsal rotation in bunion deformities is systematic. Eustace et al. [13] devised a way to measure pronation of the first metatarsal based on the observation of the location of the inferior proximal tuberosity of the first metatarsal base. The lateral translation of the tuberosity that takes place with metatarsal pronation or valgus position was established in a cadaveric study. They found that the degree of first metatarsal pronation has a linear relationship to the amount of medial deviation of the first metatarsal. They concluded that derotational surgical procedures should be further explored (Fig. 6.3).

Recent computed tomography studies have clarified the position of the first metatarsal in the frontal plane then in normal and bunion feet. Collan et al. [3] first reported on the use of weight-bearing 3-D CT on hallux valgus patients and found that pronation (valgus position) of the first metatarsal and proximal phalanx existed in all ten patients with hallux valgus. While not found to be statistically significant, they found that the amount of first metatarsal rotation of the hallux valgus group was 8° everted versus the control group of 2°. They found that the cuneiform was rotated into valgus to a greater degree than the first metatarsal although they were both rotated. One methodological issue that may confuse their findings is the fact that while the scans were taken weight bearing, the patient was in single leg stance, not in functional angle and base of gait. This fact alters the overall kinematic relationships because in single leg stance, the weight-bearing extremity is externally rotated inducing supination of the foot. Kim et al. [25] evaluated 166 ft with hallux valgus versus 19 normal control feet utilizing semi-weight-bearing 3-D CT analysis and measured the amount of first metatarsal rotation, which they referred to as the α angle. This angle, representing first metatarsal pronation, averaged 21.9° in their hallux valgus group versus 13.8° in the control

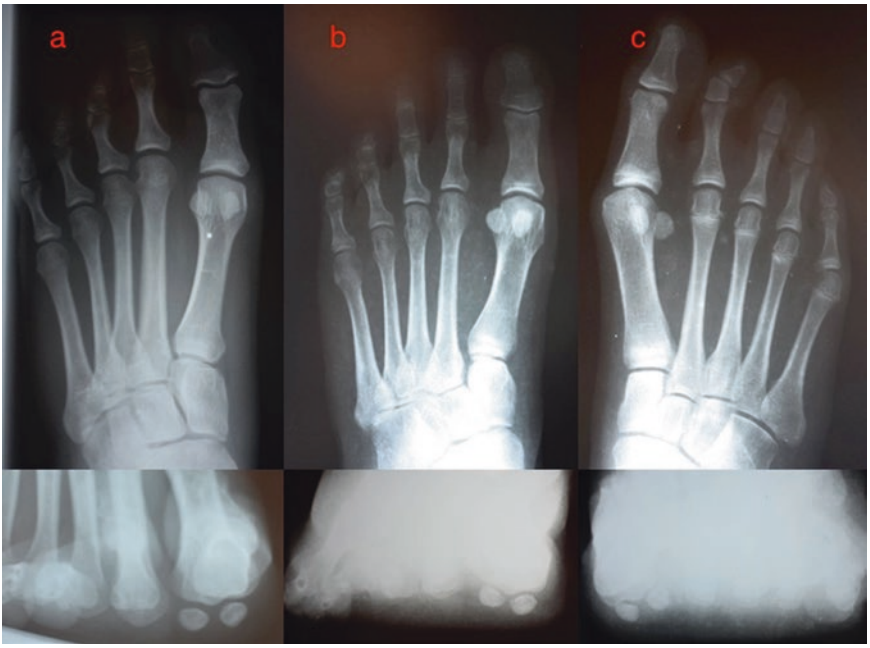

Fig. 6.3 AP and sesamoid axial views of three patients. (**a**) Normal alignment of bone segments used to diagnose HAV and corresponding normal frontal plane rotation of the first metatarsal. (**b**, **c**) Patients with HAV showing the AP and sesamoid axial alignment. Note the easily visible eversion of the first metatarsal in the frontal plane relative to the lesser metatarsal plane

group. They concluded that the first metatarsal pronation in subjects without hallux valgus is typically less than 15.8°, and that pronation higher than 15.8° is abnormal (Fig. 6.4). Kim and colleagues [25] further identified four groups based on the presence of either pronation of the first ray (87.3% of patients) and/or subluxation of the sesamoid (71.7% of patients) (Fig. 6.5). We also have data to suggest that in a foot without HAV, the first metatarsal and/or the first ray are neither pronated or supinated. Lamo-Espinosa et al. [29] found that in normal subjects, the CT appearance of the sesamoid complex showed no subluxation and minimal metatarsal rotation. The utilization of computerized tomography will provide further three-dimensional information to help elucidate the pathomechanics of hallux valgus. A more detailed analysis of CT studies is discussed in Chap. 5.

It is clear that a bunion is in reality a triplane deformity with components in the transverse, sagittal, and frontal planes. Despite this anatomical fact, the most commonly accepted paradigm for the correction of a bunion employs transverse plane metatarsal and, to a lesser extent, hallux osteotomies to reposition the metatarsal in the transverse plane only. Osteotomies must almost universally be combined with lateral capsular release and medial plication to reposition the sesamoids under the metatarsal head which cannot be achieved with osteotomy alone in most cases. The common practice of transverse plane metatarsal osteotomy does not fully address the deformity, and it is not performed at the CORA (which is proximal to the metatarsal), both of which are believed to be principal factors in the high recurrence rates that have been identified with metatarsal osteotomy as discussed in the next chapter (Fig. 6.6).

At this time, we do not know the exact anatomic site of the frontal plane rotation. That is, whether it is occurring at the TMTJ or at a site proximal. Most likely it is occurring at a combination of joints similar to sagittal plane mobility of the medial column which is well known to occur at multiple joints along first ray including the naviculocuneiform joints, talonavicular joint, and to a lesser extent the TMTJ. Studies by

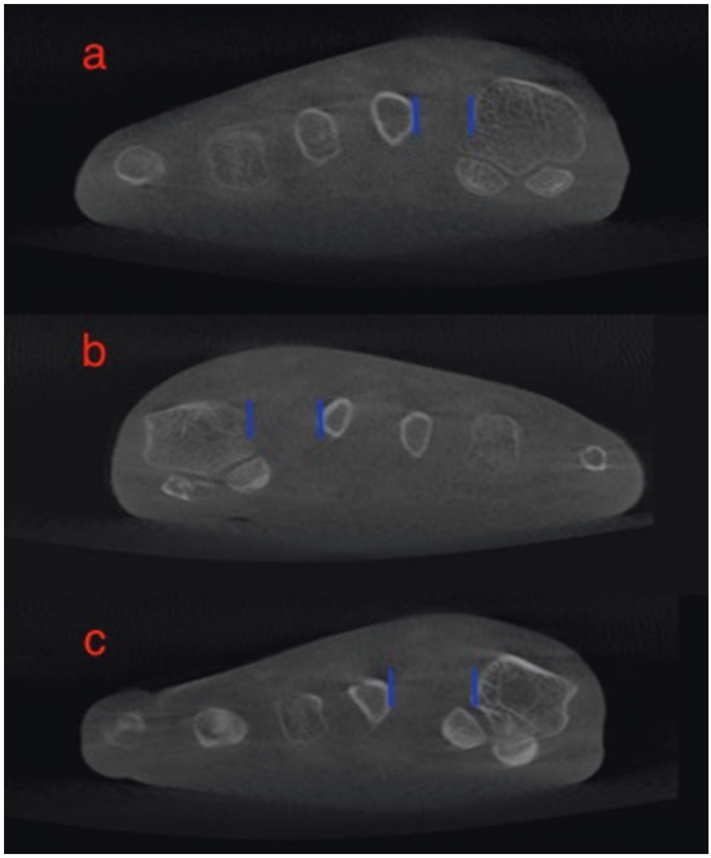

Fig. 6.4 Weight-bearing CT scan views of three patients with hallux valgus deformity (**a**) Patient with small increase in IMA with minimal to no eversion of the first metatarsals. (**b**) Patient with moderate increase in IMA with notable eversion of the first metatarsal relative to the lesser metatarsals. (**c**) Patient with a large increase in IMA again clearly showing eversion of the first metatarsal relative to the lesser metatarsal plane

Johnson and Christensen [20] and Dullaert et al. [11] provide insights into both the frontal plane position of the medial column and the mobility present. Using different models both groups showed in a weight-bearing foot, activation of the peroneus longus tendon pulls the first ray into eversion. Dullaert et al. [11] further stated that if this frontal plane mobility was not controlled through TMTJ fusion for correction of HAV that there is a concern for persistent frontal plane deformity. This phenomenon is a potential cause for poor results and recurrence as discussed in Chap. 7.

Effect of Rotation on Sesamoid Position

From our observations and from available literature, it is clear that radiographic tibial sesamoid position can largely be influenced by metatarsal frontal plane rotation rather than solely an observation of the metatarsal moving off of the sesamoids in the transverse plane [1, 6, 7, 19, 48]. In reality, both frontal plane rotation and transverse plane deviation of the first metatarsal produce the positional components of the bunion deformity. Two-dimensional radiographic findings are directly influenced by the three-dimensional deformity.

Several studies have demonstrated a correlation between the degree of sesamoid displacement observed on AP radiographs and the transverse plane severity of the bunion deformity [22, 34]. Discussion of this correlation often includes the observation that there is a constant position of the sesamoids in relationship to the second metatarsal [16, 17, 22, 42, 46] as well as the proximal phalanx to the second metatarsal [26]. The constant relationship of the sesamoid position in the transverse plane lends itself to a proposed process where the first metatarsal slides medially off of a stable and stationary sesamoid apparatus that is tethered in place via ligamen-

Fig. 6.5 Two patients with HAV and eversion of the first metatarsal relative to the plane of the lesser metatarsals. (**a**) No sesamoid subluxation from the normal position medial and lateral to the crista. (**b**) Everted first metatarsal starting to sublux medially off of the sesamoids with the medial sesamoid now partially on the crista

tous and tendon attachments. However, it is important to understand that the appearance of the sesamoids on AP radiograph is not always indicative of their actual position in relation to the median crista and the bisection of the metatarsal shaft through the median crista. Frontal plane rotation of the first metatarsal can significantly alter what is seen on the AP radiographic projection. The pronated or valgus position of the metatarsal can give the false appearance that the metatarsal head has migrated off of the sesamoid complex and that the fibular sesamoid resides in the interspace when in many cases the sesamoids are still positioned correctly medial and lateral to the median crista of the rotated plantar first metatarsal head (Figs. 6.3 and 6.4).

Inman [19] used a combination of models and radiographs to show that in a valgus or pronated metatarsal position, the sesamoids appear to deviate laterally in an AP radiograph. However, the comparison of sesamoid axial radiographs to their AP counterparts show the sesamoids are still found in their anatomic positions (in their grooves and separated by the median crista) despite their appearance of lateral translocation. Boberg and Judge [1] make the same observation after bunion correction without interspace release. In the majority of their cases, the preoperative AP radiographs showed apparent deviation of the sesamoids, and the sesamoid axial failed to confirm the sesamoid displacement. They explained that the apparent subluxation of the sesamoids is due to an oblique rotation of the metatarsal head much the way that a medial oblique radiograph shifts the perspective making structures appear more lateral. The authors called into question the use of AP radiographic sesamoid measurement as a tool of bunion assessment. Talbot and Saltzman [48] came to a similar conclusion regarding the use of AP radiographs to evaluate sesamoid subluxation. They found that sesamoid position as estimated from AP radiographs did not correlate to the actual sesamoid position when viewed using a tangential

Fig. 6.6 (**a**) Patient who had a sliding osteotomy without correction of frontal plane eversion. The sesamoids are not aligned in the sagittal plane, and therefore the forces exerted by pull of the long and short flexors on the everted sesamoids are angular and pull the hallux into valgus and abduction. There is a medial force exerted by the hallux on the first metatarsal driving increased IMA and recurrence. (**b**) In the normal state the movement of the sesamoids and the hallux are predominantly in the sagittal plane without abnormal angular forces induced by metatarsal and sesamoid rotation

view, a term synonymous with sesamoid axial. The difference between the observations could not be accounted for by changes in MTPJ positioning while obtaining the sesamoid axial view. Because of the valgus (pronated) position of the metatarsal, measurement models based on AP radiographs are not valid in assessing true sesamoid position. These studies are corroborated by a cadaveric study by Dayton et al. [6], in which the first TMTJ was freed and the metatarsal was moved into various degrees of inversion and eversion. With eversion (pronation) of the metatarsal, there was the appearance of lateral displacement of the sesamoids on AP radiograph. With inversion (supination) the apparent sesamoid position was corrected. In this study, the metatarsal clearly did not move off of the sesamoid apparatus, rather rotation altered what was observed on AP radiographs.

Because they recognized the difficulty in assessing sesamoid position from an AP radiograph, Kuwano et al. [28] devised a measurement used to observe sesamoid position on tangential or axial radiographs. Not only did they find a correlation to the degree of HAV and the valgus (pronated) position of the sesamoid apparatus, but they also found the AP assessment of sesamoid subluxation was inadequate to assess true sesamoid position. These results also support the observations from Dayton et al. [6], DiDomenico et al. [9], and Mizuno et al. [35] that varus (supination) rotation imparts correction of sesamoid position on AP radiographs when the coronal plane valgus (pronated) position of the metatarsal is addressed. Kim et al. [25] identified both rotation of the first metatarsal and sesamoid subluxation on CT scans of HAV patients. Both states can exist in isolation and in combination. The striking finding is that, in many cases, the AP radiographic views do not accurately define the position of the sesamoids and thus AP x-rays cannot be reliably used to identify sesamoid subluxation. Obtaining axial views of the sesamoid complex is a necessary and vital part of evaluation

Fig. 6.7 Progressive deviation of the hallux first metatarsal and sesamoids after correction with metatarsal osteotomy and capsular balancing. Note the increase in the HVA, IMA, and apparent re-subluxation of the sesamoids. The axial clearly shows the sesamoids have returned to their normal positions medial and lateral to the crista driving the recurrence

and management of the complex triplane deformity of HAV. Similarly, Katsui et al. [24] found a direct correlation of sesamoid displacement with increased severity of hallux valgus and arthritic changes.

If the pronated or valgus metatarsal is a consistent reason for perceived deviation of the sesamoids, what is really taking place with transverse plane translational osteotomies that produce the appearance of restored sesamoid position in AP radiographs immediately post procedure? In the case of a sliding osteotomy that corrects the IMA but cannot produce inversion (supination) rotation to correct frontal plane position of the metatarsal, we hypothesize that iatrogenic subluxation of the sesamoids medial to the median crista creates the perception that the sesamoids are correctly positioned under the metatarsal on the AP radiograph. This occurs after the lateral release and during the medial capsular plication. An additional explanation is that in some cases a degree of frontal plane correction takes place spontaneously when retrograde buckling forces of the hallux acting on the metatarsal are relieved. If the appearance of sesamoid correction is a result of iatrogenic medial subluxation, then the position on AP radiograph would not be maintained over time. The sesamoids would appear corrected on the postoperative film due solely to the lateral soft tissue release and medial soft tissue plication, but over the ensuing months, the sesamoids would find themselves returning to their anatomic position in the sesamoidal grooves, which are still rotated in a valgus (pronated) orientation. This lateral drift, which is in reality resumption of normal position relative to the metatarsal head, is due to the plantar soft tissues including the short and long flexor tendons resuming their linear orientation after joint motion resumes and therefore pulling the sesamoids back to their anatomic location under the metatarsal head, which is still in a rotated position. This sesamoid position relative to an everted metatarsal would mean recurrence of a displaced

Fig. 6.8 Pre- and postoperative AP and sesamoid axial radiographs of a patient who had correction with included inversion of the first metatarsal in addition to transverse plane angular correction completing triplane realignment and normalizing the forces exerted on the hallux and first metatarsal

appearance of sesamoids on an AP radiograph. Though immediately postop sesamoid position would be predictable and within control of the surgeon via soft tissue balancing, long-term maintenance of this position would not be predictable nor under control of the surgeon as the pathologic position of the metatarsal causing the appearance of subluxation has not been addressed. This would also produce deforming forces from the hallux proximal to the metatarsal because of the lateral position of the sesamoids and tendons as described by Mortier (2012) and can result in recurrence of both the HAV and increased IMA (Fig. 6.7). Thus, if frontal plane metatarsal pronation is present as a component of the deformity (PVB Class 2A or 2B, described in Chap. 5), it must be addressed by the corrective procedure to achieve full anatomical correction of the metatarsal sesamoid complex (Fig. 6.8).

Effect of Rotation on the Appearance and Function of the First MTPJ

Grode and McCarthy [18] looked at an axial representation of the foot through cryomicrotomy rather than radiographs. They sectioned cadaveric feet in multiple planes and at multiple levels in varying degrees of bunion severity. They observed that the position in the medial eminence or “bump” actually represents the dorsomedial surface of the head of the first metatarsal that is “brought into prominence by rotation through eversion.” The frontal plane sections of HAV deformities confirmed the metatarsal head is oriented in eversion, a term synonymous with both pronation and valgus in the literature. In a study looking at the medial eminence in bunion and non-bunion feet, Thordarson and Krewer [50] observed that when comparing bunion and normal feet, there was no statistically significant difference in the width of the medial eminence. Their finding was that the average medial eminence in bunions is 4.37 mm and in non-bunions is 4.14 mm concluding that if the goal of bunion surgery is to reconstruct normal anatomy, then medial eminence resection does little to help as there was no significant eminence present. This study was performed prior to the greater acknowledgment of frontal plane rotation, and they did not make an association with frontal plane rotation.

A similar study was performed by Lenz et al. [31], using the same measurement of medial eminence width, they analyzed bunion and non-bunion feet. They found the width of the medial eminence in bunions is statistically different with a mean of 4.40 mm in bunions and 3.28 mm without. Their measurement of medial eminence width of 4.40 mm in a bunion was nearly identical to Thordarson (4.37 mm). However the control group was 3.28 mm versus 4.14 mm measured by Thordarson. A possible explanation for this finding is the effect of metatarsal pronation making the medial head more prominent on AP radiograph. Assuming that the first metatarsal head is more square than circular, when the metatarsal rotates in the frontal plane, the width of the head would enlarge on the AP radiograph. While no study has measured the frontal plane rotation and compared it to medial eminence width, a linear correlation between the two could explain the difference between these two studies (Fig. 6.9).

DiDomenico et al. [9] described a procedural approach to multiplanar bunion correction using the hallux to drive derotation of the valgus metatarsal via ligamentotaxis. As the hallux was moved in a supinated or varus direction, the metatarsal followed. This in turn aligned the metatarsal phalangeal joint reducing the HVA, sesamoid position, and the proximal articular surface angle (PASA/DMAA). The authors noted the resolution of the medial prominence without resection of the medial eminence in their procedure.

We note a consistent reduction in the prominence of the medial first metatarsal prominence following triplane correction as well, and we rarely resect any significant bone. The traditional eminence resection removing the section of bone medial to the sagittal groove is unnecessary and undesirable after the metatarsal is supinated into anatomical alignment because it can result in the removal of a large portion of normal joint surface. There are cases in which adventitious thickening of the medial capsule and other soft tissues occurs, and in these cases, capsular thinning reduced the visible medial prominence (Fig. 6.10).

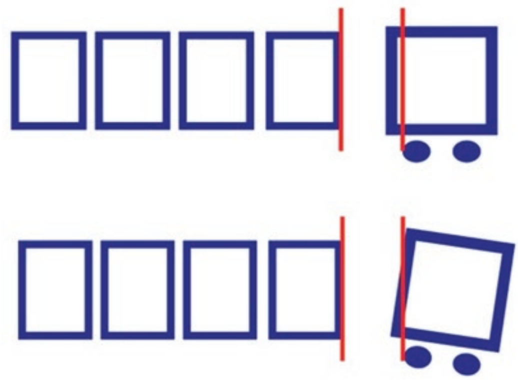

Fig. 6.9 Geometric effect of eversion of the first metatarsal bringing the dorsal medial corner of the first metatarsal into prominence which would show on the AP radiograph as an artificial enlargement of the medial eminence

The shape of the lateral first metatarsal head perceived on AP radiographs also changes with frontal plane rotation of the metatarsal. Studies have classified the lateral edge of the first metatarsal head into three shapes: round, square (angular), and chevron (intermediate). Okuda et al. [38] studied these shapes in female patients with moderate to severe bunions, pre- and postoperatively. These shapes were also compared to a control group. They found round metatarsal heads more prevalent in bunion feet than in the control group, while angular shapes were more prevalent in the control group than in the bunion group. They also found postoperatively that some bunions would change from round to either intermediate or angular. In their early follow-up, they noted that if a patient had a positive round sign on AP radiograph, there was a greater hallux valgus angle and a greater chance of recurrence. Their explanation is that as the bunion worsens and frontal plane rotation increases, the lateral first metatarsal head appears more round. When in its anatomic rectus position, the metatarsal head is flattened medially and laterally. With a pronated first metatarsal, the round plantar condyles lateral of the metatarsal head are brought into profile, and their projection appears quite convex on the AP radiograph. They concluded that this lateral round sign, a marker of frontal plane pronation, should be corrected intraoperatively and, if seen postoperatively, is a risk factor for bunion recurrence due to failure of complete derotation to neutral position (Fig. 6.11).

We recently completed a retrospective review of pre- and postoperative AP and sesamoid axial radiographs of bunion patients that confirmed that the sesamoid position identified on the AP radiographic view and the lateral round sign are associated with a pronated position of the first metatarsal (Dayton and Feilmeier 2016 submitted for publication). Seventeen of the 21 feet (81%) included in this review displayed radiographic findings of metatarsal pronation preoperatively based on axial sesamoid views and a positive lateral round sign on AP radiograph. At a mean follow-up of 5.2 ± 1.6 months after triplane

Fig. 6.10 (**a**, **b**) Radiographs showing the dramatic change in the medial eminence prominence on the AP radiograph when inversion of the first metatarsal is included as part of the correction and without medial eminence resection

Fig. 6.11 Pre- and postoperative AP radiographs with corresponding sesamoid axial views showing the shape of the lateral metatarsal head going from rounded in the everted metatarsal position to angular after frontal plane inversion as part of the correction. The change in the appearance of the medial eminence and the joint surface alignment resulting from frontal plane inversion can also be seen

deformity correction, a significant improvement in tibial sesamoid position on both AP and axial radiographs was measured. A negative metatarsal round sign, indicating correction of frontal plane metatarsal rotation, was observed in 20 of the 21 feet (95.2%) on AP radiographic evaluation, and the same number exhibited complete reduction of metatarsal pronation as noted on axial radiograph. Sesamoid subluxation from the normal position with the tibial sesamoid on or lateral to the median crista was noted in 4 feet (19%) preoperatively. All of the patients (100%) had a resolution of sesamoid subluxation on sesamoid axial at final follow-up. The sesamoid axial position was consistently normal when the round sign was absent, and the TSP was in the normal range of 1–3 on AP radiograph.

An additional two-dimensional radiographic finding often used in the definition of the bunion deformity and used in decision-making regarding procedure choice is the PASA/DMAA. Coughlin et al. [4] concluded, "The interobserver reliability in the assessment of the DMAA is questioned." Coughlin further stated that the decreased reliability of this measurement between the different observers was due to the "difficulty in consistently determining the medial and lateral extent of the distal metatarsal articular surface." Robinson et al. [45] also confirmed the PASA/DMAA measurement to be unreliable between observers. In both of these studies, they radiographically measured cadaveric first metatarsals and found that with frontal plane rotation of the metatarsal, the PASA measurements changed. Martin [32] presented a different perspective on the changes at the head of the metatarsal in his critical analysis of PASA. Martin found that preoperative PASA is rarely visualized intraoperatively and often decreased postoperatively without any procedures to address the PASA or the head of the metatarsal. Chi et al. [2] questioned the accuracy and the validity of DMAA and noted in a series of patients that underwent proximal first ray procedures the finding of a consistent reduction in DMAA without distal procedures indicating that this two-dimensional parameter may be a radiographic artifact. This highlights one of the most striking deficiencies in the two-dimensional radiographic analysis. Measurements are made of the articular surface angle and osteotomies chosen to correct this deformity when in fact this measurement may be simply a radiographic artifact that is based on metatarsal frontal plane rotation. Naziri et al. [37] also cautioned against choosing procedures based on DMAA. Using cadaveric feet, a transverse first metatarsal osteotomy was created, and the first metatarsal head was rotated in the frontal plane. An AP radiograph was then obtained using fluoroscopy, and DMAA was measured at certain increments of frontal plane rotation. The measured DMAA was not constant as frontal plane rotation occurred and the rotation caused the DMAA to vary unpredictably. The authors concluded that surgical procedures should not be based on DMAA, as frontal plane rotation in the bunion deformity can cause variance in DMAA. This emphasizes the point that frontal plane rotation should be evaluated and an integral component in the workup for bunion correction.

If the PASA/DMAA is indeed a radiographic artifact, which is becoming more apparent, we have to question the wisdom of performing additional procedures aimed at changing the joint surface alignment. When a transverse plane sliding or angulation osteotomy is done without coronal supination the joint surface angle (PASA/DMAA) may appear worse. On the other hand, it is interesting to observe the degree of change that can be seen in the PASA/DMAA when the pronated position of the metatarsal is corrected. Dayton et al. (2012) measured the IMA, hallux abductus angle (HAA), PASA, and TSP on weight-bearing radiographs of 25 ft in 24 patients who underwent tarsal metatarsal corrective arthrodesis without lateral capsular release. Specific attention was given to the reduction of the frontal plane rotation of the first metatarsal during correction. Angular measurements observed by four investigators identified a mean change in IM angle of 10.1°, HAA of 17.8°, and a mean change in TSP of 3.8. A very interesting finding regarding apparent joint surface alignment was noted with a mean reduction in PASA of 18.7° without osteotomy of the metatarsal head or any soft tissue or bone joint balancing (Fig. 6.12).

This makes a strong argument for radiographic appearance of joint surface angulation being merely a product of the nonspherical head of the metatarsal casting a deviated radiographic image rather than a true anatomic deformity of the distal metatarsal. Considering this, the common practice of doing secondary wedge osteotomies to realign the joint surface may not be necessary. Triplane correction with the addition of metatarsal supination is an excellent alternative to secondary osteotomies to realign the joint surface. Additionally, we need to recognize that measured PASA/DMAA abnormalities are often a result of radiographic artifact, and we perform an osteotomy in an attempt to correct the artificial abnormal alignment; we have not only performed an unnecessary osteotomy but also created a new deformity and exposed the patient to further surgical morbidity, healing, and scarring.

Finally, the function of the first MTPJ is directly affected by frontal plane position of the metatarsal. Ebert et al. [12] presented a poster presentation at the American College of Foot and Ankle Surgeons Annual Scientific Conference 2016 in which they performed a cadaveric experimental study to better understand the impact that frontal plane rotation of the first metatarsal has on first MTPJ ROM. They noted a statistically significant relationship between frontal plane rotation and the first MTPJ ROM in a simulated first TMTJ arthrodesis positioned in 10° increments of increasing valgus position of the first metatarsal. As they increased the valgus position (pronation) of the first metatarsal, there was a resulting decrease in the first MTPJ ROM. Though they did not propose a reason for the decrease in MTPJ ROM, the work of Mortier et al. [36] lends some insight into the mechanism. They discuss the "drive belt" effect that occurs as the first metatarsal pronates in the frontal plane, and the sesamoid apparatus rotates along with it. The sesamoids no longer slide normally in their grooves, and the sagittal plane hallux movement is restricted, replaced by a transverse pull, displacing the hallux laterally. This biomechanical concept can then be extended to provide a potential explanation for the fact that the if the frontal plane malposition of the first metatarsal is not addressed with the bunion correction, there may still be reduction of joint movement because of

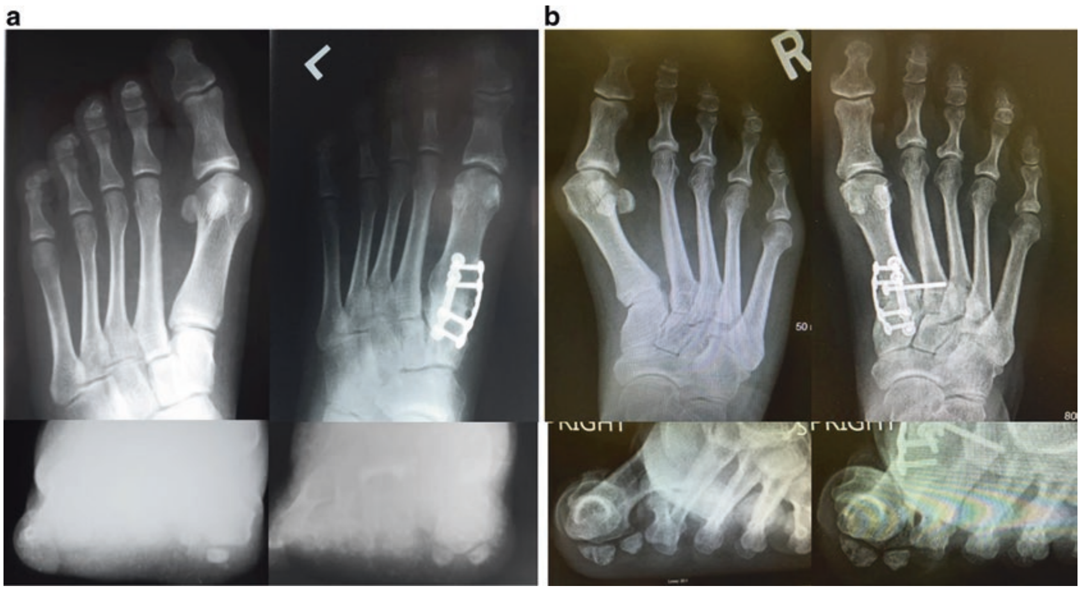

Fig. 6.12 (**a**, **b**) Two cases with pre- and postoperative AP radiographs with corresponding sesamoid axial views showing dramatic change in the metatarsal joint surface alignment (PASA/DMAA), TSP, and hallux position after inversion of the first metatarsal relative to the plane of the lesser metatarsals as part of correction without metatarsal osteotomy or capsular balancing

the tethering of the soft tissues that occur as the first MTPJ is not fully restored to its anatomic position and thus lead to joint degeneration over time.

Myerson et al. [33] reported a decrease in the ROM of the first MTPJ in their cohort of 67 patients undergoing a first TMTJ arthrodesis, with ROM 85% of normal postoperatively. Of note is that they performed a closing wedge TMTJ arthrodesis and did not specifically address the frontal plane component of the deformity. If in their procedure the metatarsal was left everted, the previously described binding effect of the sesamoids described may have interfered with motion. This differs from the findings of Perez et al. [41] who noted an increase in first MTPJ ROM after TMTJ fixation. In a cadaveric study they confirmed an increase in the MTPJ ROM and a decreased resistance to dorsiflexion after the TMTJ was fixated with the first ray anatomically aligned in a cadaveric study. Although their model does not prove why the ROM improved, it is important to note that they did not find a reduced first MTPJ ROM after simulated TMTJ fusion in a non-deformed model. It is apparent from these studies, and readily intuitive, that having the first ray positioned in a neutrally rotated position and positioning the sesamoids and muscular and tendinous units purely in the sagittal plane can restore the normal functional MTPJ alignment and consequently preserves MTPJ ROM. Based on extensive study of the first ray anatomy, we believe restoring or maintaining neutral frontal plane rotation prevents binding of the sesamoids and joint surfaces during first MTPJ ROM. The normal motion of the first MTPJ requires dorsal sliding of the hallux with a concurrent plantarflexion of the metatarsal when it moves in the sagittal plane. Frontal plane malposition of the metatarsal and hallux unit disrupts this normal ginglymoarthrodial mechanism. This concept is corroborated by Rush et al. [44] who showed an improvement of first MTPJ ROM after the correction of HAV deformity in a cadaver model. They suggested that the windlass mechanism is more efficient when the first metatarsal, sesamoids, and the hallux are properly aligned with the orientation of the plantar aponeurosis. It is worth noting at this point that the TMTJ is not the source of the majority of motion in the first ray and that normal mechanics of the first ray are minimally affected by TMTJ fusion. Biomechanical analysis has shown that the majority of motion comes from the naviculocuneiform and intercuneiform joints, and this is discussed comprehensively in a review paper by Roukis [43] as well as a biomechanical analysis by Martin et al. [32]. This concept is also reinforced by multiple studies showing that significant transverse, sagittal, and frontal plane instability persist after the elimination of TMTJ motion through fixation [8, 14, 15]. If the TMTJ was the primary anatomic site providing motion of the first ray instability would be eliminated after fixation. The fact that motion persists after fusion and the windlass mechanism seems to be improved after triplane alignment at the TMTJ points to joints other than the TMTJ as prime sites of movement in the first ray. This concept also supports the concept that triplane correction can be carried out through the fusion of the TMTJ without detrimental effects on first ray mechanics including the first MTPJ [23].

We have noted an interesting protective effect on hallux position post correction when frontal plane pronation is corrected to neutral. In some cases, the hallux position and IMA actually improve over time with weight bearing. We believe that this occurs because the sesamoids and the long flexors have been realigned to function purely in the sagittal plane. The activation of the tendons and the normal windlass mechanism during walking no longer place deforming forces on the hallux to pull it laterally and secondarily push the first metatarsal medially. Theoretically and in our experience, this reduces recurrence and in some cases provides for the improvement of the correction over time (Fig. 6.13).

Another interesting effect of realignment procedures for HAV was discussed by Doty and Coughlin [10]. They reviewed multiple studies that indicated an improvement of first ray sagittal plane stability following the correction of HAV with first MTPJ fusion and metatarsal osteotomy correction. They attributed the improved stability to realignment restoring proper mechanics of the first ray. They further stated that this finding may indicate instability in the first ray is a result rather than the cause of HAV deformity. Further indication of abnormal first ray mechanics associated with HAV was reported by Koller et al. [27]. They measured decreased loading under the hallux and increased loading under the lateral metatarsals in patients with HAV and sesamoid subluxation. Looking at this data and the previously cited works, we speculate that this abnormal pressure phenomenon resulted from the alteration of the normal windlass mechanism compromising the plantar flexion effect on the first metatarsal and therefore decreasing the loading at the first and increasing lateral loading.

When looking at the effect of more common osteotomy procedures, a decrease in first MTPJ ROM has been reported. Jones [21] performed a cadaveric study using cadavers with bunions. Following proximal metatarsal osteotomy and distal soft tissue reconstruction, specimens lost 22.6° of dorsiflexion and only 0.6° of plantarflexion. They hypothesize that this selective loss of dorsiflexion is secondary to non-isometric capsular repair or tight intrinsic musculature but could not correlate the loss of motion with an amount of IM or HVA correction. They did not take into account frontal plane rotation or sesamoid position. In performing proximal metatarsal osteotomies, no frontal plane correction is performed; it is possible that the rotated metatarsal leaves the MTPJ out of normal functional alignment and explains the failure to increase first MTPJ ROM. Further, it is possible that the distal soft tissue reconstruction actually displaced the sesamoids from their grooves on the metatarsal, leading to a loss of dorsiflexion. If first MTPJ ROM is reduced in the bunion deformity, then corrective surgery should aim restore the normal functional anatomy of the MTPJ in order to increase first MTPJ ROM back to a nonpathologic state. Therefore, if frontal plane rotation is not addressed, at best, decreased first MTPJ ROM may persist as the sesamoids bind during dorsiflexion and, at worst, displaced sesamoids may lead to a loss of dorsiflexion, HAV recurrence, or hallux varus.

Although not a commonplace in 2016, this concept of metatarsal triplane rotation to correct a

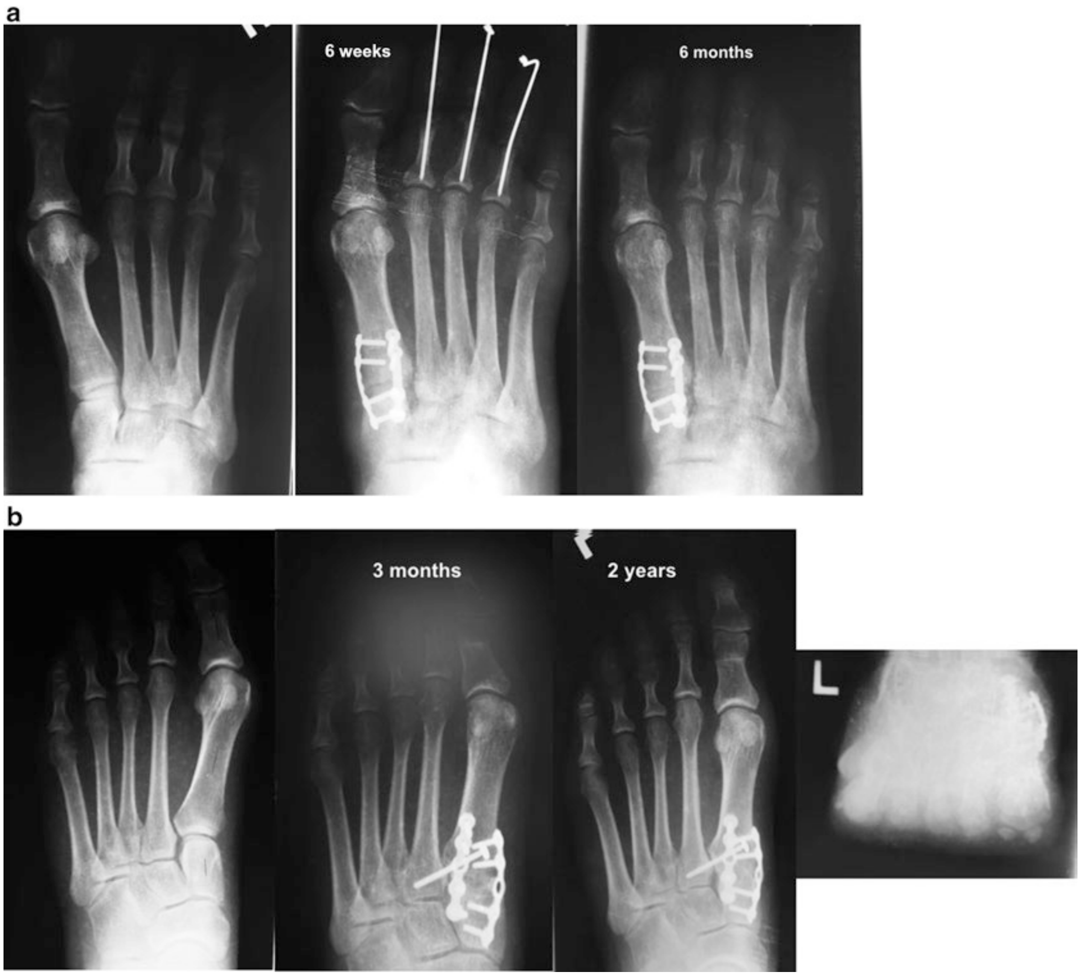

Fig. 6.13 (**a**, **b**) Two cases in which the hallux angle and first ray alignment improved over time. Frontal plane realignment resolved the angular forces on the hallux that occur with tendon pull during the windlass effort during gait. This allowed proper soft tissue alignment to improve the overall alignment. When frontal plane eversion of the first ray remains, the angular forces pull the hallux lateral during weight bearing and push the metatarsal medial resulting in recurrence. Removing rotation seems to protect against this effect

bunion was first described six decades ago. Mizuno [35] observed the frontal plane position of both the hallux and the metatarsal. He used the term torsion to describe the pronated position that the metatarsal assumed as it moved medially. He also proposed a derotational osteotomy of the first metatarsal, termed a "detorsional osteotomy" in his paper. Mizuno's paper highlights a difficulty found in reading about rotational position across the literature. This difficulty lies in the variety of terms used to describe the same pathologic position which can lead to confusion and misunderstanding. We presented an analysis of anatomic nomenclature in an attempt to overcome this semantic stumbling block [7]. With respect to metatarsal rotational position, one should read the terms pronation, valgus, and eversion as equivalent. Likewise, the terms supination, varus, and inversion are equivalent. The term hallux abducto valgus (HAV) with metatarsus primus adducto valgus (MPAV) is used to describe the multiplane deviation of both the hallux and the metatarsal segments within the deformity. This concept is discussed in detail in Chap. 2.

HAV with MPAV is a triplane deformity and correction of the valgus (pronated) position of the metatarsal with osteotomies or arthrodesis that imparts frontal plane mobility which allows the surgeon an ultimate flexibility in obtaining complete and consistent deformity correction. We typically choose a triplane first TMTJ arthrodesis as our preferred procedure because it addresses the deformity at the CORA, and it is at a level in which all components of the deformity can be reduced giving the surgeon complete control of positioning including the transverse, sagittal, and frontal plane. When the surgeon is aware of the rotational position of the metatarsal and understands the intraoperative assessment to observe anatomic alignment, all components of the deformity can be addressed without having to do multiple osteotomies, extensive joint releases, and soft tissue balancing at the MTPJ. The technical concepts for triplane correction will be discussed in detail in Chap. 13.

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Recurrence and Hallux Varus

7

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Outcomes for HAV Surgery

Detailed search for studies specifically reporting outcomes for bunion correction reveals close to 185 manuscripts in the past 15 years. There are hundreds of additional presentations of techniques and unique perspectives on bunion surgery. A theme in the recent literature is higher than expected recurrence rates and much higher than expected patient-reported dissatisfaction especially when long-term outcomes are studied. An example of this trend is a recent long-term follow-up study comparing popular procedures. Chong et al. [16] reviewed the patient-reported and radiographic outcomes of 162 feet 5 years after undergoing either a scarf/Akin procedure (65%), chevron procedure (21%), Mitchell procedure (4%), Wilson procedure (5%), or Bunionectomy (5%). Recurrence occurred in 9.9%, and the striking finding is that 67% of the patients were still symptomatic and 25.9% of patients dissatisfied (based on MOXFQ) at the endpoint 5.2 years after surgery. They concluded that long-term results for hallux valgus surgery are much worse than short- and midterm outcomes as well as worse than they expected. Chen et al. [10] studied pain after hallux valgus surgery in 308 patients; 31% had residual pain 6 months after surgery. Seventy-one percent of all patients were pain-free by the 2-year postsurgical point; however satisfaction was only 82% for patients with pain at 6 months compared to 95% satisfaction in patients who had no pain. Chen et al. [11] in another patient series review found that a closer to normal tibial sesamoid position was a marker for improved functional results and satisfaction. They noted that in patients with a tibial sesamoid position less than IV, indicating a more complete deformity correction, there was higher patient satisfaction and associated better anatomic correction with better satisfaction. Fokter et al. [30] presented a long-term review and reported deterioration of satisfaction after the modified Mitchell procedure between midterm and long-term follow-up in the same patient population. They reported 64% good to excellent results at mean 21-year follow-up compared to 97% satisfaction at an 11-year mean in the same cohort. Results were based on both patient subjective findings and physician rating of final correction with 41% recurrence of bunion pain at the endpoint.

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The Effect of Bias on Reported Results

We are seeing more papers that indicate less than favorable patient-reported outcomes and higher than expected recurrence rates. Studies such as those noted above indicate poorer than expected outcomes and/or deterioration of satisfaction following HAV surgery. The interesting finding when reviewing these studies is not only the diversity of procedures but also the wide variation in methods used to evaluate clinical and radiographic outcomes. The lack of standardization of the measurement tools for patient-reported outcomes, clinical evaluation, and objective radiographic measurement makes study comparison difficult at best and systematic analysis impossible. This diversity of research methods makes it very difficult to compare results for individual procedures and to compare outcomes that allow us to draw accurate evidence-based conclusions. In some cases, poorly applied tools can result in severely biased or even incorrect conclusions. Schrier et al. [67] looked at patient-reported outcomes following HAV surgery and noted a wide variation in outcomes measurement tools. They reviewed the types of patient-reported outcomes measures (PROMs) in three categories: general quality of life, pain scale, and disease-specific outcomes measures. It is generally accepted that validated PROMs are more reliable than the physician-specific outcome scores. They further state that patient outcomes and expectations are only partially revealed by physician-based clinical outcome score examples of which would be the AOFAS and ACFAS foot scores. PROMs that are validated for use to measure outcomes in the foot following HAV surgery are the Medical Outcome Study Short Form (SF-36), Visual Analog Scale (VAS) for pain, the Manchester-Oxford Foot Questionnaire (MOXFQ), the Foot and Ankle Outcome Scores (FAOS), and Self-Reported Foot and Ankle Score (SEFAS). The AOFAS score which is the most commonly used for reporting HAV correction outcomes is not a validated PROM; therefore studies using this system are in reality reporting physician important rather than patient important outcomes data. As noted above studies that do not focus on patient perception of the outcome and instead focus on factors which are physician specific such as local examination findings mechanical findings and radiographic findings may not lead to the true answer as to whether the procedure is effective in achieving the patient's goals. The authors [67] noted that the poor patient satisfaction rates which occur in up to one third of cases are not always reflected in the outcomes parameters reported in the literature which lack uniformity and in some cases relevance to patient outcomes. Chopra et al. [15] presented a similar finding related to the inconsistency of physician-driven evaluation vs. PROM. They looked at gait function, ADL subscore of the FAAM, and the AOFAS forefoot subset. Although the preoperative gait alterations persisted postoperatively and the FAAM showed no improvement in functional status from the patient's perspective, the AOFAS subscale showed significant improvement. These studies suggest that we need to reevaluate and standardize or approach to measuring outcomes following corrective procedures so that we can gain a true understanding of the success and failure rates for varied procedures and methods based on the patient's perception.

Further complicating review of the existing literature is patient selection bias and radiographic reporting bias which are present in many published case series, both of which leave us with an incomplete understanding of the true surgical outcomes. Underreported recurrence in some cases is a product of measurement technique bias and in other cases may be due to collecting data at short-term follow-up. When looking at deformity recurrence, we must recognize a major methodology issue, which is the common practice of using dual measurements to assess preoperative and postoperative intermetatarsal angle (IMA), HVA, and TSP. Multiple researchers have noted the discrepancy between measurements following metatarsal osteotomy using the anatomic intermetatarsal angle (aIMA) before surgery and the mechanical intermetatarsal angle (mIMA) after surgery. In the normal state, the anatomic and mechanical axes of the first metatarsal are collinear, and therefore true anatomic correction of the first metatarsal requires alteration of the mid-diaphysis axis (aIMA) (Fig. 7.1). In other words, the deformity

Fig. 7.1 In the normal state, the first metatarsal is straight; therefore the anatomic axis of the first metatarsal (mid-diaphysis bisection) is collinear with the mechanical axis (center of MTPJ to center of TMTJ)

is not within the first metatarsal but is in fact a deviation of the entire metatarsal relative to the adjacent structures. Once the first metatarsal is cut and angulated or translated, as is common in many bunion surgeries, a new deformity is created and added to the original deviated metatarsal deformity. Measurement of the aIMA before the procedure and subsequent measurement of the mIMA postoperatively represent an unacceptable observation bias if one considers normal anatomy (Figs. 7.2 and 7.3).

Alteration of the reference points and axis lines for the first metatarsal from the aIMA preoperative to the mIMA postoperative overestimates the correction achieved for the first metatarsal. In fact, this practice hides the fact that a new deformity has been created while the original anatomic axis deviation persists. One could argue that the center of distal joint (MTPJ) to center of proximal joint (TMTJ) system should be used for both preoperative and postoperative measurements due to the ease of locating landmarks with this method. However, this represents the exact same bias of measurement as the dual measurement technique since in the normal first metatarsal, the anatomic axis and the mechanical axis are collinear (the bone is straight) and following an osteotomy the metatarsal is no longer straight. It is impossible to draw accurate conclusions regarding deformity correction using these two measurements in the now deformed metatarsal for the same reason as using dual measurements as noted above (Fig. 7.4).

When reviewing study results, it is vital for the reader to understand which measurement techniques were used and what the effect of measurement technique has on the values reported [66]. Coughlin et al. [20] discussed the observed differences in IMA reported based on measurement technique. They showed how this convention of dual measurements affects the validity of radiographic outcomes by overestimating the correction. Despite the recognition that dual measurements lead to inaccurate reporting, they recommended that center of head and center of base technique be used (i.e., mechanical axis) due to the difficulty in identifying landmarks in a metatarsal in which osteotomy has been performed. This recommendation builds bias and error into the method of measurement as noted above because in the normal condition, the mechanical and anatomic axes are collinear. Ravenell et al. [61] explored the unreliability of the intermetatarsal angle in choosing a hallux abducto valgus surgical procedure. Radiographs measured postoperatively in a variety of osteotomy procedures showed no difference in the amount of angular correction achieved regardless of the procedure chosen. They called into question the common convention on choosing procedures based on the severity of the angular measurements on AP radiographs and commented that using the IMA to select an appropriate procedure is not reliable. An interesting study looking at intra- and interrater reliability of IMA, HVA, and TSP, Saro et al. [65] added an additional five-point rating scale to assess the normality of the cosmetic appearance of the postoperative radiographs. Consistent with other similar measurement reliability studies, they showed good reliability for

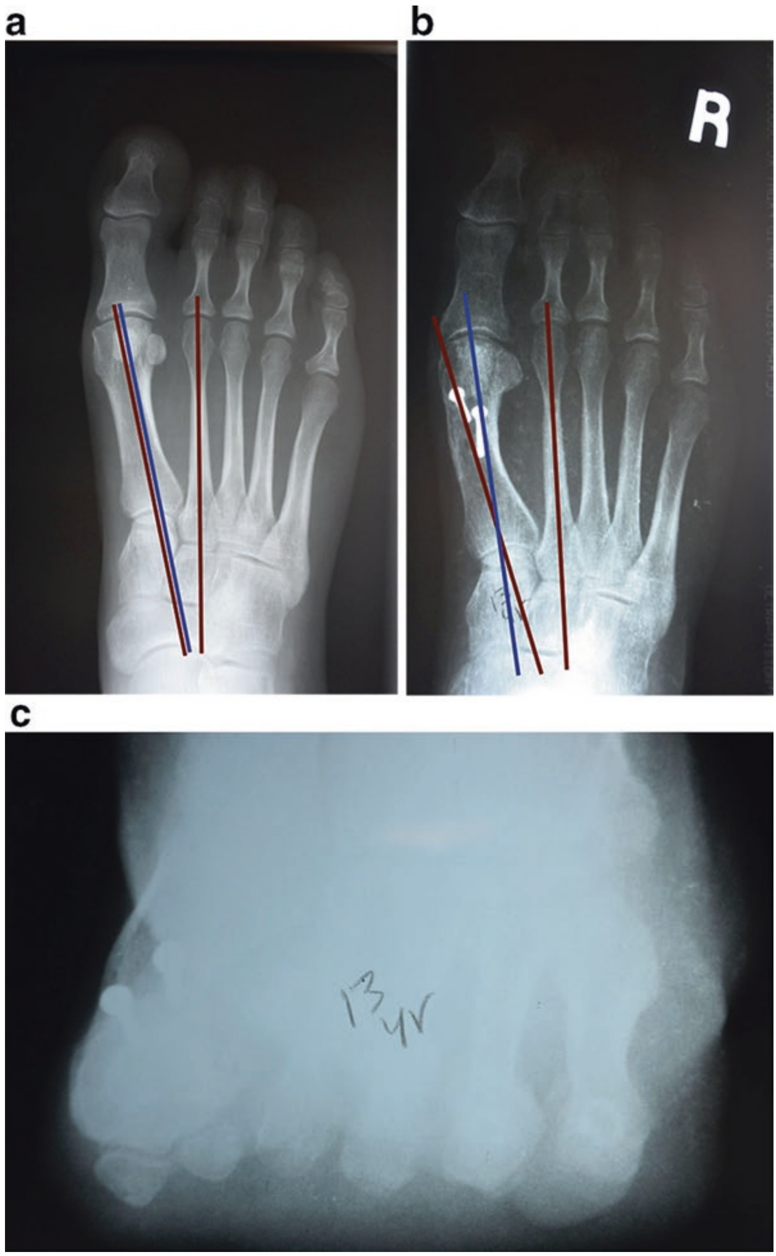

Fig. 7.2 (**a**) Preoperative AP radiograph showing the aIMA and mIMA in their normal collinear orientation. The IMA would be measured the same with both lines. (**b**) Post metatarsal osteotomy showing the mismatch of the mechanical and anatomic axes. The measurement of aIMA indicates increase in the reported IMA, while the mIMA suggests decrease of the reported IMA. There has been a severe new deformity created in the first metatarsal. Also note the residual AP signs of metatarsal frontal plane eversion and the corresponding axial view showing residual eversion of the metatarsal. (**c**) Rotation makes the sesamoids appear displaced from the metatarsal head on the AP, while they are in fact located medial and lateral to the crista. This is an additional bias of observation that causes misinterpretation and reporting of results

angular measurements of IMA using the center of head to center of base technique. However, there was poor consistency for the overall rating of cosmetic appearance of the foot. We think this highlights the bias introduced by using dual measurements, i.e., the measurements suggest correction is adequate but the agreement on the "normal" appearance of the foot is questionable (the foot did not look normal). Van Ho et al. [73] attempted to determine the most reliable way to measure IMA. Measurements made by bisecting the first shaft were compared to bisecting the head and base of the first metatarsal and measuring the angle from the tangent of the first and second metatarsal shaft from the medial or lateral aspect. Measurements were then compared to those made by a computer program using ten points on the medial and lateral aspects of the first and second

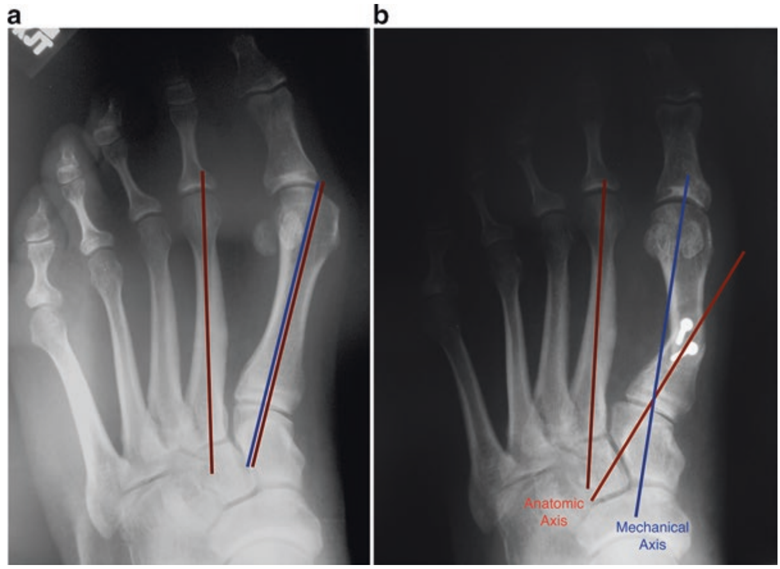

Fig. 7.3 A second case showing the mismatch of the axis's pre- (**a**) and post-operation (**b**) illustrating the reporting bias introduced by using dual measurements. Note the marked difference in the angular relationship when using mIMA vs. aIMA

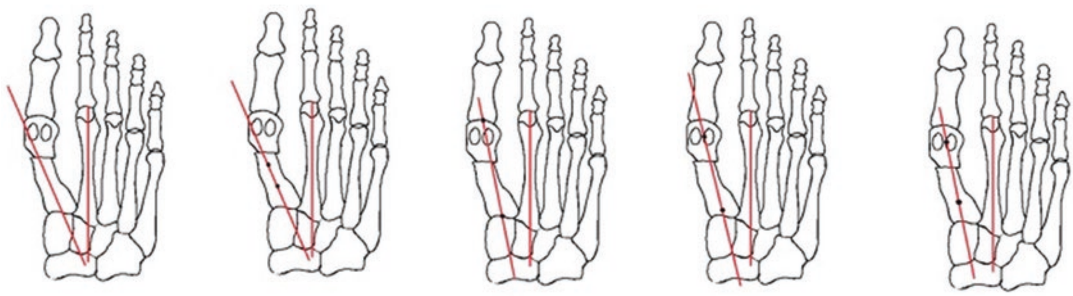

Fig. 7.4 Five different methods of first metatarsal axis as reported in the literature (Adapted from Schneider and Knahr). The two methods on the left measure using the longitudinal axis of the first metatarsal – the anatomic intermetatarsal angle (aIMA). The other three methods do not assess the anatomic axis of the metatarsal, rather they use a mechanical axis (mIMA) identified by the center of the metatarsal head or distal articular surface. In the normal state, the aIMA and the mIMA are collinear in the first metatarsal calling into question the use of mIMA

metatarsal. Bisecting the shaft had the smallest absolute mean (2.8%) which translates to the lowest amount of error of any of the computerized measurements. An example of the effect of using dual measurements on reported radiographic outcomes was presented by Akpinar et al. [5]. The authors analyzed the distal chevron osteotomy in 29 feet for proximal intermetatarsal divergence following corrective osteotomy which would indicate a medial deviation of the first metatarsal. Proximal intermetatarsal divergence was defined as an increase in postoperative aIMA or maximum intermetatarsal distance (MID). Patients with a mild deformity were noted to have a decrease in postoperative mIMA (10.91–7.00 mm); however the aIMA and MID actually increased by 11.8–13.55 mm and 17.97–20.60 mm, respectively. The mIMA for patients with severe deformity also decreased, and the postoperative aIMA showed very little change. This clearly shows the bias that exists when using dual measurements. In other words, even in patients where the separation of the first and second metatarsal proximal shafts increased, they could measure and report an artificial decrease in IMA using dual measurements.

To better understand the effect of dual measurements on outcomes reporting accuracy, we received IRB approval to assess the difference in measurement values when using the anatomic and mechanical axis of the first metatarsal for radiographic assessment of hallux valgus in patients that underwent a first metatarsal osteotomy at any level for correction of hallux valgus. Seventeen patients returned to our clinic for clinical evaluation and standard weight bearing AP and axial radiographs at a mean of 10.4 years post surgery. The hallux valgus angle (HVA), aIMA, and tibial sesamoid position (TSP) were measured pre- and postoperatively in a standard fashion. Additional postoperative measurements were made using the mIMA to study the difference in one to three IMA, HVA, and TSP difference between the two measurements. All preoperative measurements of IMA were made with the anatomic axis only as compared to the anatomic second metatarsal axis.

The mean aIMA using the mid-diaphysis bisection was 13.32 degree preoperatively and 13.58 degrees postoperatively. This is in contrast to a mean mIMA measured postoperatively of 3.72 degrees (sd2.76). The difference in postoperative measurements when using the dual measurements, anatomic axis (aIMA) and mechanical axes (mIMA), was significant for all measurements ($p < 0.005$). In contrast there was no significant difference between the preoperative aIMA when compared to the postoperative aIMA ($p = 0.984$). In other words the procedure did not correct the original deformity, but if using dual measurements, we could erroneously report an improvement. Additionally, using the mechanical axis postoperatively, we noted significantly lower mean values for HVA and TSP than those noted with the anatomic axis despite the anatomy being the same in both measurements. Although these improved postoperative measurements using the mechanical axis method may suggest better correction, the difference was erroneous and was based on alteration of axis placement and measurement technique, not improvement of anatomic alignment. The use of dual measurements can lead one to the conclusion that the true IMA, HVA, and TSP position have been corrected when in reality the original deformity is maintained, and new metatarsal deformities have been introduced (Fig. 7.5).

Fig. 7.5 Pre- and postoperative radiographs 4 years after metatarsal osteotomy. Before surgery the metatarsal is straight (anatomic axis collinear with mechanical axis). After surgery measuring angles with anatomic axis of the first metatarsal (*red line*), we see worsening of all of the angular relationships. If we use the mechanical axis (*blue line*), the angular relationships are reported as improved despite the fact the true anatomic position has worsened. Note despite an abnormal appearance of the sesamoids on the AP view, the axial position shows the sesamoids normally located medial and lateral to the metatarsal plantar crista showing the effect of metatarsal pronation on alignment (this is discussed in detail in Chap. 6)

Review of HAV Recurrence

When we separate studies that used dual measurements from those using aIMA, a more complete picture of the incidence of recurrence can be drawn. We reviewed all peer-reviewed published studies looking at bunion deformity correction at the time of writing this review and found deformity recurrence rates of between 4% and 73%. Those that reported measurements based on the aIMA both pre- and postoperatively were considered first and considered to provide the most accurate data on recurrence. Those who measured pre and post center of head and base (mIMA) or used dual measurements (first the aIMA and then the mIMA) were considered biased and are presented in the next section. A number of articles did not state the method used to measure the HVA or IMA, and they were omitted.

Studies Reporting Anatomic Axis Data

Shibuya et al. [68] compared feet that had first metatarsal osteotomies with (n = 73) and without (n = 81) an additional Akin procedure. Hallux abductus angles (HAA) were analyzed throughout this study. The HAA of the group that had the Akin procedure was significantly greater 6 months after surgery than the group that did not have Akins. The tibial sesamoid position was also significantly more laterally deviated in the Akin group when compared to their non-Akin peers. No difference in the revision rate was noted with 17.8% of the Akin group and 11.1% of the non-Akin group needing repeat surgery. Based on their results, the authors questioned the value of adding the additional hallux procedure. Bock et al. [8] reviewed 115 feet at 124 months that had undergone the scarf osteotomy procedure. ROM, VAS, HVA, IMA, DMAA, AOFAS, and sesamoid position were all significantly improved postoperative compared to preoperative. However, there was recurrence of 30% defined as an HVA of greater than 20° at final follow-up. The authors found correlations with recurrence to be higher HVA (preoperative and 6 weeks), higher IMA (6 weeks), sesamoid bone position, and DMAA. Iyer et al. [38] studied the proximal medial opening wedge (PMOW) osteotomy in 17 patients over an average 2.4-year follow-up. IMA improved at 6 weeks but deteriorated at final midterm follow-up. HVA also was noted to be improved at 6 weeks; however at the final midterm follow-up, the HVA was not significantly different from the preoperative value indicating a high degree of recurrence (64.7%). Interestingly the DMAA increased from 10.2 degrees to 13.6 degrees after surgery. Those patients who did have recurrence had higher HVA and DMAA preoperative scores compared to their colleagues who did not have recurrence. 23.5% of patients went on to have additional revision surgeries, and 35% had continued pain at the MTPJ at final follow-up. Fakoor et al. [28] compared the chevron, scarf, and McBride procedures in 44 feet. HVA was evaluated pre- and post-operation for each surgical group. The postoperative HVA of correction for both the chevron (16.7 degrees) and scarf (18 degrees) procedures was significantly different from the McBride (11 degrees) procedure but not from each other. The IMA of correction for the chevron (4.5 degrees) and scarf (6.3 degrees) was also significantly different from the McBride (2.6 degrees) procedure but not from each other. Osteotomy procedures had significantly better radiological outcomes than the McBride procedure. Recurrence was defined as any deformity reformation and occurred in 0% of scarf, 13% of chevron, and 27% of McBride patients. Pentikainen et al. [58] analyzed radiographic results of 100 feet at 6 weeks, 6 months, 1 year, and an average of 7.9 years (range 5.8–9.4 years) after distal chevron surgery to determine factors associated with hallux valgus recurrence. Recurrence in this study was determined to be an HVA of greater than 15 degrees and was seen in 73%. The mean HVA of patients who had recurrence was 28 degrees, and the IMA was significantly greater than in those who did not have recurrence. Every patient who had an HVA of greater than 30 degrees during the preoperative X-rays had recurrence. Along with the HVA, the position of the sesamoids, DMAA, congruence, and IMA all significantly affected recurrence rates.

Choi et al. [12, 13] reviewed 24-month follow-up of 53 feet that had scarf osteotomies with soft tissue realignment. SF-36 scores had a small non-statistically significant improvement (46 pre to 52 post). It is interesting that the radiographic improvement could be reported based on the measurement technique, but the SF-36 scores pre- and post-operation did not show a statistically significant change. The complication rate was 15%, with additional operations being deemed necessary in 7.5% of feet for removal of hardware. There were no reported cases of recurrent HAV; however there was a statistically significant loss of correction of the IMA (2.2 degrees) and MSP (0.4 grades). Hallux varus occurred in 3.9%, and an additional 3.9% were noted to have first metatarsophalangeal joint arthritis. Choi et al. [12] reviewed 103 Ludloff osteotomies that were combined with other procedures. The patients were divided into three groups depending on the type of distal soft tissue procedure they underwent. Thirty percent had first web space releases, 34% had Akin osteotomies and trans-articular releases, and 36% had Akin osteotomies with supplementary axial K-wire fixation and trans-articular releases. AOFAS and VAS improved in all three groups, without a significant difference between groups. Recurrence, which was defined as an HVA greater than 20 degrees, occurred in 15.5%, with all three groups having similar amounts of recurrence. Sixty-eight percent of patients who had recurrence did not report any symptoms. Deveci et al. [23] reviewed 50 scarf procedures, at a follow-up of 26.2 months (range 18–36 months). Ten percent of patients reviewed were found to recurrence of the deformity which defined as an HVA of greater than 15 degrees. Incongruity of the joint, which was the authors' hypothesized cause of recurrence, was found to be a statistically significant risk factor for recurrence. George et al. [31] examined outcomes 37.6 months following scarf osteotomies performed in 19 adolescent feet (average age of 14.3 years). IMA, HVA, and DMAA improved significantly at 6-week postoperative evaluation; however only IMA was maintained throughout the 3-year follow-up, and deterioration of the other measures was noted. 36.8% had pain and recurrence after surgery, while 9% had superficial infections. These results led the authors to the conclusion that the scarf procedure should be used with caution in adolescents. Veri et al. [74] analyzed 37 feet that had crescentic osteotomy and distal soft tissue reconstruction. A short-term follow-up was conducted at 1 year, along with a long-term follow-up at 12.2 years (31 feet). HVA and IMA values both deteriorated during the follow-up period. Ninety percent of patients were satisfied with their physical abilities during long-term follow-up, while only 80% were satisfied with the appearance. At the short-term follow-up, superficial infection occurred in 16%, 8% had delayed unions, 5% had varus after surgery, and 11% had recurrence.

To this point we have defined deviations from the normally accepted angles based on a comparison of preoperative and postoperative angles as recurrence. Looking at this issue from another perspective, we can ask, are we in reality even correcting the original deformity? Edmonds et al. [26] looked at postoperative radiographic measurements following distal, proximal, and double osteotomies in 106 juvenile feet (mean age 14.7 years). Their primary aim was to report which of the procedures returned the radiographic measurements of IMA, HVA, and DMAA to within a normal range. For the single distal first metatarsal osteotomy, the IMA was corrected to within normal limits in only 21% of the cases, HVA was within normal limits 42% of the time (however 13% of the time there was overcorrection), and the DMAA was within normal limits 46% of the time (with 4% overcorrected). The single proximal osteotomy had 36% of IMA, HVA, and DMAA within normal limits, with only DMAA having overcorrection in 7% of the cases. Finally the double osteotomy had 54% within normal limits for IMA, HVA within normal limits 40% (7% overcorrected), and DMAA was within normal limits for 56% of the cases (22% overcorrected). From these numbers it was found that the rate of HVA overcorrection was not correlated with the type of osteotomy performed, but there was a significantly higher rate of overcorrection in the double osteotomy when compared to both types of single osteotomies. This study highlights the shortcomings of these popular procedures in returning the radiographic bone segment positions to the normal range. We may in fact not be dealing with recurrence but simply our failure to correct the original deformity. If we consider the fact that the CORA for a bunion is not within this first metatarsal but at a point proximal to the deviated metatarsal, we are in fact creating a new deformity with metatarsal osteotomy. We believe that failure to correct the original deformity is likely the prime reason for poor outcomes. This is discussed in detail in Chap. 6 (Table 7.1).

Studies Reporting Mechanical Axis or Dual Measurements

As discussed above, since in the normal state the anatomic axis and the mechanical axis of the first metatarsal are collinear, using center of joint landmarks both before and after the procedure represents the exact same bias of measurement as the dual measurement technique. Alteration of reference point for the first metatarsal incorrectly reports a normal anatomic position (IMA) of the first metatarsal when in fact a new deformity has been created and the original aIMA deviation persists. The following studies used the system of dual measurements or the center of head and base technique to report on correction. Although we cannot fully critique the data, knowing the effect this convention has on the measured results, we can assume that degree of correction is overestimated and incidence of deformity recurrence is underestimated.

Jeuken et al. [40] compared 36 scarf to 37 chevron osteotomies 14 years after surgery. Patient-reported satisfaction and patient satisfaction with pain reduction ranged between 59% and 73% for each of the groups in all three of these categories based on MOXFQ, SF-36, and VAS scores. Seventy-three percent of feet in the chevron group and 78% of feet in the scarf group had recurrence based on their definition of HVA greater than 15 degrees. The high recurrence rate was determined using the center of head to center of base technique raising the question about the possibility of underestimation of true correction. As could be expected, the satisfaction was not particularly high in this study population despite the authors reporting significant improvement in AOFAS scores after surgery illustrating the potential bias between physician-rated scales and PROMs. Aiyer et al. [2] studied the recurrence of hallux valgus after 587 foot surgeries, comparing patients who have underlying metatarsus adductus (29.5%) (MA) to those who do not. Recurrence was defined as HVA of more than 20 degrees. HVA, IMA, and metatarsus adductus angle (MAA) were all measured, with MAA being considered abnormal if greater than 20 degrees. Patients with MA had greater HVA and IMA pre- and postoperative angles as compared to individuals without MA. There was a 15% recurrence rate in patients without MA, compared to a 29.6% recurrence rate in patients with MA. The rate of recurrence in the patients with MA did not vary based on procedure (Lapidus 28.5%, distal first metatarsal osteotomy 29.4%, proximal first metatarsal osteotomy 28.9%). Interestingly patients who had less severe MA (<31 degrees) were shown to have a higher rate of recurrence than those with more severe MA (82% vs 18%). In a previous study [3], reported metatarsus adductus to be associated with HAV in 30% of the cases reviewed. We have noted that the presence of metatarsus adductus clearly changes the ability to adequately and consistently correct the deformity long term and that this finding needs to be considered in the treatment algorithm. Metatarsus adductus assessment and clinical implications are discussed further in Chap. 5. Groningen et al. [34] analyzed the outcomes of 438 feet that had chevron osteotomies. The average IMA improved from 12.4 to 6.2 degrees after surgery, while the HVA improved from 28.5 to 14.8 degrees. FAOS assessments were completed at an average of 3 years for 250 of these patients, 28.3% had complications with undercorrection of the deformity occurring in 11.6% and hardware complications occurring in 9.1%. Those who had undercorrection had significantly lower FAOS assessment scores than their counterparts who had the original deformity corrected. With the use of dual measurements, we must question the true recurrence rate due to the bias imparted by the measurement technique. Agrawal et al. [1] looked at

Table 7.1 Studies using anatomic axis measurements

Author	Year	*N*=	Procedure	Recurrence rate	Recurrence definition	Satisfaction change/tool
Shibuya	2016	154	Metatarsal osteotomies with and without Akin	14.30% complications	Needed revision surgery	Not reported
Bock	2015	115	Scarf osteotomy	30%	HVA >20 degrees	VAS improved 6.3–0.4 AOFAS improved 57–95 No PROM
Edmonds	2015	106	Distal, proximal, and double osteotomies	Not defined	Argues that the original deformity was never really corrected	Not reported
Iyer	2015	17	Proximal opening wedge osteotomy	64.70%	Increase of HVA during recovery of >5 degrees	Significant improvement FAOS QoL subscale No PROM
Fakoor	2014	44	Chevron vs. scarf vs. McBride	21% (13% chevron, 27% McBride, 0% scarf)	Any reforming of the deformity occurring 6 months after surgery	Reported difference between VAS and Persian FADI for the three procedures with McBride having the worst outcomes of the groups
Pentikainen	2014	100	Distal chevron	73%	HVA >15 degrees	Not reported
Choi	2013	51	Scarf osteotomies	15.6% total complications, did not report recurrence	Not defined	AOFAS improved 52–88 SF-36 physical component 46–52
Choi	2013	103	Ludloff	15.5%	HVA >20 degrees	AOFAS improved 52.3–89.9 VAS improved 5.8–0.8
Deveci	2013	50	Scarf	10%	HVA >15 degrees	AOFAS improved 50.66–80 VAS 7.52–2.48
George	2009	19	Scarf	36.80%	Symptomatic and deformity had recurred	61% Nonvalidated survey AOFAS at final follow-up average was 80
Veri	2001	31	Crescentic osteotomy and distal soft tissue reconstruction	11%	Greater than 10 degree increase in HVA	90% physical 80%appearance SF-36

the clinical, functional, and radiological outcomes of the scarf-Akin procedure on 47 adolescent and juvenile feet. Radiological recurrence defined as IMA greater than 9 degrees and an HVA of greater than 15 degrees occurred in 29.8% with 21% needing additional or repeat surgeries. It should be noted that these high recurrence rates were probably underestimated based on center of head radiographic measurement technique and because of a very short radiographic follow-up (6-week post-radiographs used to report results). Despite the high radiographic recurrence, the AOFAS scores at short-term follow-up between the recurrent and nonrecurrent were not significantly different; therefore one has to question the validity of the outcomes scale based on these conflicting findings. Lee et al. [48] compared outcomes of proximal and distal chevron osteotomies in 92 feet in 46 female patients that were undergoing moderate to severe hallux valgus bilaterally, one foot proximal and one foot distal for comparison. The average follow-up was 40.2 months (range 24.1–80.5) at which point 6.5% of the distal group and 4.3% of the proximal group were dissatisfied. Recurrence occurred in 6.5% feet in the proximal group and 2% of feet in the distal group. Again due to measurement technique, the conclusions are biased so we cannot draw accurate conclusions based on comparison to normal. If we analyze the radiographs provided in the study, the aIMA and the TSP are quite abnormal despite the report of these measures being corrected by use of the center of head technique similar to the figures presented in this chapter (Fig. 7.5). Buciuto [9] presented a comparison of the outcomes for the Mitchell osteotomy and the chevron osteotomy. They reported satisfactory correction for both procedures (chevron had better results) based on the dual measurement technique with a loss of hallux valgus correction of 4–6 degrees. Of note they reported a 36% rate of transverse metatarsalgia pain. Recurrence rate was not specifically discussed in their analysis. Evaluation of the pre- and postoperative images provided in the paper clearly shows overestimation of the correction of all measured angles. There are a plethora of additional papers reporting individual author's results with a wide diversity of procedures. Unfortunately the use of dual measurements and the diversity of outcomes scales make systematic analysis impossible and leave us with a lack of solid answers as to the best and most reliable methods to correct HAV. Faber et al. [27] compared the Lapidus procedure with the Hohmann distal closing wedge metatarsal osteotomy in 91 feet specifically to determine if arthrodesis procedures are necessary to control hypermobility. AOFAS scores which were taken preoperatively, 2 years postoperatively, and 10 years post-operation were compared. The AOFAS significantly increased between preoperative and both 2 and 10 years post surgery. However there was a significant decrease in AOFAS scores between 2 years and 10 years. The IMA was significantly worsened in both groups between the 2- and 10-year follow-ups. Both of these factors show the importance of long-term follow-up. The average recurrence rate in both of the groups was 8.8% with underestimation of recurrence likely secondary to measurement technique. Farrar et al. [29] assessed scarf osteotomies of 39 feet in 28 adolescent patients (mean age 14.1 years). Of the 18% that had recurrence, they defined 71% as minimal recurrence that did not desire repeat surgery and 14% as significant symptoms that required revision surgery and 14% whom did not choose to have additional surgery. Okuda et al. [55] reviewed 77 feet treated with a proximal metatarsal osteotomy omitting five cases from the result due to hallux varus at a 14–120 months final postoperative visit. Hallux valgus recurrence defined as an HVA greater than or equal to 20 degrees was found in 13.9%. Seven percent had recurrence occurring at 10 weeks after surgery. Patients who had a preoperative HVA greater than 40 degrees had an increased risk for recurrence. The authors found that patients who had an HVA of less than or equal to 15 degrees and an IMA of less than 10 degrees at 10 weeks after surgery had a decreased risk of recurrence. Kilmartin and O'Kane [45] reviewed scarf and Akin osteotomies in 73 feet at an average of 9 years post surgery. Patients reported stiffness in the first MTP joint in 8%; hallux varus occurred in 4% and recurrence of 4%. The authors considered an

HVA of 20 degrees as "mild." An additional 8% of feet had HVA greater than 15 degrees which has been defined by some authors to be abnormal. Total satisfaction rate was 88% based on their definitions. This again highlights the difficulty in comparing studies due to methodological inconsistencies. Deenik et al. [22] studied HVA in scarf and chevron osteotomies in 136 feet. Subluxation of the MTPJ occurred postoperatively in 35% of patients with preoperative HVA greater than 37 degrees which progressively lead to recurrence. Only 3% of these cases of mild HVA preoperatively lead to recurrence. Patients whose HVA was more than 37 degrees preoperatively were only 65% satisfied after surgery and had significantly more pain than those who had smaller HVAs preoperatively. Coetzee [17] investigated scarf osteotomies in 20 patients at 6 and 12 months post-operation. Preoperative AOFAS was 53, 6 months 54, and 12 months after surgery 62. Fifty-five percent were satisfied at 6 months, while only 53% were satisfied after 1 year. IMA reduced from 16 degrees preoperatively to 13 degrees at 12 months; HVA improved from a mean of 40–34 degrees. Overall satisfaction was 55%, with 45% being dissatisfied in the early postoperative and 47% still unsatisfied at 12 months. Recurrence rate was 25% defined as HVA angle greater than 32 degrees and an IMA of greater than 10 degrees. Seven patients required revision surgery. Fokter et al. [30] studied 105 feet in patients who returned for clinical exam with a mean of 21 years (range 15–24 years) after a modified Mitchell procedure. They found that pain was present either at the first MTPJ or under the lesser metatarsals in 41% of the patients. Clinical return of the hallux valgus deformity was present in 47% of their patients. First and second toe overlap was noted in 18% and rotational deformity of the hallux in 39%. They concluded that the results of the procedure could not withstand the test of time for more than a decade (Table 7.2).

The question that must be considered in future investigations is why do we see recurrence. As noted above we believe that creating a metatarsal osteotomy creates a new deformity and leaves the original problem uncorrected. The fact that there are so many types of procedures that have been recommended and so many modifications seems to indicate we are approaching the problem from the wrong root cause. Others have noted clinical and radiographic factors that seem to be associated with recurrence. Although many of the factors described as associated with recurrence are most likely not causative, they do potentially signal factors to consider to avoid recurrence. Okuda et al. [57] analyzed the shape of the first metatarsal head in patients with hallux valgus deformities. The lateral edge of the lateral first metatarsal head was classified as round, angular, or intermediate. The round type was more prevalent in the presurgical group (78%) when compared to the normal group (1.7%). Following a proximal metatarsal osteotomy, the authors determined that feet which had a positive round sign at 3.4-month follow-up were more likely to have recurrence (defined as an HVA greater than 20 degrees) during the 48-month follow-up. A total of 25% had recurrence of the hallux deformity. The rounded sign of the lateral metatarsal head has been shown to be associated with the presence of frontal plane eversion of the first metatarsal. We discuss the effect that coronal plane rotation has on hallux position, radiographic appearance, and measurements and the potential role it plays in recurrence in Chap. 6. Okuda et al. [56] analyzed the position of the sesamoids after surgery with the possibility of recurrence after proximal osteotomy. They noted an initial improvement of both the IMA and HVA; however, there was a significant increase in HVA and IMA between the 3.1- and 45-month follow-up. They positively associated recurrence with a high preoperative and immediate postoperative tibial sesamoid position. Their final conclusion was that the sesamoids must be completely reduced in order to decrease the probability of recurrence. Again the authors made the association of these findings to frontal plane pronation or eversion. Yasuda et al. [75] discussed a proximal supination osteotomy of 83 feet specifically analyzing the round sign and reduction of the sesamoid position. Of the feet which had recurrence, all of them had a preoperative IMA of 18 degrees or greater and an HVA of 40 degrees or greater and postoperatively had a round sign indicating lack of correction of frontal

Table 7.2 Studies using mechanical axis or dual measurements

Author	Year	*N*=	Procedure	Recurrence rate	Recurrence definition	Satisfaction and tool	
Jeuken	2016	71	Chevron and scarf osteotomies	73% chevron, 78% scarf	HVA>15 degrees	64–67% scarf	MOXFQ,SF-36,VAS
						59–73% chevron	AOFA S
						79.5 scarf	
						80.1 chevron	
Aiyer	2016	587	Lapidus, distal first metatarsal osteotomy, proximal first metatarsal osteotomy	15% in those without MA, 29.6% in those with MA	HVA >20 degrees	Not reported	
Groningen	2016	438	Chevron	13.5%	Needed reoperations	FAOS at 36 months postoperative:	
				11.6%	Recurrence = HVA greater than 20° with less than 10° of angular correction	83 for pain	
						82 for symptoms	
						88 for ADL	
						74 for sport and rec	
						71 for QoL	
Agrawal	2015	47	Scarf-Akin	29.80%	HVA>15 degrees and an IMA>9 degrees	No PROMs	
				21.3% revision surgery needed		AOFAS scores above 90	
Yasuda	2015	83	Proximal supination osteotomy	4%	HVA >25 degrees	No PROMs	
						AOFAS 53–93.8	
Lee	2015	92	Proximal vs. distal chevron osteotomies	4% (6.5% proximal, 2% distal)	Not defined	91.30% (93.5% proximal, 95.7% distal)	Nonvalidated survey, AOFAS proximal 55.2–91.7
							Distal 55.7–91.8
Fleming	2015	38	Lapidus arthrodesis	5%	Not defined	Not reported	
Faber	2013	91	Lapidus vs. Hohmann distal osteotomy	8.80%	Satisfaction rate about the position of the toe was scored at 3 and/or AOFAS subscore for alignment was 0	80.2% total (78% Hohmann, 83% Lapidus)	Nonvalidated survey
Choi	2013	53	Scarf-Akin	0%	Not defined	No PROMs	
						AOFAS improved 52–88	
Farrar	2012	39	Scarf	18%	Defined by alignment section of AOFAS	93%	Nonvalidated survey, AOFAS post-op 94.2
Okuda	2011	72	Proximal metatarsal osteotomy	13.90%	HVA >20 degrees	Not reported	
Kilmartin	2010	73	Scarf and Akin	4%	HVA >20 degrees	88%	Nonvalidated survey
Okuda	2009	65	Proximal metatarsal osteotomy	25%	HVA >20 degrees	Not reported	

(continued)

Table 7.2 (continued)

Author	Year	*N*=	Procedure	Recurrence rate	Recurrence definition	Satisfaction and tool	
Deenik	2008	136	Scarf vs. chevron	9%	Not defined	No PROMs, AOFAS improved average 46 to 87	
Okuda	2007	60	Proximal metatarsal osteotomy	25%	HVA >20 degrees	Not reported	
Coughlin	2007	122	Crescentic osteotomies and distal soft tissue repair	5%	HVA >20 degrees	93%	Nonvalidated survey
Coetzee	2003	20	Scarf	25%	HVA>32 degrees and IMA >10 degrees	62 at 12 months	AOFAS
						55% at 6 mon, 53% at 1 year	Nonvalidated survey
Fokter	1999	105	Modified Mitchell procedures	47%	Not defined	86%	No PROMS
							AOFAS

plane rotation. Instability or hypermobility is another factor that has been associated with recurrence. Although there are many opinions regarding this subject, the true existence of hypermobility especially at the TMTJ is not clear [19]. The concept of first ray stability is discussed in Chap. 2.

It is clear that the recurrence rate for hallux valgus surgery remains unacceptably high. Additionally, the inconsistency and variability of both measurement techniques and lack of PROMs in the analysis of many studies leave us with an incomplete understanding of the true complication rates. We must move toward universal standardization of outcomes measures if we are to understand the true successes and failures of our common techniques. Furthermore, we must examine the most basic components of our philosophy for procedure selection and preoperative radiographic evaluation and apply sound anatomical principles and judgment to improve our understanding of this complex deformity if we wish to improve outcomes.

Hallux Varus

Hallux varus is a troublesome and sometimes disabling iatrogenic complication associated with bunion surgery. McBride [53] was the first to describe to deformity in 1935 citing an overall incidence of 5.1% [52]. The overall reported incidence is between 2% and 17% after hallux valgus correction [59, 62]. The classic description of the deformity is a true triplanar malalignment with transverse plane adduction of the hallux, dorsal contracture of the MTP in the sagittal plane, and in some cases frontal plane rotation of the first metatarsal with medial deviation of the sesamoids relative to the first metatarsal head [25]. Advanced cases may result in flexion of the hallux IP joint and a rigid deformity due to arthritis if left untreated.

While various etiologies exist for hallux varus, including trauma, inflammatory arthritis, and congenital deformity, the most common reason remains surgical overcorrection [6, 7]. Specific causes of hallux varus are excessive medial eminence resection or loss of the anatomic sagittal groove overly tightened medial capsulorrhaphy, aggressive lateral release, osseous overcorrection by osteotomy, or TMT arthrodesis with excessive transposition or attempt to reduce the intermetatarsal angle ([39, 50]). The true McBride procedure with removal of the fibular sesamoid is the most frequently associated procedure with loss of the lateral soft tissue restraints either when performed alone or in combination with an osteotomy [18] (Goldman [33]; Johnson [41]; Leemrijse [50]; Rochwerger [63]; Skalley [69]; Tourne [70]). Weakening the lateral flexor hallucis brevis can result to a mechanical advantage to the medial structures including the medial head of the FHB and the abductor hallucis. Other procedures commonly implicated include the Keller Brandeis (Skalley [69]; Tourne 70) [71] scarf (Killmartin 2011; Leemrijse [50]), and Lapidus [52].

Clinical Presentation and Examination

The classic clinical presentation of hallux varus includes pain, multiplanar deformity, clawing, weakness of push-off during gait, and, in some cases, reduced motion or a rigid deformity. In many cases, the patient does not consider hallux varus a failure, but an oddity or unusual position as long as they can wear shoes. Frequently, a foot and ankle specialist will be the first to clarify that the position is not a normal expected outcome and represents a complication.

The patient is examined while both weight bearing and non-weight bearing. Gait evaluation is important to determine if the deformity is accentuated during the swing or stance phase and whether weight bearing magnifies the positional abnormality. A dynamic deformity is due to imbalance caused by altered function of the stabilizing intrinsic muscles after surgical correction. Static hallux varus is an osseous deformity due to overcorrection of the intermetatarsal angle or excessive resection of the medial bunion prominence and normal associated bone [43, 51].

Examination of the skin for surgical scars or suggestion of prior wound healing complication that could have resulted in residual infection is important. The pattern of lesion formation is an important consideration and may coincide with other areas of pain such as adjacent MTP joint pain or digital deformity due to dynamic changes in gait, altered pressure distribution, or associated deformities. It is important to assess the second MTP joint for stability as with first ray malalignment, there is frequently overload to the second MTP due to pressure transfer. Frequently with long-standing deformity, the lesser toes will begin to adduct at the MTP and can become difficult to reduce requiring surgical procedures to address them whether by osteotomy or MTP capsular release and rebalancing. The range and quality of motion to the first MTP and hallux IP joints are important when examining for potential degenerative changes in long-standing deformity. The ability to reduce the deformity manually and to maintain it in a corrected position is essential in determining whether potential exists for a soft tissue correction alone or whether osseous procedures are indicated. Medial column instability is important to assess as are proximal deformities such as gastrocnemius equinus or a planovalgus foot type that may result in first ray instability.

Classifications

Classifications previously described are not easy to follow and implement ([7], Skalley 69). A classification described by Tourne et al. [70] is broad and excessively simple. Hawkins [36] developed a classification which includes static or dynamic presentations. Static deformities tend to be asymptomatic, and dynamic presentations most commonly involve a multiplanar deformity and are symptomatic [62]. Alternative classifications describe the complexity of the deformity or simply the joint plane of involvement [42]. These classifications are descriptive only and have not been validated to predict prognosis or guide treatment and therefore are of limited utility. Most recently, Akhtar et al. [4] reviewed 402 patients who underwent scarf osteotomy for hallux varus. Four patients developed hallux varus postoperatively, and based on these patients, the authors propose a new classification system based on the anatomic factors that caused the deformity. Three categories are identified: (1) osseous, (2) myoligamentous, and (3) combined. Osseous deformities are treated by osseous reconstruction involving either reverse scarf osteotomy or bone grafting procedures. Myoligamentous causes are treated by nonsurgical management depending on the degree of symptoms and deformity or by tendon transfers. The authors state that for combined deformities, the appropriate response is to "treat the cause" without providing specific recommendations.

The role of nonoperative management is limited [7]. There are reports supporting an attempt at nonoperative care in deformities that are recognized early and remain flexible. Skalley and Myerson reported [69] 22% of patients avoided surgical intervention and improved clinically with combination therapy including taping, shoe modifications, and NSAIDS. Hallux varus can be a well-tolerated deformity when flexible, and deformities ranging between 8 and 15 degrees can be well tolerated with little clinical significance [46, 71]. In many cases, operative intervention is recommended if the deformity presents after 6–12 weeks and is progressive or unresponsive to nonoperative modalities.

Treatment

Early aggressive surgical management is paramount for a successful outcome; however, it is difficult to apply treatment algorithms due to the individual presentation of each deformity. The goal of treatment is realignment and restoration of motion with the end result being joint salvage when possible. However, arthrodesis is the treatment of choice in non-reducible deformities or when degenerative changes dictate. What is clear is that a lateral capsular repair alone is insufficient and that tendon rebalancing alone or in combination with osseous reconstruction is also necessary. There is strong support for MTPJ fusion resulting in a durable and mechanically stable foot which functions near normal in gait [discussed in detail in Chap. 15]. This coupled with the inconsistency of hallux varus deformity understanding and questions regarding the wide variety of approaches, one could make a strong argument for fusion in all cases of symptomatic or progressive hallux varus.

Soft Tissue Reconstruction

The difficulty is often in determining when a soft tissue correction alone is feasible. In general, a flexible deformity with a painless first MTP and no degenerative changes is the optimal presentation for attempt at soft tissue rebalancing (Graisek 2016). In mild deformities which are recognized early, surgical release of the medial capsule combined with tenotomy or release of the abductor hallucis may be sufficient [18]. However, when applying a stepwise approach to the deformity, complete reduction is often impossible and osseous techniques often become necessary. The preoperative informed consent and documentation should allow for broad categories of procedures should they become necessary. A thoughtful structured plan is important; however, the intraoperative course will dictate the final approach.

Multiple soft tissue reconstructive options have been described in the literature and are largely based on surgeon opinion. The current lack of strong outcomes studies leaves the surgeon with an abundance of confusion and concern as to which approach to take as we noted previously. Hawkins [36] first described a dynamic transfer of the abductor hallucis by releasing the tendon distally from the medial base of the proximal phalanx and the insertional fibers to the tibial sesamoid. The tendon was then passed from medial to lateral plantar to the metatarsal and deep transverse intermetatarsal ligament. The tendon was next passed through a drill hole from lateral to medial in the proximal phalanx and fixated with a biotenodesis screw [36].

Leemrijse et al. [50] described a reverse transfer of the abductor hallucis tendon which resulted in good outcomes but was limited to seven patients who met inclusion criteria. The American Orthopaedic Foot and Ankle Society (AOFAS) hallux metatarsophalangeal-interphalangeal (MTP-IP) score increased from 61 to 88.

EHL transfer was first described by Johnson and Spiegel [41]. The authors released the EHL tendon distally which was then passed from proximal plantar to dorsal distal under the deep transverse intermetatarsal ligament and repaired to the proximal phalanx after being appropriately tensioned. Since the entire EHL tendon is utilized, the authors recommend arthrodesis of the IP joint of the hallux to avoid deformity. Average follow-up was 37.5 months, and 10 out of 14 patients reported excellent results. As an adjunct to this technique, Gradisek and Weil [35] recommend attempt to repair the conjoined adductor tendon. Johnson et al. [42] later modified the EHL transfer by using a split EHL technique where the lateral half was transferred. IP joint arthrodesis was not included; however mild weakness of MTP extension was noted.

Lau and Myerson [47] also described a split EHL transfer, where the lateral half of the EHL was released proximally and attached to the first metatarsal distally after being passed under the DTIL. The authors did not feel that tensioning the tenodesis resulted in alteration of the first MTP joint mechanics. Goldman et al. [33] reported complete satisfaction in eight out of nine patients who underwent transfer of the entire EHL tendon (in five patients) or split EHL tendon (in four patients) with or without hallux IP joint arthrodesis. Diebold and Delagoutte [24] reported recurrent hallux varus in 2 out of 13 patients who underwent the technique described by Johnson with EHL transfer combined with hallux IPJ fusion. Valtin [72] described transfer of the first dorsal interosseous muscle.

One must question the feasibility of transfer under the deep transverse intermetatarsal ligament (DTIL) as it is often excessively scarred within the first interspace. The standard lateral release involves sectioning the DTIL during approach to the conjoined tendon of the adductor hallucis and metatarsal sesamoid ligament. While it is possible to restore the anatomy, dissection and transfer under the remnants of the ligament may be tedious.

Myerson and Komenda [54] described a static transfer involving an EHB tenodesis. The technique involves distal release of the EHB tendon which is then passed from distal to proximal deep to the DTIL. Next, the tendon is passed from lateral to medial through a first metatarsal osseous tunnel and secured with suture or a biotenodesis device. Excellent correction was maintained in all patients at an average of 27 months after surgery. A decrease in dorsiflexion (average 10 degrees) was noted; however no other complications were reported. A variation of the EHB tenodesis was described by Juliano and Campbell [43] which involved distal mobilization of the tendon and lateral to medial transfer via an osseous tunnel in the proximal phalanx. Six patients were included in the study, and all achieved an excellent outcome with AOFAS scores improving from 61 preoperatively to 85 postoperatively. Tourne et al. [70] described a technique of lateral ligament reconstruction using synthetic graft material reporting "excellent outcome" in all patients. Giza et al. (2014) expressed concern regarding potential for infection and high cost associated with synthetic graft application. Tourne and Saragaglia (1995) describe a simple technique of suture reconstruction of the lateral collateral ligament in five cases reporting excellent outcome in all cases at an average follow-up of 4 years. Pappas and Anderson reported correction of hallux varus deformity using a suture endobutton-type device to realign the hallux where it is tensioned to the necessary level for correction which is determined intraoperatively. Crawford and Patel et al. [21] reported potential complications with the technique which include breakage, hematoma, limited joint range of motion, frontal plane deformity, loss of correction, or fracture of the proximal phalangeal base.

Gerbert et al. [32] and Hsu et al. [37] also published isolated case reports that exist using endobutton suture devices with good outcomes reported.

Plovanich et al. [60] performed a systematic review including a total of eight studies which concluded that tendon transfer resulted in satisfactory outcomes for flexible hallux varus deformity; however the rate of postoperative complications was 16%. The studies that met inclusion criteria were almost exclusively level IV retrospective studies and one level V study. The authors indicated that sustainable correction of hallux varus deformity is possible with tendon transfer and release of soft tissue contractures. Despite the presence of an abundance of opinions regarding soft tissue repair of hallux varus, we still have no clear and consistent scientific information to guide our recommendations.

Osseous Correction

Overcorrection of the intermetatarsal angle or hallux abductus angle via osteotomies is a frequent cause of hallux varus. Overcorrecting the hallux abductus angle via aggressive or unnecessary Akin osteotomy can result in a medializing force applied by the flexor hallucis longus tendon. This can be corrected via a reverse Akin osteotomy [7]. In most cases, simply utilizing an osteotomy alone will be insufficient for correction, and a combination of osseous and soft tissue balancing procedures is necessary (Fig. 7.6). Lee et al. [49] reported a technique tip using a reverse

Fig. 7.6 (**a**) Preoperative AP radiograph of a 50-year-old female patient with moderate hallux abducto valgus deformity. (**b**) Initial postoperative AP radiograph 10 days status post modified chevron bunionectomy with lateral release. (**c**) Eight-week post-op AP radiograph demonstrating negative hallux abductus angle with medial deviation of the tibial sesamoid. (**d**) Six-week postoperative clinical view demonstrating mild hallux varus deformity. (**e**) Revision with sequential soft tissue release of MTP joint. Image demonstrates dorsal and medial capsulotomy first MTP joint. (**f**) First MTP joint complete with soft tissue release including dorsal, medial, and plantar medial capsulotomy. (**g**) Despite complete soft tissue release, clinical hallux varus deformity remains. (**h**) Reverse chevron osteotomy completed with medial shift of the capital fragment. (**i**) Reverse chevron complete with medial displacement of the capital fragment. (**j**) Fixation of the reverse chevron osteotomy with a 3.0 mm cannulated cancellous bone screw. (**k**) Twelve-week postoperative radiograph of revision via complete sequential soft tissue release and reverse chevron osteotomy. Congruent joint is noted; however fibular sesamoid is laterally deviated. (**l**) Three-month postoperative clinical appearance with rectus-appearing joint

chevron osteotomy where the osteotomy is recreated and the capital fragment is translated medially to reduce the negative relative correction to the intermetatarsal 1–2 angle. Rochwerger et al. [63] described the use of a medial bone graft to restore more appropriate anatomy when an excessive medial bone resection has occurred. This was thought to improve function of the tibial sesamoid. They reported no recurrences with good motion in seven cases at an average follow-up of 8.6 years. Kannegieter and Kilmartin [44] described a reverse scarf procedure with a proximal opening wedge of the proximal phalanx reporting excellent patient satisfaction in five cases. Choi et al. [14] reported a reverse biplanar chevron incorporating a lateral-based wedge in the osteotomy for angular correction. Patient satisfaction was high with only 1 patient out of 19 reporting dissatisfaction; however there were two recurrences.

Arthrodesis is a definitive procedure for management of hallux varus. The procedure is reproducible and results in a high degree of patient satisfaction with symptomatic nonunion rate of 1.8% [64]. The selection of fusion is based on the degree of pain, presence of degenerative changes, time, and reducibility. Time can be a variable indication as some patients may have moderate to significant degenerative changes despite a short period of deformity ([18, 70], Skalley [69]).

In conclusion, nonoperative care has a small role in the management of an iatrogenic hallux varus deformity. The ultimate solution is best determined by intraoperative assessment, as these findings do not always match the clinical and radiographic parameters. Isolated soft tissue release of medial contractures is insufficient and leads to a high degree of patient dissatisfaction. While many variations of tendon transfer have been reported with good results, the cohort size in these studies is generally small, and it is difficult to draw meaningful conclusions as to their long-term efficacy. Osseous correction by reversing the deforming force restores the deformity to some degree and, while reliable, may result in patient dissatisfaction. In general, combining osseous reconstruction with tendon transfer will lead to a high degree of patient satisfaction. When the deformity is long-standing, non-reducible, or demonstrates limited painful range of motion with degenerative changes, a first MTP arthrodesis offers the most definitive solution and results in significant improvement in objective outcome scores. Taking into consideration the diversity of opinions and level of evidence regarding repair of hallux varus and the contrasting good results with fusion across a wide patient population, we conclude that arthrodesis represents a strong choice for repair.

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8 Phalangeal Osteotomy Procedures

Michael H. Theodoulou and Laura Bohman

Background

Proximal phalangeal osteotomy for correction of hallux valgus was first introduced in 1925 by O.F. Akin [1]. He presented a medial closing base wedge osteotomy performed at the proximal metaphysis of the proximal phalanx of the great toe. Since that time, the osteotomy has been shown to be executed at all levels of the proximal phalanx, which includes the proximal and distal metaphysis and diaphysis. It has been presented as a closing and opening wedge-type osteotomy, rotational osteotomy, shortening, and even dorsiflexing for hallux limitus/rigidus condition. The osteotomy has been executed in traditional open surgical fashion as well as in minimal incision approach. Fixation methods have included no stabilization, sutures, percutaneous Kirschner wire, monofilament wire, staple, surgical screw, and plate. The intent of the procedure is to correct valgus angulation intrinsic to the proximal phalanx prompting the great toe to deviate contributing to the formation of a bunion. Each technical approach has espoused benefit from the standpoint of ease of performance, correction of deformity, maintenance, and stability of correction. It is critical to understand the limitations of this procedure. Given that it is executed distal to the metatarsophalangeal joint, structural deformity can only be corrected at this level. Any proximal deformity will be neglected, and if not addressed, the execution of an Akin-type osteotomy procedure alone may in fact worsen the presentation [2]. However, the influence of realignment phalangeal osteotomy may influence vectors of pull to the attaching flexor and extensor tendons that can alter proximal deformity through retrograde forces applied to the metatarsophalangeal joint. Postoperative management of this procedure is consistent with any other skeletal osteotomy to include protection with varying levels of immobilization and weight-bearing based on concomitant procedures and technique employed. Complications are not limited to but can include postoperative wound healing disturbance, infection, malunion and nonunion deformity, hardware-induced and secondary arthrosis of surrounding joints. When appropriately performed, the procedure can provide excellent outcomes assisting in the realignment of the metatarsophalangeal joint and improved function of the first ray.

Preoperative Evaluation

Workup for hallux valgus deformity requires a thorough historical evaluation of the patient to include understanding of chief complaint, medical

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history, prior surgeries that may be related, and familial and social history. A comprehensive physical examination of the patient and involved lower extremity both in an open and closed kinetic presentation is critical. Finally, appropriate radiographic imaging is necessary to identify centers of rotational and angular deformity, joint status, as well as quality of bone.

Patient history is directed toward progression of deformity, duration, impact to quality of life, measures that have been employed to relieve symptoms, and factors that exacerbate the deformity and condition. Understanding the patient's expectations regarding activity level, pain relief, use of desired footwear, and esthetic implications is essential. It is imperative to identify medical history particularly those conditions relevant to surgical wound healing. Social circumstances to include any substance use that may be detrimental to healing such as tobacco and excessive alcohol should be identified.

A routine physical examination of patient should be considered with emphasis to the lower extremity to neurovascular well-being and biomechanical considerations evaluated both in open and closed kinetic chain (Figs. 8.1 and 8.2). Appreciation of those disturbances that may influence presentation of deformity and sustainability of repair when correction is performed should be documented. Relative contraindications to this procedure include but are not limited to include poor arterial perfusion, poor bone quality, surrounding joint arthrosis, and lack of intrinsic deformity of the proximal phalanx contributing to hallux valgus.

Fig. 8.1 Open exam of hallux interphalangeal deformity

Fig. 8.2 Closed exam of hallux interphalangeal deformity with increased valgus rotation and hallux hammer toe

Radiographic Imaging

Radiographic findings are one objective component for determining whether phalangeal osteotomy will be needed for correction of the hallux valgus deformity. Evaluation of the proximal phalanx in relation to the first ray and distal phalanx has been established through plain film radiographs particularly in the anterior-posterior view. The intermetatarsal angle (IMA) is commonly measured and has been associated with the severity of the deformity with normal values variably reported but commonly said to be less than 8° [3]. The issues surrounding radiographic evaluation are discussed in Chap. 5. As an accepted rule, proximal phalangeal osteotomies are not appropriate sole procedures to correct

Fig. 8.3 Hallux interphalangeal angle

Fig. 8.4 Distal articular set angle (*DASA*): angle measured from a perpendicular bisector of the articular surface with the long axis of the proximal phalanx [4]. Normal values for PASA and DASA are approximately 0–8°

hallux valgus. The higher the intermetatarsal angle, the greater the need for correction of the bunion by a first metatarsal procedure. The relationship of the long axis of the proximal phalanx to that of the first metatarsal has been identified as the hallux abductus angle (HAA) with generally accepted normal value of 15° [4]. The hallux interphalangeal angle (HIA) is established between the long axis of the proximal phalanx in relation to that of the distal phalanx and is found to be 10° abducted in the normal presentation [4] (Fig. 8.3). The distal articular set angle (DASA) is the angular relationship of the articular surface of the base of the proximal phalanx to the long axis of phalanx and is normally established to be 7.5° [4] (Fig. 8.4). DASA correlates with a proximal deformity in the phalanx. An increase in the HIA can represent an intraosseous deformity of the proximal phalanx which would not be corrected without a phalangeal osteotomy. Rettedal et al. suggested another way to assess for an intraosseous proximal phalanx deformity by radiographically measuring the length of the medial and lateral cortices of the phalanx. If there is a longer medial side, a proximal phalanx osteotomy may be necessary to fully reduce the bunion deformity and produce a rectus toe [5]. However, it is imperative to note that as the hallux valgus angle increases, the hallux rotates in a valgus direction which can skew measurements [5].

Surgical Technique

Indications for a proximal phalangeal osteotomy should be considered specific to correct proximal phalanx incongruities versus bunion correction. After the metatarsophalangeal joint has been corrected and is congruent, the toe should be examined. An increase in DASA represents an incongruity of the cartilage of the base of the phalanx and would be better corrected with a proximal osteotomy. If the deformity exists in the hallux interphalangeal joint, the deformity is likely to be intraosseous, and correction should occur distally in the phalanx [5].

If the proximal phalanx osteotomy is being performed along with a metatarsophalangeal joint dissection, the incision is usually elongated to provide adequate exposure of the phalanx. This can be performed in either a dorsal medial or direct medial approach (Fig. 8.5). Care is taken to avoid the dorsal medial and plantar cutaneous nerves (Fig. 8.6). For a proximal correction, a proximal medial closing wedge is usually performed in the metaphyseal bone anywhere from 5 to 10 mm away from the articular surface [3] (Fig. 8.7). Care must be taken to avoid penetration into the articular surface of the base of the proximal phalanx. The thickness of the wedge depends on the amount of correction needed. The saw blade is generally accepted to take 1 mm of bone with each cut, and this should be considered in the size of the wedge. The distal cut is made perpendicular to the long axis of the phalanx, and proximal cut should be made parallel with the articular surface. Using this methodology, no calculations for wedge size are needed, and the deformity is corrected relative to adjacent structures. Shannak et al. performed a study to determine the width of the base wedge needed for specific angular corrections. They suggested for an approximate 10° correction, a wedge with a base of 3 mm of bone in men and 2.5 mm in women should be removed [6]. It should be noted that radiographic findings are two dimensional and may not represent the true 3D deformity; therefore the technique using adjacent structure landmarks may be more reliable. The wedge is removed, and the lateral cortex is gently feathered to allow the osseous gap to be reduced with gentle compression (Fig. 8.8). The axis guide of the cut should remain perpendicular with the weight-bearing surface to prevent dorsiflexion or plantarflexion translation when the wedge is closed [3]. Fixation is then employed per surgeon preference. Often, a medially placed staple is used to secure stability (Figs. 8.9 and 8.10).

A distal medial closing base wedge adheres to the same principles as a proximally performed osteotomy. It is also performed 5–10 mm away from the interphalangeal joint with the apex lateral and base medially oriented and axis perpendicular to the weight-bearing surface. This is commonly employed to address increases in HIA (Fig. 8.11).

Fig. 8.5 Medial incision approach to the proximal phalanx and metatarsophalangeal joint

Fig. 8.6 Protection of the dorsal and plantar medial nerves

A modified medially based closing wedge osteotomy extended obliquely through the shaft of the proximal phalanx with the lateral apex either distal or proximal allows for easier screw placement across the osteotomy site but usually increases surgical dissection for exposure [3] (Fig. 8.12). Cohen introduced the performance of an oblique osteotomy through the proximal phalanx from proximal dorsal to distal plantar [7]. Similar to the Ludloff procedure performed of

Fig. 8.7 Medially based proximal wedge osteotomy

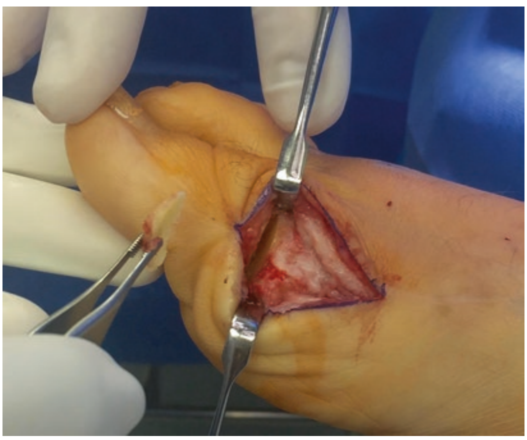

Fig. 8.8 Wedge excised preserving lateral cortical hinge

Fig. 8.9 Closed osteotomy fixated with single medial staple

Fig. 8.10 Intraoperative fluoroscopic image of staple fixation

the first metatarsal for correction of intermetatarsal angle [8], osteotomy introduced in this fashion allows for medial translation of the capital fragment of the proximal phalanx and facilitates dorsal screw placement for fixation (Fig. 8.13). It also mitigates shortening of the phalanx which is seen with wedge excision.

Although phalangeal osteotomies are frequently performed for transverse plane abduction deformity of the proximal phalanx, they have also been utilized in management of hallux limitus/rigidus as well as to shorten the great toe for congenital malformations such as macrodactyly. In hallux limitus/rigidus, it is often used to augment cheilectomy of the metatarsal phalangeal joint (Fig. 8.14). It is reserved for moderate to severe deformity in active young patients with limited dorsiflexion and normal plantarflexion.

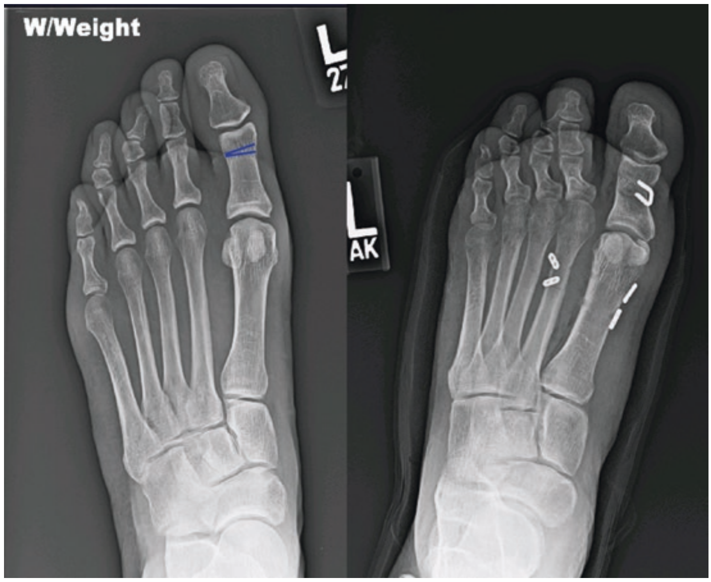

Fig. 8.11 Distal Akin osteotomy to address HIA

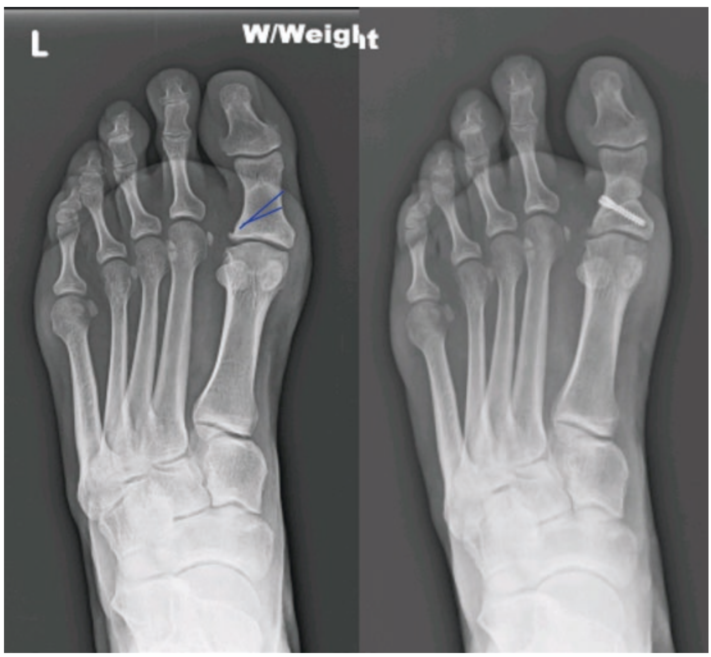

Fig. 8.12 Oblique wedge osteotomy to facilitate screw placement

Exposure is similar to traditional Akin procedure; an axis guide is placed parallel to the proximal articular surface as close to the joint surface from medial to lateral. This may be done fluoroscopically to ensure one is extra articular. Performance of proximal osteotomy as closed to joint as possible ensures maximal dorsiflexion can be achieved. The first cut is made parallel to the joint distal to the guide pin preserving the plantar cortex (similar to lateral cortex for Akin). The second cut is made 2–4 mm distal to the first and angled to converge plantarly with the first, again not embarrassing the plantar cortical hinge. The wedge is excised and fixation completed

Fig. 8.13 Sagittal oblique osteotomy in this case performed from proximal plantar to distal dorsal

Fig. 8.14 Hallux equinus with dorsiflexed and elongated first ray producing joint narrowing and limitus

(Fig. 8.15). It is felt that this procedure essentially steals from present preserved plantarflexion motion of the joint and adds to dorsiflexion by shifting the functional range of motion [9]. It also potentially decompresses the joint by shortening the phalanx with wedge excision of bone. Corrective osteotomies of the proximal phalanx can also assist in management of structural length pattern deformities such as in macrodactyly (Fig. 8.16). A cylindrical wedge is used to evenly shorten the proximal phalanx and fixated with dorsal plate. This was done in conjunction with shortening first metatarsal osteotomy (Fig. 8.17).

Postoperative Protocol and Complications

After fixation, the incision is closed in layers, and a sterile dressing is applied. Depending on concurrent procedures, healing and weight-bearing status varies. For the proximal phalanx osteotomy with stable fixation, a patient can bear weight in a protective boot for approximately 6 weeks or until radiographic signs of healing are appreciated. Complications related to a proximal phalangeal osteotomy can be instability of fixation, breaking of the lateral or plantar hinge, malunion, nonunion, shortening of the toe, fracture of the articular surface, and plantarflexion angulation of the correction [10].

Literature Review

It is generally accepted that a proximal phalanx osteotomy should not be the sole correction for a bunion deformity. However, there is literature supporting this concept. Between 1967 and 1971, Seelenfreund et al. performed 150 medially base wedge osteotomies of the proximal phalanx. Exclusion criteria for the procedure included

Fig. 8.15 Post-op dorsiflexing wedge osteotomy of proximal phalanx fixated with crossed K wire

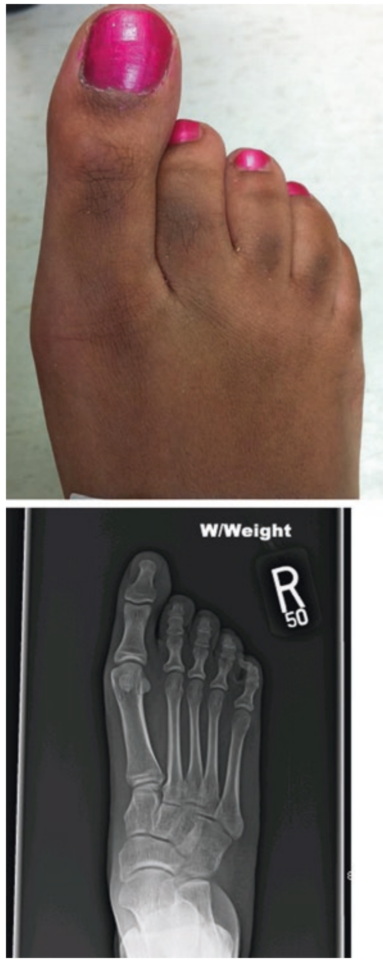

Fig. 8.16 Macrodactyly

deformities over 40° at the metatarsophalangeal joint and joint motion limitation. They followed 32 patients up to 3 years after procedure. They found that only five patients had recurrence of deformity [11].

In contrast, Goldberg et al. performed a 10.7-year follow-up of 222 patients who received a phalangeal osteotomy for bunion correction. Seventy-five percent of patients had a poor clinical appearance. They found 14% of patients developed dorsiflexion of the great toe, recurrence of deformity in 21%, and limited joint range of motion in 90%, and only 53% of patients were satisfied with their outcome. They felt the procedure did not address the actual bunion deformity and concluded that this procedure should only be used in combination with correction to realign the metatarsophalangeal joint [12]. Shibuya et al. compared bunion correction by distal first metatarsal osteotomy or first tarsometatarsal joint fusion with and without medial closing wedge osteotomy. They found that Akin osteotomies were used more to aid in correction of severe bunion deformities with a higher tibial sesamoid position. Overall, they found questionable results to any additional value to the procedure as there was no association of the use of an Akin osteotomy with decreased complication rate such as revision surgery [13].

Regarding dorsiflexing osteotomy for hallux rigidus, there is limited high-level evidence for this procedure. A meta-analysis of 11 studies performed by Roukis over a 17-year period and sample size of 374 joints demonstrated a low revision rate of 4.8%; a high patient satisfaction rate of 77%, with pain being eliminated or improved in

Fig. 8.17 Correction with shortening of first metatarsal and proximal phalanx. Phalangeal osteotomy fixed with dorsal plate

89%; and AOFAS metatarsophalangeal-interphalangeal score improvement of 39 points [14].

Summary

Phalangeal osteotomies may provide an adjunct correction to a hallux valgus deformity, but does not provide deformity correction as a sole procedure. It is an appropriate procedure for intraosseous deformity of the phalanx or increased HIA. It can also be used to assist in esthetic correction of congenital deformity such as macrodactyly.

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9 Distal Metatarsal Osteotomy and Capsular Balancing

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Background

Distal first metatarsal osteotomies have been used for decades as a corrective procedure for a wide array of pathologies of the first metatarsal-phalangeal (MTP) joint. These osteotomies are used for correction of hallux abducto valgus (HAV) and hallux rigidus (HR) by realigning and decompressing the MTP joint with countless variations presented in the literature [1–4]. The primary goal of DMO is to address the pathologic biomechanical and structural abnormalities inherent to HAV at a distal level, and based on this premise, several broad classes of procedures have evolved. We will discuss three key subclasses of DMO: (1) Reverdin style, (2) Mitchell style, and (3) Chevron osteotomies. It is not the aim of this chapter to review all modifications of the distal first metatarsal osteotomy, but rather to review the mechanical and surgical characteristics of the more common osteotomies.

HAV deformity is traditionally considered a progressive biplane deformity, existing in both the transverse and frontal plane where the proximal phalangeal base of the hallux articulates with the first metatarsal head [4]. Typically, the proximal phalanx drifts into abduction and pronation, while the first metatarsal undergoes abduction, pronation, and elevation. As the structural deformities of the bones progress, adaptive changes of the surrounding soft tissue structures simultaneously occur. This ultimately leads to contracture of the lateral joint capsule and attenuation of the medial joint capsule. Therefore, it is essential to recognize this deformity as both structural and positional [4]. For this reason when selecting a distal procedure, both osteotomies and soft tissue reconstruction, including lateral release of contracted soft tissues and medial capsule reefing, are required for a comprehensive correction.

Capsular Balancing

We will first discuss soft tissue procedures that are necessary to address the contracted and attenuated soft tissue surrounding the first MTP joint when a distal osteotomy is selected. Our preferred incisional approach for both the osteotomy and the soft tissue procedures is a medial midline incision. Although a dorsal incision is quite common, we prefer the medial midline because it provides superior exposure, minimized soft tissue striping, protection of the intrinsic blood supply, and pleasing cosmetic results. Additionally, having the scar medial avoids loss of motion that can be a component of dorsal incisions if significant

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scarring occurs. With the medial approach, the scar tissue which is less elastic is not in the plane of motion like with the dorsal approach, and therefore scarring, if it occurs, does not inhibit motion as much. Since distal procedures are intraarticular, fibrosis and scarring are an expected component of healing, and all efforts should be made to limit the effects on joint function.

A joint demonstrating a primarily positional, reducible deformity has been suggested to be amenable to soft tissue rebalancing combined with medial eminence resection, medial capsule reefing, and a DMO [5]. A sequential lateral release is performed to remove the pathologic contracture of the soft tissues and restore neutrality to the joint. A traditional lateral release consists of adductor tendon release/transfer, lateral capsulotomy, and lateral suspensory ligament release with an occasional need for flexor hallucis longus recession [6]. Fibular sesamoidectomy was historically also included as part of this release but is rarely used in contemporary practice. In some cases we perform the lateral soft tissue release through an ancillary incision made along the dorsal aspect of the first webspace. This incision is deepened to the investing fibers of the dorsal hood. At this level the transverse fibers of the deep transverse intermetatarsal ligament are identified and transected to gain access to the lateral head of the adductor tendon (Fig. 9.1). The release of the adductor tendon is performed at the base of the proximal phalanx, which provides an adequate length to the tendon for potential transfer. However, the location of the transection is not as critical if the adductor tendon is not being transferred. A 15 blade can be inserted into the lateral capsule and brought superiorly to resect the lateral suspensory ligament of the fibular sesamoid. The hallux should be stressed in varus to test for complete release. If insufficient reduction is noted after release of the lateral suspensory ligament, then one should consider release of the lateral head of the flexor hallucis brevis tendon. Further varus testing should be performed following release of the tendon. In the event of persistent contracture, a fibular sesamoidectomy has been recommended [7]; however, the authors rarely find this procedure necessary. Additionally, the authors also avoid adductor tendon transfer to mitigate the risk of varus [8]. A retrospective study by Kalish et al. showed that individuals with an intermetatarsal angle (IM) less than 15° who underwent DMO and adductor tendon transfer were at increased risk of developing a postoperative varus deformity [8]. This suggests that adductor tendon transfer may only be indicated in situations where a distal procedure is being used for aggressive IM correction. Caution should be taken when balancing the MTP capsule, as seemingly minimal correction can produce hallux varus.

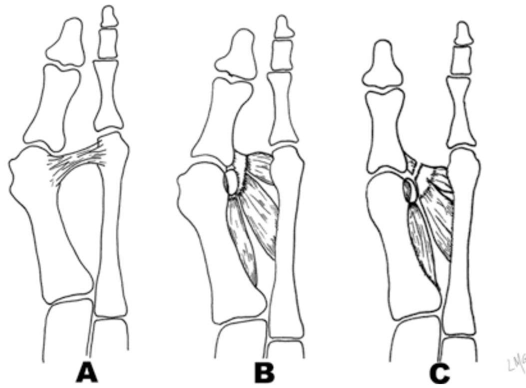

Fig. 9.1 Anatomic structures of interest during release of the adductor tendon. (**a**) Represent the deep intermetatarsal ligament, which requires transection to access the adductor tendon. (**b**) Identification of the shared head of the adductor tendon as it inserts on to the lateral condyle of the proximal phalanx. (**c**) The insertion site of the adductor hallucis tendon is transected at the proximal phalanx base. The tendon may be left or later transferred to medial capsule of the hallux

The authors will often perform a lateral release through a medial approach. Many of the contracted lateral structures, especially for moderate deformities, can be accessed through a medial incision releasing the lateral structures through the joint itself. The intersesamoid ligament is first identified and transected; further release is performed as needed to provide mobility in the transverse plane at the MTPJ.

Distal Metatarsal Osteotomy Modifications: Reverdin Style

The Reverdin style osteotomies are considered in patients with mild to low-moderate IM angle deformity (12–15°) and a subluxed MTP joint [9]. For the purpose of this text, we will define a Reverdin style osteotomy as any procedure of the distal metatarsal, which serves to correct an abnormal proximal articular set angle (PASA). A mild sagittal plane deformity can also be treated with Reverdin style osteotomies; however, correction may not be as dramatic as with other procedures. Adequate joint space with pain-free range of motion is required for improvement of functional outcomes utilizing this technique. Moreover, despite the inherently stable nature of the Reverdin osteotomy, adequate bone stock with the capacity to heal is also important.

The Reverdin procedure, first described in 1881, depicts a trapezoidal osteotomy made in the metaphyseal region of the first metatarsal head [10]. This medially based wedge, made at the level of the sesamoids, acts to adduct the capital fragment and realign the proximal articular cartilage. Hinging the distal articular fragment effectively corrects an abnormal proximal articular set angle (PASA) and realigns the hallux from its valgus orientation via reverse buckling [11] (Fig. 9.2). Several variations have been made to the Reverdin technique with distinct differences in anatomic location and orientation of osteotomies. With the addition of angulation to the osteotomy and plantar-based wedge resection, the Reverdin can produce both IM correction and plantar flexion. The osteotomy is positioned with the distal cut parallel to the articular cartilage and the proximal cut perpendicular to the long axis of the first metatarsal. Maintaining the lateral cortex will provide added stability.

Modifications to the osteotomy have produced multi-correctional capabilities (Reverdin-Green, Reverdin-Laird, and Reverdin-Todd). In 1977, Green described a modification that avoids possible damage to the dorsal articular surface of the sesamoid groove (Fig. 9.3) [12]. In 1988, Laird described a transcortical osteotomy, which penetrated the lateral cortex of the metatarsal head, allowing transposition of the capital fragment with relative reduction of the intermetatarsal angle (Fig. 9.4) [13]. Today, Reverdin style procedures are seldom performed in isolation and are usually a component part of HAV reconstruction. Lombardi et al. recommend the use of Reverdin procedures with basal or Lapidus type procedures as a method to address abnormal PASA [14]. Isolated Reverdin procedures have been largely replaced by aggressive soft tissue reconstruction or more aggressive osteotomies of the first ray; however, the recent emergence of percutaneous Reverdin procedures has continued

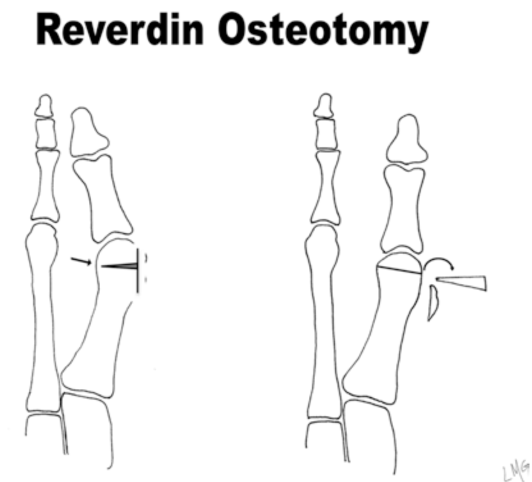

Fig. 9.2 Reverdin osteotomy begins with a resection of the medial eminence and is followed by a medially based wedge, which does not extend into the lateral cortex (as noted by *arrow*). Once medial based wedge is removed the distal fragment is rotated correcting the valgus orientation of the proximal articular surface and hallux

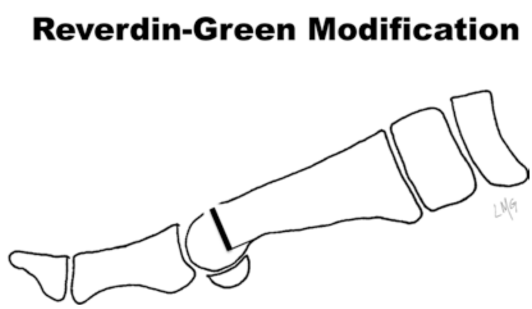

Fig. 9.3 Reverdin-Green modification aims at producing a protective shelf to sesamoid articular surface

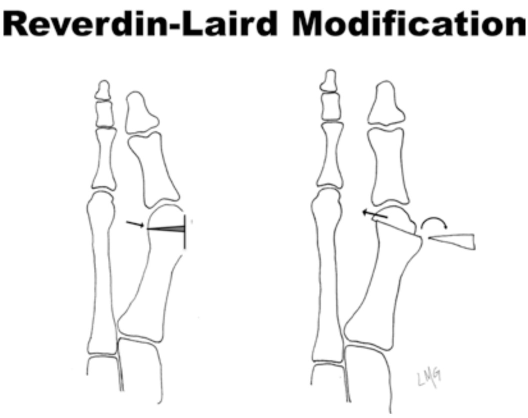

Fig. 9.4 Reverdin-Laird modification begins with a resection of the medial eminence and is followed by a medially based wedge, which does extend into the lateral cortex (as noted by *arrow*). Once the medial based wedge is removed, the distal fragment is translated laterally, correcting the valgus orientation of the proximal articular surface and improving the IM angle

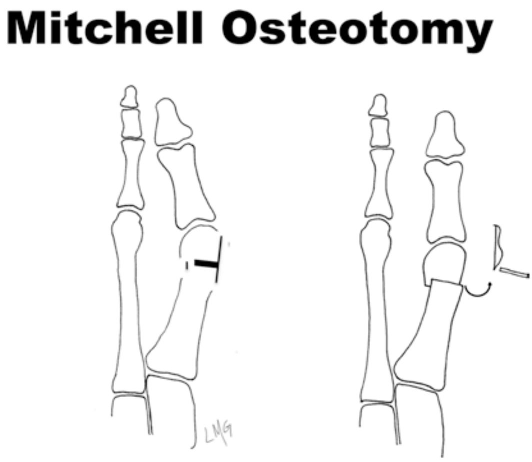

Fig. 9.5 The Mitchell osteotomy takes use of a step-cut to transfer the metatarsal head laterally. Because this osteotomy removes 4–5 mm of bone it shortens the first metatarsal much more than other DMO procedures and may lead to associated complications

Fig. 9.6 A plantar-based wedge taken in the sagittal plane aids in plantar flexion of the distal fragment. This increases weight bearing to the first metatarsal head and rotates the articular surface plantarly

to make this a relevant topic within the foot and ankle literature [15]. Although these multiplanar modifications have been described and have appeal, the exact degree of deformity correction in each plane may indeed be minimal. Solid evidence regarding the mechanical and functional outcomes is not available.

Distal Metatarsal Osteotomy Modifications: Mitchell Style

The Mitchell style osteotomies (Fig. 9.5) are considered in patients with mild to low-moderate IM angle deformity (12–15°). For the purpose of this text, we will define a Mitchell style osteotomy as any procedure of the distal metatarsal, which serves to correct an abnormal IM angle while attempting to reestablish normal load sharing to the forefoot [16]. Mild sagittal plane deformity can also be treated with Mitchell style osteotomies; however, correction may not be as dramatic as with other procedures. Adequate joint space with pain-free range of motion is required for improvement of functional outcomes utilizing this technique. Additionally, adequate bone stock with the capacity to heal is also important.

First defined in the literature by Hawkins et al. in 1945, this osteotomy describes a step-cut through the neck of the metatarsal used to reduce the intermetatarsal angle [16]. It was not until 1985 that Mitchell modified this technique to allow for the addition of plantar flexion to the capital fragment. This was achieved by the removal of a plantar-based wedge from the step-cut (Fig. 9.6). This osseous "wedge" removal often results in an excessively short first metatarsal. Merkel et al. performed a retrospective analysis of patients who underwent Mitchell osteotomies and found that 86% of patients were satisfied despite significant metatarsal shortening of greater than 5 mm [17]. The initial aim of the Mitchell modification was to reduce the incidence of transfer metatarsalgia seen in other IM corrective procedures. Transfer metatarsalgia is a potential concern with any osteotomy that may reduce metatarsal length; however, the subtle plantar flexion of the capital fragment has been suggested to offload the adjacent metatarsal heads. Nevertheless, a study by Heerspink et al. showed no significant reduction in transfer metatarsalgia when compared to Chevron osteotomy and found a significant shortening in first metatarsal length [18]. Furthermore, Shapiro and Heller noted transfer metatarsalgia in nearly 33% of patients who underwent a Mitchell procedure [19]. In their series, they found that individuals with a metatarsal 4–5 mm shorter than their second metatarsal were at increased risk for developing transfer metatarsalgia. The inherent instability of this osteotomy makes it necessary to consider non-weight bearing and even casting to prevent displacement. This factor along with the potential for shortening and lateral overload has made this procedure less popular within the foot and ankle community.

Distal Osteotomies: Chevron Style

Austin, Leventon, and Coreless first described the Chevron osteotomy, also referred to as an "Austin procedure," in 1962 [20]. Their technique describes a V-shaped osteotomy with the apex distal, within the metaphysis of the metatarsal head, used for the sole purpose of IM correction. This transcortical osteotomy utilizes a 60° horizontally directed V-shaped cut for lateral displacement of the capital fragment. The authors described the inherent stability of the Chevron osteotomy as a major advantage. It requires no fixation and allows for early weight bearing without casting. For added versatility, several modifications have been introduced which have improved fixation capabilities and stability. Modifications of the Austin have allowed for correction of PASA, plantar flexion of the hallux, and shortening or lengthening of the metatarsal. When multiple deformities are corrected within the same plane, the osteotomy is termed a *bicorrectional Austin*. In contrast, when deformity is corrected in multiple planes (transverse, sagittal), the osteotomy is called a *biplane Austin*. As with the other osteotomies described, the overall amount of accessory plane correction may or may not be robust. There are no current modifications to the Austin that address frontal plane deformity.

Chevron Modifications

In 1982, Youngswick et al. proposed an osteotomy that would correct for metatarsus primus elevatus by plantar flexing the capital fragment [21]. The Youngswick modification acts as a biplane correction as it plantar flexes the metatarsal and simultaneously corrects the IM angle. A standard 60° Chevron is the basis for the Youngswick modification. A second, more proximal dorsal cut is then made parallel to the initial, effectively removing a small segment of bone (Fig. 9.1). This results in shifting the metatarsal head proximal and plantar to offload the MTP joint. The resultant metatarsal is shortened and slightly plantar flexed, which is theoretically self-protective against transfer metatarsalgia.

The Kalish modification is a commonly employed variation of the Chevron osteotomies [9]. This modification was designed to address some of the limitations of the classic Austin procedure, namely, fixation and stability. To aid in fixation, the dorsal arm of the Kalish modification is lengthened, penetrating the dorsal cortex along the mid-diaphysis region (Fig. 9.7). The arm should be long enough to accommodate two 2.7 mm screws. Additionally, the angulation of the Chevron cut is decreased to 55°, which is more inherently stable than the traditional 60° cut. In a study performed by Kalish et al., they found high patient satisfaction and minimal recurring in individuals who underwent the Kalish modification. They attribute their low recurring rate to rigid internal fixation of their osteotomy, which was previously not performed in standard Chevron procedures. Scarf osteotomies are often considered a further modification.

Fig. 9.7 Modifications of the Chevron osteotomy. The Kalish modification has an extended dorsal arm and an internal apical angle of 55°. Youngswick modification removes a small trapezoidal portion of bone dorsally to both shorten and plantar flex the metatarsal head

However, this is considered a shaft osteotomy, which is covered in Chap. 13.

The Chevron cut can be modified to address sagittal plane deformity by adjusting the cut in the sagittal plane. An axis guide aids in positioning an osteotomy and can produce both shortening and lengthening, as well as dorsiflexion and plantar flexion of the metatarsal. The ability to manipulate the distal fragment of the first metatarsal is dependent upon the position of the axis guide. An axis guide positioned toward the fourth metatarsal will produce shortening of the metatarsal upon lateral translation, whereas an axis guide positioned toward the second metatarsal will produce lengthening upon lateral translation (Fig. 9.2). Typically, one will sacrifice a corresponding amount of transverse plane (IM correction) when combined with length modification.

Axis guides can also be used to control sagittal plane position by altering placement. Plantar flexion can be achieved by directing the guidewire in a plantar direction. Dorsiflexion can also be achieved by dorsally directing the wire; however, this is rarely necessary for HAV reconstruction. Similar to manipulating metatarsal length through the guidewire, one will sacrifice some component of transverse plan correction.

Preoperative Considerations

Subjective criteria for DMO include progressive pain confined to the medial bump, pain predominately when wearing shoes, and recent progression in the deformity. The patient may demonstrate neuralgia to the first dorsal digital nerve and its distributions. The authors will also consider DMO in patients that may objectively require a more proximal procedure for ideal intermetatarsal correction, but cannot tolerate non-weight bearing. Some surgeons consider DMO a reasonable option in those patients that cannot afford the extended convalescence associated with more proximal procedures. It must be noted that overall corrective result may not be equivalent to alternative procedures depending on the degree and configuration of the deformity.

Objective criteria for selection of DMO include a moderate deformity, pain-free first MTP range of motion, and a reducible deformity. The authors prefer DMO in patients with a stable forefoot where the first ray is stable without clinical signs of lateral forefoot overload (tender second MTP joint, hyperkeratosis plantar to the lesser metatarsal heads, global hammertoe deformities, etc.). Additionally, we prefer DMO when there is no significant evidence of hind foot pathology (equinus, flatfoot deformity, etc.) that might result in recurrence. These patients are better managed with more proximal procedures that might be more durable in the presence of hind foot pathology. Otherwise, one may consider addressing hind foot pathology concomitantly with a DMO in this situation. Additionally, as noted above this osteotomy does not provide for frontal plane axial correction which should be assessed preoperatively.

Preoperative radiographs are essential in planning a distal metatarsal procedure. Traditionally, DMO has been recommended for mild to moderate intermetatarsal angle (12–15°) with a deviated to subluxed metatarsal-phalangeal joint (HAA < 30). First intermetatarsal angles of 12–15° demonstrate good patient satisfaction and less reoccurrence. The author's primary radiographic parameter when considering DMO is first metatarsal head width. Metatarsal head width will be the limiting factor in the amount of translation of the capital fragment and the degree of correction obtained with a DMO. Patients with relatively wide metatarsal heads will have the capacity for greater correction, regardless of the IM angle. The opposite is true for thin metatarsal heads, where excess lateral displacement of the capital fragment can result in an unstable osteotomy.

Contraindications

Although the majority of contraindications are relative, they nonetheless will affect outcome. DMO is not recommended when the distal metatarsal area is narrow or thin. As previously described, there will be insufficient capacity for lateral translation with subsequent under-correction. Otherwise, attempting to "push" the translation beyond its limits will result in instability and possible dislocation of the capital fragment. Traditionally, DMO has not been recommended for IM angles greater than 16°. However, this is a relative contraindication, depending on the aforementioned factors. Other contraindications include forefoot instability, a skeletally immature foot, and advanced degenerative joint disease of the first MTP joint. There is very little scientific evidence to support a minimum or maximum level of deformity as an indication for DMO. For the most part the decision is based on individual surgeon preference.

Technique

Medial Approach and Exposure of First Metatarsal Head

The patient is placed on the OR table in a supine position in preparation for sedation and local field block. A bump is placed on the ipsilateral hip to align the tibial tuberosity directly anterior. Furthermore, another small bump is placed under the ankle to suspend the foot. This facilitates retraction, especially for a medial approach. A medial incision located between the dorsal and plantar nerves is made through the skin to the level of the subcutaneous tissue centered along the first metatarsal, beginning at the distal two-thirds of the metatarsal diaphysis and extending approximately 1 cm past the MTP joint (Fig. 9.8). The medial capsular tissue is exposed with very little dissection or undermining. An inverted L-shaped capsular incision is made with the long arm central along the metatarsal neck and the short arm positioned just proximal to the joint (Fig. 9.9). A capsulorrhaphy is performed by making a second incision parallel to the vertical arm and excising the diseased, attenuated medial capsule and collateral ligaments. This technique results in transverse plane realignment following closure. The capsular incision can be extended distally (converted to a T-shape) to permit easier access to the joint. The capsule is dissected

Fig. 9.8 Medial incision centralized along metatarsal

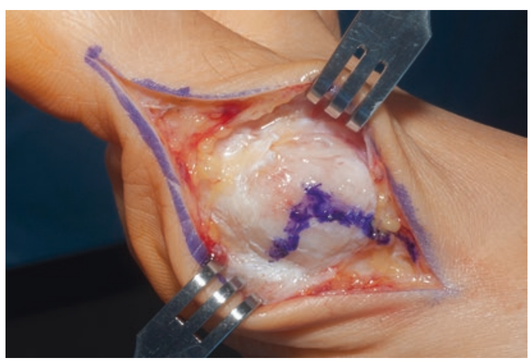

Fig. 9.9 The medial incision is deepened to the capsule, where an inverted L is drawn. The short arm is positioned just short of the joint line and the long arm is placed along the long arm of the metatarsal

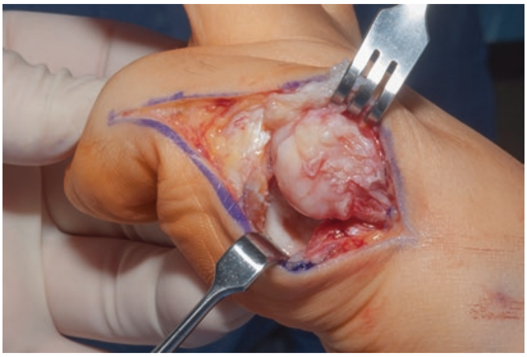

Fig. 9.10 The capsule is incised and freed medially, dorsally, and inferiorly. This allows for better exposure of metatarsal head

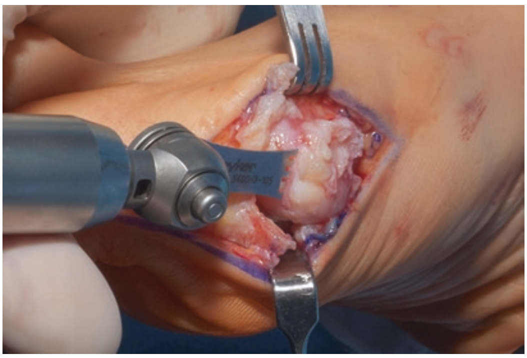

Fig. 9.11 The medial eminence is resected with care not to invade sesamoid complex

Fig. 9.12 A guidewire is applied to the medial aspect of the metatarsal. This wire acts as an axis guide for future metatarsal bone cut

from the medial, dorsal, and plantar aspects of the first metatarsal head, and the medial collateral ligaments are incised (Fig. 9.10). Care must be taken to thoroughly release the plantar structures that might otherwise be an impediment to lateral transposition of the capital fragment following osteotomy. A small portion of bone is then removed from the medial head of the metatarsal in preparation for osteotomy (Fig. 9.11). Medial eminence resection should remain medial to the sagittal sulcus of the metatarsal head and be performed in line with the shaft of the first metatarsal. Care should be taken to avoid excessive medial eminence resection, as this can result in violation of the sesamoid complex. A 0.045 mm Kirschner wire, which will serve as an osteotomy guide, is inserted from medial to lateral into the central portion of the first metatarsal head (Fig. 9.12). The wire is driven through the far cortex of the first metatarsal directed toward the fourth metatarsal head in the transverse plane, staying horizontal (Fig 9.13a). As mentioned previously, the position of the wire can be altered to accomplish sagittal plane correction as well as shortening/lengthening (Fig 9.13b). A 60–90° osteotomy is then performed beginning with the plantar arm. The orientation of the plantar cut will depend on the angle of the osteotomy as well as choice of fixation. The capital fragment is translated laterally until the desired degree of correction is achieved (Fig. 9.14). We will transpose the capital fragment at least 50% of the width or until the medullary canal of the first metatarsal shaft is visualized, depending on the exact location of the osteotomy. A 0.045 Kirschner wire is used for extra-articular provisional fixation (Fig. 9.15). The authors prefer a 3.5 mm headless, cannulated screw that is oriented from dorsal-central-proximal to plantar-central-distal. However, because of the inherent stability of the osteotomy, there are many fixation options that are acceptable. The medial overhang is resected and contoured (Fig. 9.16). A medial capsular plication is then performed, which provides excellent transverse plane correction. For larger corrections, further wedge resection of the medial capsule is performed. Layer closure of the soft tissues is then performed to the surgeons' preference (Fig. 9.17). Postoperative radiographs are recommended to confirm positioning (Fig. 9.18).

Fixation

In their hallmark article, Austin et al. made no mention of fixation; however, they did address impaction of the distal capital fragment upon

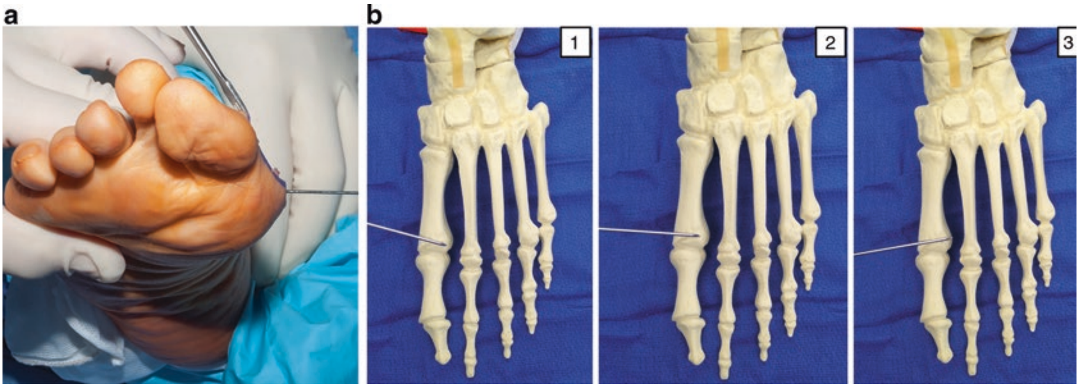

Fig. 9.13 (**a**) The axis guide is checked in the frontal plane to check for appropriate placement. (**b**) Axis guide placement for variations in transverse plane correction. (**1**) Demonstrates an axis for lengthening the metatarsal. (**2**) Demonstrates a neutral axis guide, which has no effect on the length of the metatarsal. (**3**) Demonstrates an axis for shortening

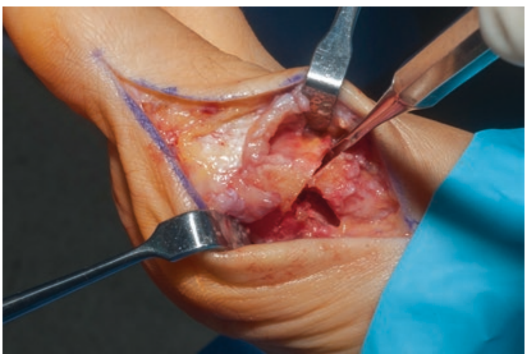

Fig. 9.14 The Chevron osteotomy is cut and transposed laterally until reduction of the intermetatarsal angle is achieved

Fig. 9.15 Temporary fixation is applied to affix the capital fragment to the metatarsal in preparation for screw placement

the apex of the metatarsal cut. The Chevron is traditionally reported to be a stable osteotomy,

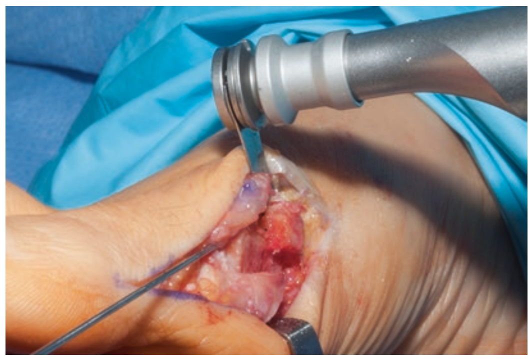

Fig. 9.16 Medial overhang is then resected and the medial surface is smoothed

Fig. 9.17 The incisions is closed in layers and placed into a soft compressive dressing

which does not require fixation. A common concern was the loss of correction when fixation was not utilized, especially in situations of concomitant lateral release. Jahss et al. reported nearly 12.5% loss of correction when no fixa-

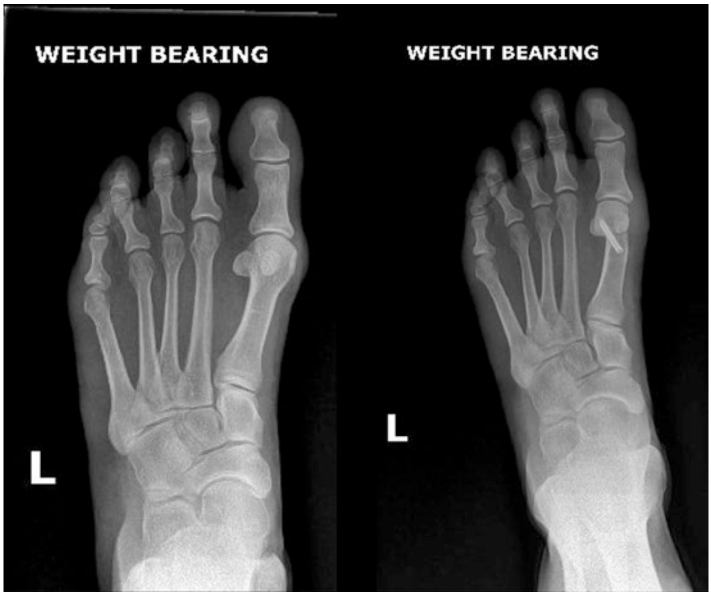

Fig. 9.18 Postoperative radiographic alignment check

tion was applied to a Chevron osteotomy site [22]. Trnka et al. prospectively followed 55 ft for an average follow-up of 34 months after undergoing fixation with a single 0.62 Kirschner wire following Chevron osteotomy and lateral release [23]. In this series, no significant loss of correction was noted. Klein et al. followed patients who utilized screw fixation and demonstrated a diminished time to return to shoe without increased complication rates [24]. The authors use a headless lag screw technique. We fixate all distal metatarsal osteotomies with a 3.0 mm cannulated, headless compression screw. This fixation construct allows for adequate compression and reduces the complaint of palpable fixation. In our experience, the addition of hardware allows for improved consistency and reliability.

Post-op Course

Patients can begin immediate weight bearing in a fracture brace following surgery. Sutures are removed at approximately 10–14 days following surgery and patients may begin wetting their foot. First MTP range of motion exercises can also be instituted at this time. We recommend protected weight bearing in a fracture brace for an additional 4 weeks. X-rays are taken at 6 weeks to assess healing, and patients are the gradually transitioned to standard foot gear.

Clinical Outcomes

Distal Chevron osteotomies of the first metatarsal are considered a reliable procedure with high satisfaction rates among patients with mild to moderate bunion deformity. Trnka et al. prospectively surveyed 57 ft at both short and midterm follow-up to reveal no assessable change in correction [23]. They concluded that Chevron osteotomies performed on the mild/moderate bunion reliably correct HAV deformity irrespective of a patient's age. An average IM angle correction has been reported at 4–5°. Data from Harper et al. suggests for every millimeter of translation, 1° of IM correction is produced [25]. For this reason, the Chevron is often seen as limited in its potential IM correction. Meier and Kenzora suggested a decrease in patient satisfaction as the preoperative IM angle increased to over 12° [26]. The relative amount of correction in IM angle, however, is debated, as some studies have suggested the ability for a Chevron style osteotomy to produce significantly higher degrees of correction. Oloff et al. retrospectively reviewed Chevron osteotomy in 13 ft with severe hallux valgus (greater than 16°) which resulted in an average correction of 11.6°. All feet were treated with a combination of soft tissue release and osteotomy. In this series, no complications or recurrence was noted at 2 years following surgery [27]. Stienstra et al. retrospectively reviewed 38 bunions with an average pre-op IM angle of 15.03° [28]. At a mean follow-up of 31 months, the average IM angle correction was 10° with an AOFAS score of 93.5.

Tips and PearlsOsteotomy Angle

The most stable orientation is the 55° to 60° osteotomy. This is ideal when you are considering large amounts of translation. Instability increases with osteotomy angles >60° and the amount of lateral translation can be limited. Avoid modifying this angle (>60°) to accommodate fixation as this may compromise the degree of correction due to instability of the osteotomy as the capital fragment is translocated in a lateral direction.

Osteotomy Location

Avoid placing the apex of the osteotomy too proximal. The guidewire should be placed such that the arms of the osteotomy, especially the dorsal arm, can be contained within the distal metaphyseal region of bone. Maintaining the osteotomy in metaphyseal bone will result in faster bone healing. Avoid placing the apex too distal; otherwise the articular surface can be at risk. Additionally, there will be a limited amount of distal bone to secure fixation. This is especially an issue in postmenopausal females and patients with osteopenia. The authors will often place the osteotomy more proximal, with the osteotomy entering diaphyseal bone in these patients. This provides enough room to secure fixation in more solid, dependable bone. However, healing time might be extended in these cases. The angle of the osteotomy cuts will also influence location. Acute osteotomies (<60°) will often need to be placed more distal than 90° osteotomies to stay within metaphyseal bone.

Osteotomy Cuts

Avoid making the plantar cut too vertical, especially if a 90° osteotomy is planned. Otherwise the dorsal cut will be “forced” down the shaft into metaphyseal bone. As a general rule, we will try to keep the plantar cut parallel to the weight bearing surface of the foot. Orientation of the dorsal cut then becomes much easier. The choice of fixation will also influence osteotomy placement.

Amount of Lateral Displacement of the Capital Fragment

The capital fragment can safely be laterally displaced at least 50% without risking displacement. The only time we will limit the degree of lateral translation is when the medullary canal is visible. This is seen when the osteotomy was placed more proximal than usual either inadvertently or to engage higher-quality bone for fixation purposes. Stienstra et al. looked at 38 cases of DMO procedures with an average of greater than 40% lateral displacement. The average translation was 9.8 mm. There were no cases of avascular necrosis, nonunion, or delayed union. They reported one case of a dislocated capital fragment [28].

Inadequate Lateral Translation of the Capital Fragment

There are times when the capital fragment will not easily (or only minimally) translate in a lateral direction. This is usually due to inadequate release of soft tissue structures, preexisting degenerative joint disease (DJD) with stiff soft tissues, or the orientation of the osteotomy not permitting translation. In this situation, we will inspect the joint and release any remaining soft tissue structures that might be limiting translation. A small osteotome is then placed within the osteotomy and an aggressive lateral capsule release is performed. The capital fragment is now completely released and should laterally translocate. However, this technique is not recommended if there is preexisting DJD. The authors believe that the incidence of avascular necrosis following DMO is greater in patients with DJD of the first MTP joint. Further aggressive soft tissue release might adversely affect posterior blood supply to the capital fragment and further increase this risk. In these cases, one should consider taking a dorsal wedge to provide some shortening and plantar flexion. Simply reinsert the osteotomy guidewire and make a cut parallel to the dorsal osteotomy. This maneuver will relatively lengthen the stiff soft tissues and allow lateral translation of the capital fragment. These patients may have been better served with a more proximal osteotomy or joint destructive procedure. This should be identified in the preoperative physical exam and radiographic assessment. We suggest intraoperative imaging to assess the osteotomy orientation. The osteotomy may require a minor adjustment or wedge resection may be required. Obtaining adequate correction is the primary goal and some shortening is acceptable. One can compensate with a small degree of plantar flexion.

Capsulorrhaphy

Vertical wedge resection of the medial capsule allows excellent transverse plane correction. This can be adjusted based on the amount of attenuated tissues that require resection or the amount of correction that is needed. The wedge of tissue should be resected in a manner where the amount of tissue resected along the plantar aspect is the same or greater than dorsal to avoid elevation of the hallux with closure. We will sometimes consider closure of the vertical arm with a nonabsorbable suture material.

Necessity of Lateral Release

This remains a somewhat controversial topic. Although we consider lateral release in more severe deformities, we don't do this routinely, especially with DMO, which we reserve for moderate deformity. This has been discussed elsewhere in the literature [29]. Boberg and Judge evaluated 37 DMO cases without lateral release and concluded that predictable results can be obtained.

Complications

Reoccurrence of HAV deformity for Austin procedures has been estimated within the literature to be as high as 10%. A study by Hattrup and Johnson demonstrated 18 of 225 ft developed reoccurrence [30]. They related this to an under-corrected HAA. Additionally, Hirvensalo reported a 10% reoccurrence rate of HAV following Austin procedures and correlated this to a preoperative HAA over 37° and a preoperative IM over 13° [31]. As such, a standard rule of thumb is to perform larger IM corrections on patients who concomitantly have lower HAA. Trnka et al. suggest that with the addition of lateral soft tissue release, IM correction of up to 18° can be achieved utilizing a Chevron osteotomy [23]. Additionally, lateral release significantly improved sesamoid position. The authors believe that many cases of recurrence are, in fact, under-corrected deformities from either technical issues or in patients where DMO didn't have the capacity to correct the deformity. The authors have seen a higher incidence of recurrence in patients with forefoot instability as well as hind foot deformity.

Early reports of combined lateral release and distal Chevron osteotomies revealed an increased propensity toward avascular necrosis (AVN). Some reports estimate the incidence of AVN as high as 40% [32]. Cadaveric studies have revealed extensive extraosseous vascular networks both distal and proximal to Chevron osteotomy sites, which supports the notion that a properly performed osteotomy should not have significant risk for AVN. The occurrence of AVN following Chevron procedure has been reported as 0–20% [32–34]. The work of Jones et al. suggests how erroneous cuts made at the osteotomy site or poor osteotomy placement may be the cause of AVN [35].

One of the most common complications following distal metatarsal osteotomy is the loss of first MTP range of motion. In a retrospective analysis following postoperative complications, nearly 8% of patients who underwent metatarsal head procedures had some degree of motion loss at the MTP. The authors attributed this loss of motion to elevation of the metatarsal head and capsular adhesions surrounding the joint. A rigid fixation construct permits early ROM, which might be beneficial. Patients with preexisting DJD have a higher incidence of limited ROM. However, this is likely secondary to their underlying arthritis rather than surgery, and these patients should be counseled regarding this issue prior to surgery.

Transfer metatarsalgia and lateral forefoot overload have also been described secondary to metatarsal shortening. However, due to evolution in surgical techniques, especially fixation development, the incidence of shortening is much less than once reported. Incisional neuritis is often seen following hallux valgus reconstruction. However, the authors have seen this most often with a dorsal approach. Nonetheless, this is transient in most cases.

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10 Basilar Opening and Closing Wedge Osteotomy Procedures

William T. DeCarbo and Mark J. Bullock

Background

The closing base wedge osteotomy (CBWO) was first described by Loison in 1901, and k-wires were historically used for fixation [1]. Early concerns regarding the closing base wedge osteotomy were related to first metatarsal shortening and first metatarsal elevation. Banks et al. (1997) performed the closing base wedge osteotomy on a saw bone model and measured the amount of shortening with digital calipers. Mean shortening was 1.1 mm with a 5-degree wedge, 1.7 mm with a 10° wedge, and 2.5 mm with a 15° wedge. The amount of shortening was less than in previous reports. The authors felt their measurements were more accurate than previous reports because radiographic measures can misinterpret dorsiflexion or plantarflexion as shortening [2]. Nyska et al. (2002) noted 2.0 mm of shortening when an oblique 8-degree closing base wedge osteotomy was performed in a saw bone model, and reference points were taken with a 3D digitizer. The 8-degree wedge resulted in 5° of intermetatarsal correction [3]. The amount of shortening may depend on the obliquity of the wedge because a more oblique wedge results in more lateral bone resection.

Initial publications on the closing base wedge osteotomy allowed immediate weight bearing. Jeremin et al. (1982) performed the CBWO on 24 feet and found 50% of patients had a dorsiflexion malunion. Average first metatarsal shortening increased from 1.76 to 4.58 through the postoperative period [4]. Resch et al. (1989) described a 20% incidence of metatarsalgia secondary to dorsiflexion malunion, while Wanivenhaus and Feldner-Busztin (1988) described an 80% incidence of metatarsalgia secondary to dorsiflexion malunion after the CBWO [5, 6]. Ruch (1982) described the complication rates of the CBWO for different postoperative protocols. Patients who underwent CBWO with early weight bearing 3 or 4 weeks postoperatively following screw fixation had high rates of callus formation and fixation failure. In 50 patients weight bearing was not initiated until 6 weeks postoperatively, and these patients had a low rate of callus formation and fixation failure (2%) [7]. The high rates of dorsiflexion malunion in early studies may be a result of inadequate fixation and early weight bearing. Schuberth et al. (1984) reviewed 159 feet that underwent the CBWO to determine the incidence of postoperative first metatarsal elevation and determine factors associated with malunion. The first metatarsal declination angle

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decreased from 23.5° preoperatively to 17.1° postoperatively. Bilateral procedures, absence of casting, and k-wire or monofilament wire fixation were associated with higher rates of first metatarsal elevation. They noted 93.7% of patients had first ray elevation based on postoperative sagittal 1–2 intermetatarsal angle [8]. The sagittal 1–2 intermetatarsal angle lacked a control group and may overestimate the true incidence of dorsal malunion in the study. Sheriff et al. (1991) studied the initial failure yield in five osteotomies for hallux valgus using dried first metatarsal bones. The closing base wedge osteotomy had the lowest yield to failure across all fixation types. Single k-wires, crossed k-wires, and single cortical/cancellous screws all failed gradually at low yield points. Failure was characterized by gradual displacement of the osteotomy consistent with the subtle dorsiflexion malunions seen in the postoperative period. The authors emphasized the importance of non-weight bearing and cast immobilization particularly for the CBWO [9].

The opening base wedge osteotomy (OBWO) was described by Trethowan in 1923. Autograft was utilized from resection of the medial eminence, and the medial hinge of the osteotomy was left intact [10]. The opening base wedge osteotomy has gained popularity due to improved fixation options. Locking plate technology has reduced the complications associated with the opening wedge bone grafts allowing maintenance of correction with high union rates. Initial concerns regarding hallux limitus have been reported but are not prevalent in the literature. Saragas (2009) found a mean increase in metatarsal length of 2.3 mm when comparing preoperative and 20 month postoperative radiographs with 2 mm and 2.5 mm opening wedge plates [11]. Wukich et al. (2009) looked at postoperative radiographs in 18 patients and reported an increase of 2.6 mm in the metatarsal protrusion distance [12]. Wester et al. (2016) found no change in metatarsal protrusion distance after the opening base wedge osteotomy [13]. The variation in these results may be indicative of sagittal plane changes that affect the appearance of first metatarsal length on radiographs. Budny et al. (2009) used a saw bone model with calipers to measure the difference in the first metatarsal length following the opening wedge osteotomy. Average lengthening varied from 0.47 to 1.35 mm for 2–6 mm opening wedges [14]. This study may provide the most accurate measurement for first metatarsal lengthening after the OBWO because it does not rely on radiographs. The OBWO is a useful procedure when the patient presents with a short first metatarsal and the surgeon would like to maintain or restore length.

An opening wedge osteotomy of the first cuneiform has also been described. Jawish et al. (2010) performed an opening wedge osteotomy of the cuneiform and reported no nonunions, high patient satisfaction, and adequate correction in 101 feet at 7.7-year follow-up. They did note 12 cases with new osteoarthritis at the metatarsophalangeal joint (MTPJ) and 8 cases with new osteoarthritis at the first MPTJ [15].

Reasoning and Philosophy

The closing base wedge osteotomy provides correction for large intermetatarsal (IM) angles and does not have some of the technical difficulties of the lapidus bunionectomy. The lapidus bunionectomy requires resection of the subchondral bone plate, and Johnson et al. (2009) found that curettage of the first metatarsocuneiform joint often leaves a layer of calcified cartilage that may act as a barrier to osseous union [16]. Theoretically, the CBWO may result in less shortening with higher union rates than the lapidus bunionectomy although this has not been definitively established.

Metatarsal length may have an important role in the etiology of hallux valgus. Lindbergh and Sulja (1972) as well as D'Arcangelo et al. (2010) found a correlation between the length of the first metatarsal and the severity of hallux valgus [17, 18]. Hardy and Clapham (1951) as well as Mancuso et al. (2003) found increased metatarsal protrusion distances in a hallux valgus group compared with a control group [19, 20]. Other studies support increased first metatarsal length as a factor in the etiology of hallux valgus [21, 22]. The more conservative shortening associated with the CBWO may be beneficial in preventing recurrence by reducing the tension on the tendon imbalance occurring at the first MTPJ. It is not uncommon for a patient to present with hallux valgus in the presence of a short first metatarsal. The opening base wedge osteotomy can restore the metatarsal parabola without the need for shortening lesser metatarsal osteotomies [14]. Shortening lesser metatarsal osteotomies are not without complications as they change the relationship of the intrinsic muscles and tendons about the lesser metatarsophalangeal joints and can lead to a floating toe. The OBWO is also useful for revision cases where previous osteotomies caused shortening of the first metatarsal (Fig. 10.1).

Patient Selection

Patient selection for a closing base wedge or opening base wedge osteotomy is of utmost importance. All procedures have advantages and disadvantages which must be taken into consideration for the individual patient. The CBWO has been described for juvenile hallux valgus. Some patients with juvenile hallux valgus have an increased proximal articular set angle (PASA), and the CBWO may further increase the PASA in these patients [23]. Elderly patients that have difficulty remaining non-weight bearing are often best suited with a procedure that allows early weight bearing. We take preoperative vitamin D in postmenopausal women, and vitamin D deficiency or insufficiency is treated prior to hallux valgus correction with basilar osteotomies.

Basilar osteotomies are performed on patients with high IM angles, and these patients often have hypermobility, but this finding may not be a contraindication for basilar osteotomies if the hypermobility is not severe. Rush et al. (2000) noted a reduction in hypermobility after correction of the intermetatarsal angle in seven cadaveric specimens with the windlass mechanism engaged [24]. Realigning the first metatarsal head over the sesamoids may allow the plantar aponeurosis to prevent collapse of the medial column. Coughlin et al. (2004) measured first ray sagittal motion with a Klaue device in 12 cadaveric specimens before and after bunion correction with a crescentic osteotomy and a distal soft tissue release. In their study the mean IM angle was reduced from 12.9° to 6.8° resulting in a reduction in the first ray sagittal plane motion from

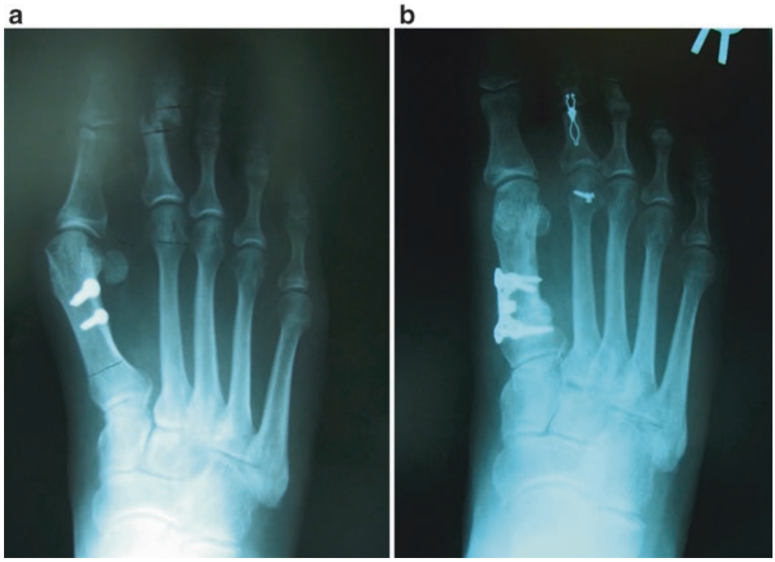

Fig. 10.1 (**a**) Shortening of the first ray after inadequate correction with chevron bunionectomy. (**b**) Revisional hallux valgus correction with opening base wedge osteotomy to restore length to the medial column

11.0 to 5.2 mm [25]. To reiterate their results, Coughlin et al. (2007) measured first ray motion preoperatively and postoperatively in 122 feet undergoing a proximal crescentic osteotomy and a distal soft tissue release with mean 27 month follow-up. The mean IM angle changed from 14.5° to 5.4° with first ray mobility diminishing from 7.2 to 4.5 mm [26]. Faber et al. (2013) found no difference in recurrence between a Hohmann osteotomy and a lapidus bunionectomy at long-term follow-up, and these findings extended to a subgroup of 63 patients with preoperative hypermobility [27]. In contrast, Haas et al. (2007) found more loss of correction with the closing base wedge osteotomy compared with the lapidus arthrodesis at 11 month follow-up, 2.55° versus 1.08°, respectively [28]. Oravakangas et al. (2016) had good maintenance of correction at 5.8 year follow-up with the OBWO, and they did not feel hypermobility adversely affected their outcomes [29].

Patients with pronation of the metatarsal head are another subset of patients that may benefit from a lapidus bunionectomy over a basilar osteotomy. Okuda et al. (2009) noted that pronation of the first metatarsal head identified as a “round sign” is associated with recurrence [30]. This coronal plane rotation is more common in patients with hallux valgus compared with controls. Sesamoid axial views show the degree of pronation preoperatively, and there is a small subset of patients with severe hallux valgus without metatarsal pronation. Kim et al. (2015) found that 87.3% of hallux valgus patients had first metatarsal pronation greater than 15.8°. The remaining patients in their study had first metatarsal pronation less than 15.8°, and these patients may not require triplane correction. The control group in their study had a mean 13.8° of first metatarsal pronation [31]. It has been hypothesized that as pronation occurs, the medial aspect of the first metatarsal head is no longer supported by the sesamoid apparatus [32]. Sesamoid relocation may promote reduction of metatarsal head pronation by supporting the medial first metatarsal head, but this requires further study. It is not known if pronation reduces with osteotomy correction. This theory has not been studied, and we choose to perform a lapidus with triplane correction to address first metatarsal pronation.

A significant elevation in PASA may be another relative contraindication for both the CBWO and the OBWO. Both basilar osteotomies increase PASA by providing angular correction of the first metatarsal distal to the CORA. Mid-shaft and distal osteotomies that correct the IM angle through translation maintain PASA with correction. Paczesny et al. (2009) found poor midterm correction of the IM angle following the CBWO in patients with an elevated PASA. The same study found that the Scarf osteotomy provided adequate midterm correction of the IM angle in patients with elevated PASA [33]. Shurans et al. (2009) noted an association between high preoperative PASA and recurrence with the OBWO [34]. Iyer et al. (2015) had a higher rate of recurrence compared with previous OBWO reports. Eleven of seventeen (64.7%) patients had recurrence defined as greater than 5-degree increase in the hallux valgus angle on weight-bearing x-rays in the postoperative period. Elevated PASA had a statistically significant association with recurrence in their study [35].

Preoperative Clinical and Radiographic Evaluation

Preoperative x-rays are taken to rule out joint space narrowing of the first metatarsophalangeal joint or a fault at the first metatarsocuneiform joint identified as plantar gapping. Patients with joint space narrowing have a more predictable outcome with first MTPJ arthrodesis. Patients with a fault at the first metatarsocuneiform joint can develop a forefoot-driven pes valgus, and a lapidus can provide correction. Coughlin et al. found a reduction in hypermobility following hallux valgus correction with a first metatarsal osteotomy, but there was little correction in plantar gapping at the first metatarsocuneiform joint on postoperative radiographs.

Another useful x-ray view is the sesamoid axial view. The closing base wedge osteotomy can be utilized with high 1–2 intermetatarsal (IM) angles in the absence of metatarsal pronation on the sesamoid axial view. The sesamoid axial view identifies significant sesamoid subluxation requiring more aggressive soft tissue balancing. Sesamoid axial views also rule out degenerative joint disease of the sesamoid apparatus. A first MTPJ arthrodesis is performed if there is degenerative joint disease of the sesamoid articulation with the first metatarsal head.

On clinical exam the first metatarsocuneiform joint is brought through range of motion. Severe hypermobility or pain with range of motion may require a lapidus. If there is preoperative hyperkeratosis, metatarsalgia, lesser metatarsal stress fractures, or thickening of the second metatarsal, an opening base wedge osteotomy or a lapidus may restore weight-bearing forces through the medial column most effectively. We have used the OBWO to reduce weight-bearing forces through the second ray in the presence of plantar plate pathology or metatarsalgia (Fig. 10.2). The lapidus may be the better option if there is plantar gapping of the first metatarsocuneiform joint. A rigid first metatarsocuneiform joint that does not reduce in the transverse plane will not provide added correction when the retrograde force from the hallux is reduced with hallux valgus correction. These patients require more aggressive IM angle correction and may benefit from proximal correction such as a basilar osteotomy.

Surgical Technique

An incision is made directly medial to the extensor hallucis longus (EHL) from the first metatarsocuneiform joint to the base of the proximal phalanx. The medial dorsal cutaneous nerve finishes crossing the extensor hallucis longus (EHL) tendon on average 16 mm proximal to the first metatarsocuneiform joint (range, 0–41 mm) and can be encountered in the proximal aspect of the incision if the incision is too medial [36]. The dorsal venous arch is retracted proximally. Following retraction of the dorsal venous arch, a full-thickness incision down to the bone can be made just medial the EHL tendon. Periosteal reflection is limited to prevent avascular necrosis of the first metatarsal. The nutrient artery enters the lateral aspect of first metatarsal at the junction of the proximal and middle third of the bone near the site of the CBWO. Care is taken not to over penetrate the lateral cortex with the saw blade. Chuckpaiwong and Korwutthikulransri (2013) described the course of the first intermetatarsal artery which can be injured with basilar osteotomies [37]. They described a triangular safe zone with the first metatarsocuneiform joint, plantar cortex of the second metatarsal, and intermetatarsal artery providing borders for the safe zone. Additional soft tissue procedures such as medial

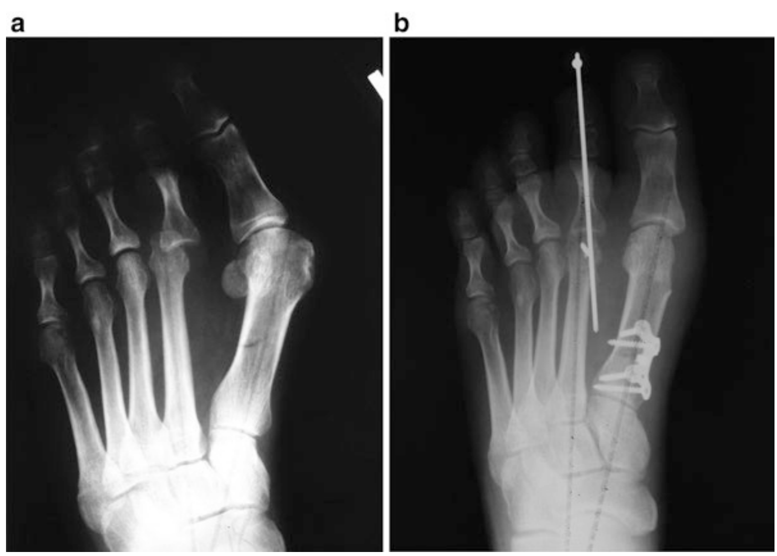

Fig. 10.2 (**a**) Chronic plantar plate rupture of second metatarsophalangeal joint in the presence of hallux valgus. (**b**) Opening base wedge osteotomy was utilized to increase loading through the medial column and off-load the second ray following repair

capsulorrhaphies and lateral releases have a cumulative effect on the reduction in blood flow to the first metatarsal [38]. Of note, avascular necrosis is rarely reported as a complication of basilar osteotomies and is more frequently reported as a complication of distal metatarsal osteotomies.

In our practice, a lateral release is performed if there is adequate reduction of the IM angle with residual sesamoid displacement. Lateral release in conjunction with the CBWO is associated with improved correction but also increased first metatarsophalangeal joint stiffness [39]. Kim et al. [31] found that sesamoid subluxation was associated with higher IM angles [31]. Achieving sesamoid relocation has been associated with lower recurrence rates in a study by Okuda et al. (2015). By definition sesamoid subluxation requires attenuation of the medial metatarsosesamoid ligament [30]. When significant sesamoid subluxation is present, we perform adjunctive lateral release of the lateral metatarsosesamoid ligament and adductor tendon with imbrication of the medial metatarsosesamoid ligament and medial collateral ligament to maintain sesamoid relocation and prevent recurrence. For soft tissue balancing, release of the adductor tendon is performed from the proximal aspect of the fibular sesamoid. Owens and Thordarson (2001) noted the adductor tendon could not be differentiated from the flexor hallucis brevis when adductor release was performed from the distal aspect of the sesamoid [40]. The medial capsulorrhaphy is performed distal to the medial metatarsosesamoid ligament. We are conservative with the amount of imbrication from the medial capsular apparatus because this can reduce the range of motion and alter joint mechanics. We do not rely on the medial capsulorrhaphy to achieve our correction.

The closing base wedge osteotomy is performed perpendicular to the weight-bearing surface of the foot to ensure no dorsal or plantar translation with correction through the osteotomy. An axis guide can be utilized to ensure the saw cuts are perpendicular to the weight-bearing surface. With the CBWO, the medial hinge acts as the center of rotation. Laporta et al. (2015) described the apex of deformity or center of rotation of angulation (CORA) of hallux valgus occurring in the proximal tarsus [41]. The more proximal the medial hinge, the closer the correction is to the CORA resulting in less medial translational deformity and less of an increase in PASA. The medial hinge of the CBWO is marked 8–10 mm distal to the first metatarsocuneiform joint to allow plate fixation. If the medial hinge is too far distal, then the corrective power of the osteotomy is reduced.

The closing base wedge osteotomy can be performed oblique or transverse to the first metatarsal. There is a trade-off because a more oblique cut leaves more room for fixation with greater bone contact area, while a more transverse cut requires less bone resection laterally for a given angle of correction with less shortening. We prefer a slight obliquity to the cut with plate fixation to allow variable angle locking screws to be directed away from the first metatarsocuneiform joint. Following the saw cuts, the osteotomy can be closed with reduction forceps. This allows the surgeon to assess the correction and further feather the lateral cortex if increased correction is desired.

The proximal oblique sliding closing wedge osteotomy (POSCOW) is a modification of the CBWO that was developed to maintain the length of the first metatarsal. Distal medial translation of the osteotomy offsets translational deformity imparted by correcting the osteotomy distal to the CORA. The authors that proposed the procedure noted a learning curve with more complications occurring in the initial patients within their series [42].

Similar to the CBWO, the OBWO is performed perpendicular to the weight-bearing surface to prevent malreduction in the sagittal plane. The lateral hinge acts as the center of rotation, and a more proximal lateral hinge is closer to the CORA of the deformity. We keep the lateral hinge 8–10 mm from the first metatarsocuneiform joint. Han et al. (2015) noted more medial translation of the first metatarsal head with a transverse OBWO compared with an oblique OBWO [43]. In their study, the lateral hinge for the transverse OBWO appeared to be more distal on the first metatarsal imparting greater medial translation. Assuming the same lateral hinge is utilized, a more oblique OBWO requires more bone for a given angle of correction and can provide greater lengthening of the first metatarsal.

Fixation Options

Two screws can be used for fixation in a CBWO with a compression screw perpendicular to the osteotomy and an anchor screw perpendicular to the first metatarsal. There are different recommendations regarding which screw should be inserted first. The authors prefer to insert the compression lag screw first because the compression is perpendicular and less likely to displace the osteotomy with initial screw insertion. The proximal anchor screw is inserted second. 2.7 mm cortical screws allow revision with larger screws if there is poor screw purchase. Fillinger et al. (1998) loaded saw bone models to failure to compare fixation strength for the closing base wedge osteotomy and the crescentic osteotomy. The use of saw bone models was a weakness of the study. Load to failure of the CBWO was 39.6 N with one 2.7 mm screw and 43.1 N with two 2.7 mm screws. The crescentic osteotomy had a load to failure of 67.7 N with one 4.3 mm screw. Neither osteotomy achieved 25% of the load to failure of the control model indicating the inherent weakness of the osteotomies with screw fixation [44]. Biomechanical testing by Landsman and Vogler (1992) agreed that screw fixation provides inadequate initial stability for the CBWO [45]. Smith et al. (2014) reviewed load to failure in 40 biomechanical testing bones. Twenty bones had an oblique CBWO fixated with two 2.7 mm cortical screws, and 20 bones had an oblique CBWO fixated with a four-hole locking plate. Mean load to failure for the plate construct was significantly greater than the mean load to failure for the screw construct, 190.0 ± 70 N versus 110.3 ± 20.3 N, respectively [46]. Plantar plate fixation with a two-hole one-third tubular plate has also been tested in the fixation of a biplanar closing base wedge osteotomy. Load to failure was tested in ten matched cadaver feet and compared with 4.0 mm cancellous screw fixation for the crescentic osteotomy. Load to failure was significantly higher with plantar plate fixation of the closing base wedge osteotomy, 127.2 ± 81.9 N versus 44.9 ± 43.3 N [47].

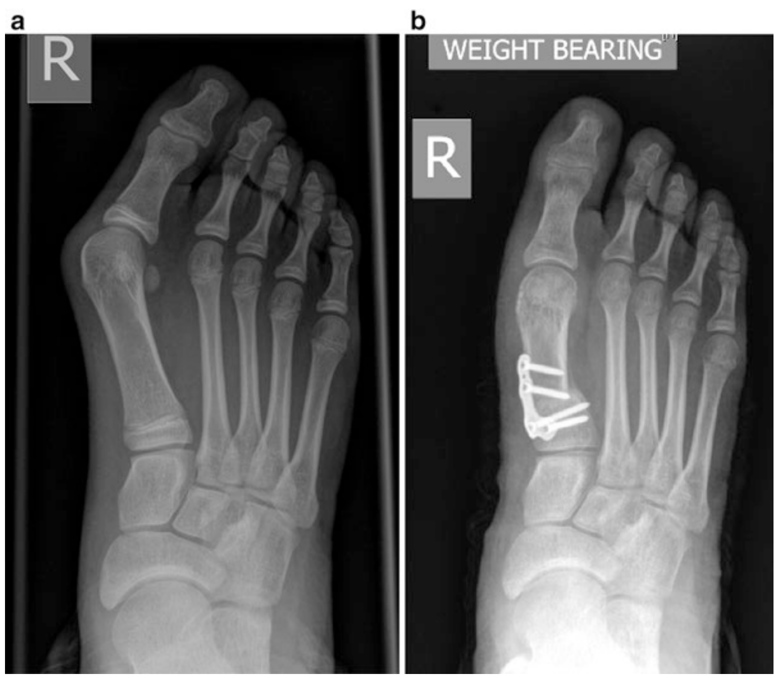

Fig. 10.3 (**a**) Juvenile hallux valgus with positive metatarsal protrusion distance. (**b**) Correction of hallux valgus with closing base wedge osteotomy and medial locking plate fixation (Radiographs courtesy of Douglas Blacklidge and Scott Hoffman)

A locking plate provides greater stability compared with two screw fixation constructs for the closing base osteotomy. The authors prefer plate fixation because the locking plate neutralizes bending and shearing forces which may reduce the incidence of a dorsal malunion (Fig. 10.3). Locking plates allow a more transverse osteotomy to be performed which requires less bone resection for correction. If shortening is less of a concern, a more oblique osteotomy may allow lag screw fixation in addition to the locking plate. L-type or T-type plates provide at least two points of fixation proximally and at least 2 points of fixation distally (Fig. 10.3). Randhawa and Pepper (2009) described the degree of correction with different wedge sizes associated with L-type plate fixation. A 3.5 mm wedge plate provided a mean correction of 8.0°. A 4.0 mm wedge plate provided a mean correction of 9.0°. A 5.0 mm wedge plate provided a mean correction of 14.9° [48]. Data from this study allows the surgeon to measure angles preoperatively and decide on initial plate application intraoperatively. It is important to remember that the amount of the correction depends on the location of the lateral hinge and the obliquity of the osteotomy in addition to the graft size.

Postoperative Considerations

Screw fixation for the CBWO requires extended non-weight bearing. The patient is made non-weight bearing in a posterior splint for 10 days followed by non-weight bearing in a short leg cast until they are 6 weeks from the date of the procedure. Weight bearing in a CAM boot is continued for an additional 3 weeks. Patients can return to work at 8 weeks for sedentary jobs and at 11–12 weeks for jobs that require manual labor. With plate fixation for closing or opening wedge osteotomies, the patient is made non-weight bearing in a posterior splint for 10 days followed by heel weight bearing in a CAM boot for an additional 4 weeks. Patients can return to work at 6 weeks for sedentary jobs and at 10 weeks for jobs requiring manual labor. The patient begins active and passive range of motion of the first MTPJ when they are no longer immobilized in a short leg cast.

Complications

A meta-analysis of proximal first metatarsal osteotomy procedures identified 62 studies eligible for inclusion. Among proximal osteotomy procedures, the three most common major complications requiring revision are hallux varus (4.3%), recurrence (3.5%), and dorsiflexion malunion (2.5%). Major complications defined as complications that could require revision had an incidence of 12.8% in the study. Major complications were reduced with the use of locking plate fixation (5.5%). Major complication rates were 15.67% ± 3.22 for the closing wedge osteotomy and 14.29%± 4.10 for the opening wedge osteotomy. Complication rates were lower for the proximal crescentic osteotomy (11.69% ± 2.86) and the proximal chevron osteotomy (6.05% ± 1.62) [49].

Dorsal malunion is a significant complication associated with the closing base wedge osteotomy. Proximal metatarsal osteotomies provide a larger lever arm for high weight-bearing forces to act on the osteotomy. Lesser metatarsalgia and hallux limits are common sequelae associated with this complication. There is a wide variety in the incidence of dorsal malunion associated with the CBWO, and the variation may be related to fixation strength and weight-bearing status.

Lagaay et al. (2008) assessed reoperation rates for recurrent hallux valgus and hallux varus in a large health care system across multiple surgeons. The closing base wedge osteotomy (34 patients) had a higher reoperation rate than the lapidus bunionectomy (342 patients) or the Austin bunionectomy (270 patients), 8.82% versus 8.19% versus 5.56%, respectively. The difference in reoperation rate was more pronounced when solely taking into account cases of over- or under correction, 5.88% versus 3.21% versus 3.33%, respectively [50]. A limitation of the study was the small sample size of patients undergoing the CBWO. The closing base wedge osteotomy may be more prone to under- or overcorrection because it is difficult to remove the precise amount of bone to achieve the desired correction, and most surgeons do not translate the osteotomy to compensate for imprecise wedge resection.

Day et al. (2011) assessed shortening and complication rates following the CBWO with plate fixation and immediate weight bearing. Mean increase in dorsiflexion of the first metatarsal was 1.3° at final follow-up. Seven of seventy patients had postoperative metatarsalgia. There were seven hardware failures with all patients going on to osseous union with no effect on sagittal alignment [51]. The rate of postoperative metatarsalgia compares favorably to other CBWO studies supporting the use of plate fixation. The opening base wedge osteotomy has unique complications secondary to lengthening of the medial column. Anecdotally, we have noticed increased rates of hallux varus and hallux limitus after the procedure. Hallux varus may be the result of excessive PASA postoperatively (Fig. 10.4). Wukich et al. (2009) noted that all 18 feet in his series had reduced range of motion and stiffness of the first metatarsophalangeal joint after the OBWO [12]. Iyer et al. (2015) found 6 of 17 patients had pain at the first MTPJ, and 3 of these 6 patients had radiographic evidence of grade 1 arthritis at final follow-up [35]. Other large series do not note evidence of first MPTJ arthritis. Saragas (2009) had the largest series on the OBWO. In 64 feet, there were 5 (7.8%) cases of hallux varus, 2 cases of recurrent hallux valgus (3.1%), and 1 nonunion (1.6%) [11].

Opening wedge plates provide stability and high union rates for the OBWO increasing the procedure's popularity in recent years. Smith et al. (2009) reported four nonunions in a subset of 15 patients treated with non-locking opening wedge plates. No nonunions were reported with the use of locking opening wedge plates in 32 patients [52]. We have seen one delayed union following OBWO with locking plate fixation (Fig. 10.5).

A disadvantage of closing or opening base wedge osteotomies is that revisions can be difficult. Resection of a malunion leaves little bone between the resected bone and the first metatarsocuneiform joint. More robust fixation is often needed for revision surgery, and there is little bone left for proximal fixation. Basilar osteotomies are not performed at the CORA and

Fig. 10.4 Hallux varus following opening base wedge osteotomy. Lateral hinge is too far from the first metatarsocuneiform joint, and too large of a medially based wedge results in significant elevation in PASA with hallux varus

Fig. 10.5 Delayed union following opening base wedge osteotomy with locking plate fixation

Table 10.1 AOFAS hallux metatarsophalangeal scores for basilar osteotomies

Author (year)	Procedure	Mean follow-up	Number of procedures	Pre-op AOFAS	Post-op AOFAS
Oravakangas et al. (2016) [29]	OBWO	5.6 years	23	52	84
Wester et al. (2016) [13]	OBWO	12 months	22	61.8	84.8
Wukich et al. (2009) [12]	OBWO	11 months	18	50.9	81.8
Saragas (2009) [11]	OBWO	18 months	64	51.3	86.8
Mean	**OBWO**			**54**	**84.4**
Nedopil (2010) [56]	CBWO	4.33 years	86	N/A	78
Paczesny (2008) [33]	CBWO	3.75 years	20	41.1	72.7
Trnka et al. (1999) [55]	CBWO	16.2 years	60	N/A	88.8
Mean	**CBWO**			**41.1**	**79.8**

impart a translational deformity further increasing the difficulty of revisions.

Evidence-Based Outcomes

The vast majority of studies on basilar osteotomies are level 4 studies. There have been few recent studies on the closing base wedge osteotomy, and older studies on the CBWO do not utilize consistent outcome measures. The AOFAS score is the most commonly reported outcome measure after hallux valgus surgery allowing comparison of data. There are concerns that AOFAS scores are not valid or relevant for hallux valgus surgery [53]. One of the few comparison studies evaluated outcomes between the Austin bunionectomy and the CBWO. Results were compared between 37 feet that underwent Austin bunionectomies and 16 feet that underwent base wedge osteotomies. Mean age was a confounding variable as it differed between the Austin bunionectomy and the CBWO, 58 years and 39 years, respectively. Overall satisfaction was similar between the two groups, with a high percentage of patients highly satisfied with the Austin and the CBWO, 70% and 69%, respectively. Radiographic evaluation for CBWOs at mean follow-up of 43 months and Austin bunionectomies at mean follow-up of 18 months showed a lower postoperative IM angle for the CBWO versus the Austin, 4.2° versus 9.3°, respectively. First metatarsal declination was unchanged with the Austin bunionectomy at final follow-up and decreased by 1.1° with the CBWO at final follow-up [54]. Another comparison study evaluated the scarf osteotomy and the CBWO. The retrospective study had at least a 2-year follow-up in both groups. Patients who underwent the scarf osteotomy had higher AOFAS scores at final follow-up although this did not reach significance, 79.1 ± 18 versus 72.7 ± 16.8 ($p = 0.123$). The authors believed that the CBWO poor results were secondary to under correction and recurrence with the CBWO in patients with a high preoperative PASA. The authors postulated that proximal metatarsal osteotomies may have improved outcomes after exclusion of patients with high preoperative PASA [33]. Conversely, Trnka et al. had excellent results with CBWO at long-term follow-up (10–22 years) in 60 feet with an average AOFAS of 88.8 (Table 10.1) [55]. Age was a confounding variable between the two studies with patients in the study by Trnka et al. being significantly younger at the time of operation, 30 years versus 51 years.

Many recent studies have reported on preoperative and postoperative AOFAS scores following the opening base wedge osteotomy (Table 10.1). Saragas et al. (2009) reported on patients 1–1.5 years out from OBWO with 32 of 64 patients having an additional akin osteotomy performed. IM angle reduced from 15° to 9°, and AOFAS scores improved from 51 to 87 [11].

Table 10.2 Preoperative and postoperative intermetatarsal angles for basilar osteotomies

Author (year)	Procedure	Mean follow-up	Pre-op IM angle	Post-op IM angle	Change in IM angle
Oravakangas et al. (2016) [29]	OBWO	5.6 years	17	10	7
Wester et al. (2016) [13]	OBWO	12 months	18.9	12.6	6.3
Iyer (2015) [35]	OBWO	29 months	13.4	9.7	3.7
Wukich et al. (2009) [12]	OBWO	11 months	16	7.5	8.5
Saragas (2009) [11]	OBWO	18 months	15	8.6	6.4
Shurnas et al. (2009) [34]	OBWO	29 months	14.5	4.6	9.9
Randawa (2009) [48]	OBWO	17 months	18.4	7.8	10.6
Mean	**OBWO**		**16.2**	**8.7**	**7.5**
Day et al. (2011) [51]	CBWO	14 months	13.2	4.4	8.8
Nedopil (2010) [56]	CBWO	4.33 years	17.6	6.5	11.1
Paczesny (2008) [33]	CBWO	3.75 years	10.5	5.5	5
Fadel (2008) [57]	CBWO	30.15 months	17.3	11.2	6.1
Haas et al. (2007) [28]	CBWO	39.1 months	14.8	7	7.8
Trnka et al. (1999) [55]	CBWO	16.2 years	16.1	6.7	9.4
Granberry and Hickey (1995) [39]	CBWO	22 months	15.3	7.7	7.6
Seiberg et al. (1994) [54]	CBWO	43 months	16.3	4.2	12.1
Resch et al. (1989) [5]	CBWO	37 months	13	10	3
Mean	**CBWO**		**14.9**	**7.0**	**7.9**

Oravakangas et al. (2016) reported on 20 of 31 patients available for midterm follow-up at 5.8 years. Mean IM angle decreased from 17° to 10°, and AOFAS scores improved from 52 to 84 with two patients requiring revision for recurrence [29]. Wukich et al. (2009) had similar outcomes for 18 OBWO procedures. IM angle improved from 16 to 7.5, and AOFAS scores improved from 50.9 preoperatively to 81.8 postoperatively at mean 11 month follow-up [13]. Wester et al. (2016) found no statistically significant difference in AOFAS scores and VAS scores at 12-month follow-up between crescentic osteotomy and opening base wedge osteotomy. AOFAS scores improved from 59.3 to 81.5 with crescentic osteotomy and improved from 61.8 to 84.8 with OBWO. IM angle correction was 6.4° with crescentic and 6.3° with OBWO [14].

The amount of correction is a concern following the basilar osteotomies. The meta-analysis of 62 studies by Schuh et al. (2013) found the CBWO provided an average of 7.2° of correction across 14 studies. The correction provided by the CBWO averaged less than the correction provided by other basal osteotomies. The OBWO, the crescentic osteotomy, and the proximal chevron osteotomy averaged 8.2° of IM angle correction. The Ludloff osteotomy averaged 9.2° of IM angle correction [50]. Resch et al. (1989) had only 3° of IM angle correction following the CBWO [5]. Three recent studies on the OBWO have found less correction compared to previous studies (Table 10.2). The inadequate correction or loss of correction in some studies may be the result of keeping the medial hinge too distal because this imparts translational deformity with correction distal to the CORA. Under correction is not inherent to the CBWO or OBWO and is the result of errors in technical planning, execution, or patient selection.

Many studies have support the use of the CBWO and OBWO with satisfactory results at short-term follow-up. Both procedures have a learning curve, and it is important to remember that the placement of the osteotomy affects the degree correction. Satisfactory outcomes also depend on sound patient selection. Coronal plane pronation of the first metatarsal and elevated PASA may adversely affect basilar wedge osteotomy outcomes. Positive metatarsal protrusion distance may increase complications following the OBWO.

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Crescentic Osteotomy

11

Ryuzo Okuda

Introduction

Numerous authors have reported the results of a proximal crescentic osteotomy combined with a distal soft-tissue procedure and have recommended it for patients with moderate-to-severe hallux valgus [1–14]. However, a proximal crescentic osteotomy is technically demanding. In addition, inadequate fixation of the osteotomy site might lead to malunion and/or loss of correction. Various fixation techniques, including use of screw [1–3, 6], Kirschner wires [7, 10, 13], screw and Kirschener wire [4, 5, 8, 11], Steinman pin [9], and plate [12, 14], have been used at the osteotomy site. Mann et al. [1] reported the results of a proximal crescentic osteotomy using Steinmann-pin or screw fixation and found dorsiflexion deformity of the osteotomy site in 28% of patients. Yasuda et al. [13] investigated the results of a proximal crescentic osteotomy using Kirschner-wire fixation and found dorsiflexion deformity in 23% of patients. Therefore, more rigid fixation technique is needed to prevent malunion and/or loss of correction in a proximal crescentic osteotomy. Chow et al. [12] examined the long-term results of a proximal crescentic osteotomy with AO T- or L-plate and stated that good clinical results can be achieved. However, stability of OA plate was not analyzed in their study. Pauli et al. [14] reported the short-term results of a proximal crescentic osteotomy using a locking X-plate and concluded that the X-plate provided good stability and allowed adequate and relatively easy fixation.

Several authors have reported that pronation of the first metatarsal was radiologically observed in patients with hallux valgus and suggested that pronation of the first metatarsal is intimately related and appear to contribute to the development of hallux valgus [15–21]. A few recent studies described that pronation of the first metatarsal was corrected with correction of the metatarsus primus varus in surgical treatment for hallux valgus and reported on clinical and radiological results of their surgical procedures [13, 22–24].

In this chapter, indication and surgical technique, consisting of the release of the distal soft tissue; excision of the medial eminence; correction of metatarsus primus varus and pronation of the first metatarsal following a proximal crescentic osteotomy; fixation at the osteotomy site using the locking X-plate; and plication of the medial part of the capsule, are presented, and surgical outcomes are reviewed in a proximal crescentic osteotomy for correction of hallux valgus.

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Indications

Proximal crescentic osteotomy with a distal soft-tissue procedure is commonly indicated for moderate-to-severe hallux valgus deformity (a hallux valgus angle ≥30° or intermetatarsal angle ≥13°) in which symptom fails to respond conservative treatment [4, 25, 26]. Although there are no strict lower limits of a hallux valgus angle and intermetatarsal angle in a proximal crescentic osteotomy, a mild hallux valgus deformity (a hallux valgus angle < 30° or an intermetatarsal angle < 12°) is mainly the indication for a distal metatarsal osteotomy [27]. The upper limits of hallux valgus angle and intermetatarsal angle which can be corrected by a proximal crescentic osteotomy are not identified. Complete correction is often not possible with a hallux valgus angle >55° or intermetatarsal angle >25° [26], and surgical results of a severe hallux valgus deformity (a hallux valgus angle > 40° or intermetatarsal angle ≥ 18°) are likely to be worse than that of a moderate hallux valgus deformity [13, 28]. A proximal crescentic osteotomy can be performed in patients of all ages except patients with open physis. The difference in surgical results between younger and older adult patients with symptomatic hallux valgus has not been found [2, 5].

Contraindications

Contraindications for a proximal crescentic osteotomy include the presence of severe osteoarthrosis and severe rheumatoid arthritis in the first metatarsophalangeal joint. The presence of severe soft-tissue contracture in the first metatarsophalangeal joint and significant instability of the first tarsometatarsal joint may be considered contraindication.

Surgical Technique

Position

With the patient in the supine position, a soft pillow is placed under the knee to set the knee joint in 20–30° of flexion.

Distal Soft-Tissue Procedure

1 Medial side of the first metatarsophalangeal joint

A 3- to 4-cm curved skin incision convexing dorsally is made on dorsomedial side of the first metatarsophalangeal joint. The adhesion between the subcutaneous tissue and the dorsal and medial parts of the capsule is carefully released so as not to injure the dorsal digital nerve, which supplies the medial site of the great toe. The abductor hallucis tendon is exposed at the medial site of the first metatarsophalangeal joint. The longitudinal capsulotomy is done at the dorsomedial part of the first metatarsophalangeal joint. And then the medial capsule and medial collateral ligament are detached at the first metatarsal head. The medial eminence of the first metatarsal head is excised to preserve the distal articular surface of the first metatarsal.

2 Lateral site of the first metatarsophalangeal joint

A 2-cm dorsal longitudinal skin incision is made between the first and second metatarsal heads. The medial capsule and the adductor hallucis tendon is carefully exposed so as not to injure the deep peroneal nerve, which supplies the great toe and second toe. The adductor hallucis tendon, including the transverse and oblique heads, is then dissected from its insertions in the base of the proximal phalanx and the lateral sesamoid. The transverse metatarsal ligament is released carefully so as not to injure the neurovascular bundle located directly under this ligament. A longitudinal capsulotomy is made at the dorsolateral part of the first metatarsophalangeal joint so that the sesamoids are reduced under the metatarsal head as much as possible (Fig. 11.1). Afterward, intraoperative confirmation that the valgus and pronation deformities of the great toe can be manually corrected is obtained. If correction of the valgus and pronation deformities is not complete, additional release of the lateral capsule of the first metatarsophalangeal joint, including a part of the lateral collateral ligament, is required.

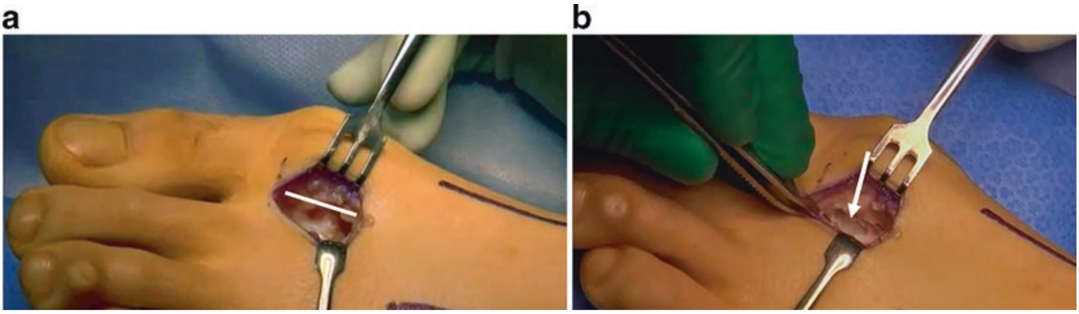

Fig. 11.1 (**a**) A longitudinal capsulotomy is made at the dorsolateral part of the first metatarsophalangeal joint (*white line*). (**b**) The articular surface of the lateral sesamoid is observed after a capsulotomy (*white arrow*)

Crescentic Osteotomy

A 3- to 4-cm dorsomedial longitudinal skin incision is made over the first metatarsal base. The extensor hallucis longus tendon is exposed so as not to injure the medial dorsal cutaneous nerve or the dorsal digital nerve. The longitudinal incision is made along the medial side of the extensor halluces longus tendon. The extensor hallucis longus tendon is retracted laterally to expose the first metatarsal base. The periosteum of the first metatarsal base is longitudinally incised by lengths of 3–4 cm, and the full circumferential release of the periosteum is performed. The first tarsometatarsal joint (TMT joint) is identified using the tip of an elevator. The osteotomy site which is located 1.5 cm distal to the first TMT joint is marked with surgical marking pen. A crescentic osteotomy is performed with a curved saw blade. The osteotomy is curvilinear, and the concavity of the cut is directed distally. The direction of the osteotomy is perpendicular to the sole of the foot on the coronal plane and is perpendicular to the long axis of the first metatarsal on the sagittal plane.

Supination Stress of the Great Toe

After completion of a distal soft-tissue procedure and a proximal crescentic osteotomy of the first metatarsal, supination stress of the great toe is performed for assessing intraoperative correction of hallux valgus and metatarsus primus varus, the shape of the lateral edge of the first metatarsal, and the sesamoid position. The maneuver of supination stress of the great toe is as follows: the plantar surface of the foot is placed on the image intensifier. The great toe is grasped, and gentle axial traction is applied by pulling on great toe, and then supination stress is manually applied to the great toe under dorsoplantar fluoroscopic view (Fig. 11.2) [19]. Dorsoplantar fluoroscopic image of the foot is obtained under supination stress (Fig. 11.3). When good corrections of a valgus deformity and metatarsus primus varus, reduction of the sesamoids, and a negative round sign of the lateral edge of the first metatarsal head are observed, the releases of the distal soft tissue and subperiosteum at the osteotomy site are

Fig. 11.2 The plantar surface of the foot is placed on the image intensifier with the ankle in plantar flexion of 20–30° and the metatarsophalangeal joint of the great toe in extension of 10–20° while the patient is in supine position. The great toe is grasped, and gentle axial traction is applied by pulling on the great toe

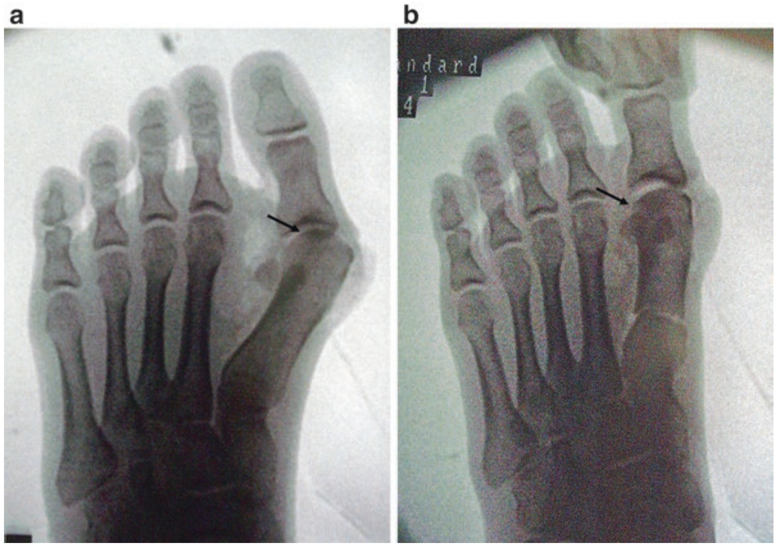

Fig. 11.3 (**a**) Intraoperative dorsoplantar fluoroscopic image is made without supination stress of the great toe and shows a hallux valgus deformity, metatarsus primus varus, lateral deviation of the sesamoids, and a positive round sign (*black arrow*). (**b**) Intraoperative dorsoplantar fluoroscopic image is made under supination stress of the great toe and shows correction of a hallux valgus deformity and metatarsus primus varus, reduction of the sesamoids, and a negative round sign (*black arrow*)

considered to be adequate. The shape of the lateral edge of the first metatarsal head, which consist of the articular surface and the lateral cortical surface of the metatarsal head on the dorsoplantar radiograph, is classified as one of three types, round (type R), angular (type A), or intermediate (type I) according to a previously published measurement system [18]. The round sign as being positive is defined when the shape of the lateral edge is classified as type R, and it as being negative when the shape of the lateral edge is classified as type I or A.

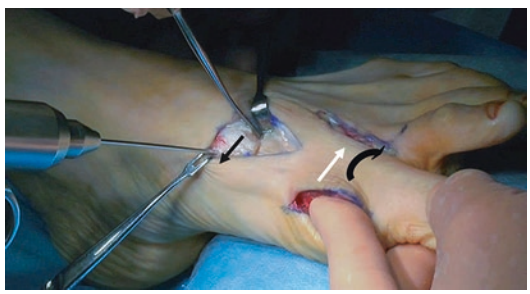

Fig. 11.4 The proximal fragment is pushed medially with an elevator as much as possible (*black arrow*), and the distal fragment is moved laterally (*white arrow*), and then the distal fragment is manually supinated (*curved black arrow*)

Correction at the Osteotomy Site

The proximal fragment is pushed medially with an elevator as much as possible, and the distal fragment is moved laterally to achieve parallelism between the first and second metatarsals, and then the distal fragment of the first metatarsal is manually supinated (Fig. 11.4). Temporary fixation with a 1.5 mm Kirschner wire is performed at the osteotomy site. And then the intermetatarsal angle and the shape of the lateral edge of the first metatarsal on the dorsoplantar fluoroscopic view and the sagittal alignment of the osteotomy site on the lateral fluoroscopic view are checked. If the parallelism between the first and second metatarsals, the angular-shaped lateral edge (type A) on dorsoplantar fluoroscopic view, or good alignment of the first metatarsal on the lateral fluoroscopic view cannot be obtained, re-correction at the osteotomy site is performed. If good correction at the osteotomy site is obtained, another 1.5 mm Kirschner wire is used for temporary fixation at the osteotomy site.

Locking X-Plate Fixation

The variable angle locking X-plate (VA locking X-plate) has four holes and is available in extra-small, small, medium, and large sizes. Appropriate locking X-plate size is selected using a template of each plate size, taking into account of the relationship between the four screw holes of the locking X-plate and the proximal and distal fragments in order to achieve bicortical screw fixation in all screws. We commonly used the extra-small-sized titanium VA locking X-plate, measuring 23.5 mm in the longitudinal and 15.0 mm in the width (Fig. 11.5). When the bending of the locking X-plate is needed, the change of the screw direction due to the plate bending should be considered. After the VA locking X-plate is placed on dorsal or dorsomedial aspect at the osteotomy site, the locking X-plate is fixed with three or four 2.0-mm Kirschner wires which is the same in diameter of drill hole for the head locking screw and can be inserted at −15° to +15° deviation from the center axis of the screw hole using the conical drill sleeve (Fig. 11.6). After confirmation of the direction of the Kirschner wires, one Kirschner wire is removed and the head locking screw inserted. The remaining three screws are inserted in the same way. And then two Kirschner wires for temporary fixation at the osteotomy are removed.

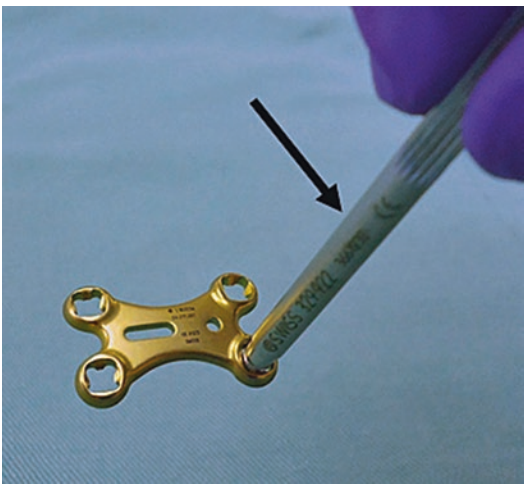

Fig. 11.5 Photograph shows titanium variable angle locking X-plate (*extra-small size*) with a plate holder (*black arrow*)

Plication of the Medial Capsule

Two drill holes are made in the metatarsal neck and head using a 1.2-mm Kirschner wire. One is drilled at the dorsomedial side of the metatarsal head in the plantar-to-medial direction and the other at the dorsomedial side of the metatarsal neck in the plantar direction (Fig. 11.7). A 2-0 braided non-absorbable suture is passed through each drill hole. The medial part of the capsule together with the abductor hallucis tendon is proximally and dorsally pulled to correct the valgus and pronation deformities of the great toe and is fixed with two intraosseous sutures. And then the capsulorrhaphy is made with absorbable sutures (Fig. 11.8).

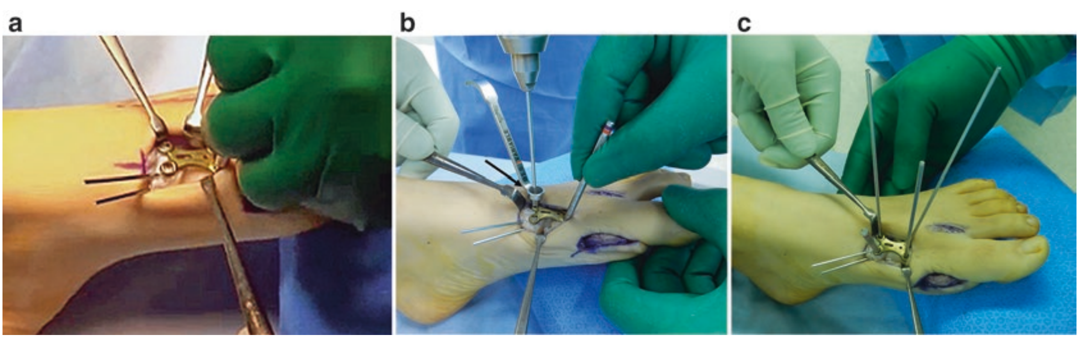

Fig. 11.6 (**a**) The VA locking X-plate is placed on dorsal or dorsomedial aspect at the osteotomy site. (**b**) A 2.0-mm Kirschner wire is insert from a screw hole using the conical drill sleeve (*black arrow*). (**c**) The VA locking X-plate is temporally fixed with three or four 2.0-mm Kirschner wires

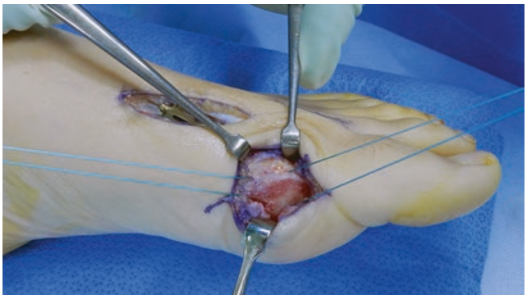

Fig. 11.7 A 2-0 braided non-absorbable suture is passed through each drill hole

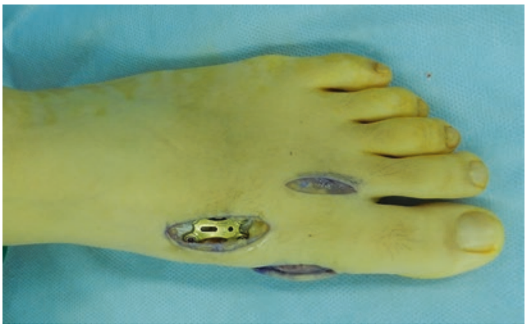

Fig. 11.8 Intraoperative appearance after correction of a hallux valgus deformity

Final Fluoroscopic Check

Intraoperative fluoroscopic dorsoplantar and lateral views of the foot are made to evaluate the hallux valgus angle (<15°), the intermetatarsal angle (<10°), the sesamoid position (<V according to Hardy classification), a round sign (negative), and sagittal alignment of the first metatarsal (no angulation at the osteotomy site).

Postoperative Treatment

A short-leg cast with rubber heel was continued for 2 weeks. A partial weight-bearing was allowed 1 day after surgery. Two weeks after surgery, a short-leg plaster shell was applied and active and passive extension and flexion exercises of the first metatarsophalangeal joint was encouraged. Three weeks after surgery, patients were instructed to wear street shoes with an arch support. Four weeks after surgery, full weight-bearing was allowed. Patients could participate in sports activity 2 or 3 months after surgery.

Surgical Outcomes

Clinical and radiological results in the literature are shown in Table 11.1. The mean American Orthopaedic Foot & Ankle Society hallux-metatarsophalangeal-interphalangeal (AOFAS) scores after a proximal crescentic osteotomy have ranged from 91 points to 96 points and significantly improved compared to preoperative scores, although there were various fixation methods and differences in follow-up periods among the articles [1–3, 6, 10, 11, 13, 14, 28]. The mean pain, function, and alignment scores on the AOFAS scale significantly improved after a proximal crescentic osteotomy [6, 11, 13, 14]. The mean hallux valgus and intermetatarsal angles after a proximal crescentic osteotomy have ranged from 9° and 5° to 16° and 9°, respectively, and significantly improved compared to preoperative angles [1–3, 6, 10, 11, 13, 14, 28]. The rate of patient satisfaction after a proximal crescentic osteotomy ranged from 85% to 96% in the literature (Table 11.1) [1–3, 6, 10, 11, 14].

Complications

Recurrence of Hallux Valgus

Recurrence is one of the most common complications and is associated with the deterioration of surgical outcomes [1, 7, 11, 29]. Several authors have reported a rate of postoperative recurrence of hallux valgus of 4–25% following a proximal crescentic osteotomy, although there were various definitions of recurrence among the articles [1, 3, 5, 9, 11, 13, 30]. The recurrence of hallux valgus after a proximal crescentic osteotomy may occur for various causes, including incomplete

Table 11.1 Clinical and radiological results of a proximal crescentic osteotomy in the literature

	Authors	No. of feet	Age*	Follow-up*	Pre-/postoperative HVA (°)*	Pre-/postoperative IMA (°)*	Pre-/postoperative AOFAS score*	Satisfaction rate
1992	Mann et al.	109	52 years (10–83 years)	34 m (24–56 m)	31(15–54)/9(−11–44)	14(6–20)/6(−3–19	–	95%
1992	Thordarson et al.	33	55 years (29–75 years)	28 m (24–36 m)	38/14	19/5	–	94%
1996	Dreeben et al.	28	48 years (14–65 years)	5.3 years (4–7 years)	33.5(15–48)/10.8(−13–29)	16.9(14–30)/5.6(−4–10)	–	85%
1997	Markbreiter et al.	25	56 years (24–74 years)	62 m (40–141 m)	38(25–60)/12(−12–42)	16(8–22)/6(0–13)	47/93	96%
2001	Veri et al.	20	52 years (23–57 years)	12.2 years (11.4–13 years)	37(24–60)/13(−14–34)	16(13–26)/6(0–14)	–	94%
2005	Okuda et al.	55	50 years (13–77 years)	62 m (36–132 m)	37(25–62)/13(−7–29)	17(8–23)/7(0–14)	–	95%
2007	Coughlin et al.	122	55 years (22–78 years)	27 m (24–37 m)	30(20–53)/10.0	14.5(7–23)/5.4	57(29–83)/91(60–100)	93%
2008	Okuda et al.	M:24	48 years (20–77 years)	31 m (12–81 m)	32(23–40)/11(5–17)	15(12–17)/6(2–9)	53(49–67)/96(77–100)	96%
		S:30	54 years (33–78 years)	30 m (12–90 m)	40(28–56)/16(0–33)	19(16–25)/9(−2–17)	56(49–70)/96(82–100)	
2015	Yasuda et al.	83	60 years (26–83 years)	34 m (25–52 m)	39(27–60)/11(0–42)[a]	18(12–28)/8(0–17)	58(22–78)/94(62–100)	NS
2016	Pauli et al.	94	56 years (17–81 years)	12 m	32(10–47)/16(−6–38)	16(11–24)/9(4–18)	60/93	NS

M moderate deformity, *S* severe deformity, *HVA* hallux valgus angle, *IM* intermetatarsal angle, *NA* not available
[a]Four feet (5%) with a hallux varus was excluded. *Values are given as the mean with the range in parentheses

release of the soft tissue, insufficient plication of the medial capsule and the abductor hallucis tendon, insufficient correction of the metatarsus varus, increased distal metatarsal articular angle, a positive round sign at the lateral edge of the first metatarsal head, incomplete reduction of the sesamoids, and instability of the first TMT joint [4, 7, 18, 29, 30].

Intraoperative undercorrection is one of the causes. However, adequate correction can be intraoperatively achieved in most hallux valgus surgery. Therefore, it is difficult to determine whether recurrence was caused by intraoperative undercorrection or not. Required intraoperative correction of HV and IM angles for preventing recurrence is little available information. Okuda et al. [31] investigated the relationship between the hallux valgus and intermetatarsal angles at the early follow-up and recurrence of hallux valgus at the final follow-up and found that the hallux valgus angle of 15° or less and intermetatarsal angle of less than 10° at the early follow-up were decreased risk factors for recurrence at the final follow-up. Therefore, the intraoperative correction of the hallux valgus angle of 15° or less and intermetatarsal angle of less than 10° are recommended.

Increased distal metatarsal articular angle is one of the causes of recurrence [32, 33]. In a proximal crescentic osteotomy, the distal fragment of the first metatarsal is laterally rotated on the horizontal plane at the osteotomy site so that the distal metatarsal articular angle is increased after correction of the metatarsus primus varus. Excessive rotation of the distal fragment should be avoided by adding the lateral translation of the distal fragment at the osteotomy site.

Postoperative positive round sign at the lateral edge of the first metatarsal head can be a risk factor for recurrence of hallux valgus [18]. Positive round sign of the first metatarsal head on the dorsoplantar radiograph of the foot was significantly associated with increased pronation of the first metatarsal [18, 34, 35]. From an anatomical point of view, the first metatarsal head presents a convex articular surface in the sagittal (lateral) and horizontal (dorsoplantar) planes that extend farther proximally on the plantar aspect than the dorsal aspect, and its lateral and medial sides are flattened. The lateral surface of the metatarsal head appears on the dorsoplantar radiograph when the pronation of the first metatarsal increases. Consequently, the lateral edge of the first metatarsal head presents a round shape on the dorsoplantar radiograph.

Postoperative incomplete reduction of the sesamoids can be a risk factor for recurrence of hallux valgus [30]. It is desirable to obtain intraoperative conformation that the sesamoids are reduced under the first metatarsal head. If incomplete reduction of the sesamoids is identified, additional release of the dorsolateral aspect of the capsule and/or the lateral collateral ligament at the first metatarsophalangeal joint is recommended to obtain a reduction. Residual pronation of the first metatarsal after a proximal crescentic osteotomy may be a possible component of incomplete reduction or lateral displacement of the sesamoids. Pronation of the first metatarsal simultaneously leads to pronation of the sesamoid articular surfaces of the first metatarsal head. Lateral displacement of the sesamoids remains on the dorsoplantar plane, even though the sesamoids are reduced in a situation that pronation of the first metatarsal is not corrected. Correction of pronation of the first metatarsal is recommended to obtain normal position of the sesamoids.

To avoid postoperative recurrence of hallux valgus, meticulous attention should be paid to the surgical technique and intraoperative fluoroscopic check for correction and alignment on the dorsoplantar and lateral planes.

Hallux Varus

Several authors have reported a rate of postoperative hallux varus (the hallux valgus angle < 0°) of 2–12% following a proximal crescentic osteotomy [1–3, 5, 6, 10, 13]. Hallux varus may occur for several causes: overplication of the medial capsule, excessive release of the lateral capsule and/or lateral collateral ligament, excessive resection of the medial eminence, and overcorrection of the metatarsal primus varus. Hallux varus tends to occur in severe hallux valgus deformity (preoperative hallux valgus angle of 40° or greater) [13, 28]. In some patients with severe hallux valgus, it is difficult to intraoperatively correct a valgus deformity at the first metatarsophalangeal joint due to contracture of the lateral capsule and/or lateral collateral ligament. In such a case, excessive release or incision of the lateral capsule and/or the lateral collateral ligament is likely to be performed to obtain adequate correction of a valgus deformity of the great toe. The author recommends that the release of the lateral capsule should not be done so excessively that the great toe can be easily brought to obvious hallux varus with manual correction. Overcorrection of the metatarsal primus varus (the intermetatarsal angle of 0° or less) may be observed in hallux varus following a proximal crescentic osteotomy, although it is still unknown whether overcorrected intermetatarsal angle is a cause or as a result of hallux varus. To avoid the overcorrection of the metatarsal primus varus, it is important to achieve parallelism between the distal fragment of the first metatarsal and the second metatarsal.

Dorsiflexion Deformity of the First Metatarsal

Dorsiflexion of the distal fragment, which was caused by incorrect positioning of the distal fragment, inadequate fixation, or early postoperative weight-bearing, is one of the common complications following a proximal crescentic osteotomy [1, 2, 5, 9, 13, 29, 36]. Mann et al. [1] found dorsiflexion deformity of the first metatarsal in 28% of patients who had a proximal crescentic osteotomy with screw fixation and stated that postoperative dorsiflexion of the first metatarsal did not influence the prevalence of transfer metatarsalgia. Yasuda et al. [13] investigate the relationship between dorsiflexion deformity and clinical outcomes and found dorsiflexion deformity in 23% of patients who had a proximal supination osteotomy with Kirschner-wire fixation and no evidence to support the notion that dorsiflexion deformity influences the postoperative clinical outcomes. On the other hand, some authors suggested that postoperative dorsiflexion may cause transfer metatarsalgia [2, 5, 36]. Thordarson et al. [2] found that the angle of declination of the first metatarsal, which was proposed by them, decreased by an average of 6.2° after a proximal crescentic osteotomy and stated that postoperative dorsiflexion of the first metatarsal may lead to intractable plantar callosities. Although the influence of dorsiflexion deformity of the first metatarsal on clinical outcome is still unclear, rigid fixation is desirable to avoid dorsiflexion deformity, loss of correction, delayed union, or nonunion at the osteotomy site. Some authors recommended plate fixation to address these concerns and improve stability instead of screw or Kirschner-wire fixation [12, 14, 37]. Chow et al. [12] reported on the long-term results of a proximal crescentic osteotomy using AO T-plate or L-plate and stated that good clinical and radiological results can be achieved. However, they did not report dorsiflexion deformity and loss of correction at the osteotomy site. Pauli et al. [14] investigated clinical outcomes and the fixation stability of a proximal crescentic osteotomy when using the small head locking X-plate and found that satisfactory and reproducible results in terms of stability, clinical outcomes, bone healing, and patient satisfaction. Ohbo et al. [38] investigated the fixation stability of the VA locking X-plate in a proximal crescentic osteotomy, which is described in this chapter, and stated that postoperative dorsiflexion deformity and loss of correction were not observed at the osteotomy site. The locking X-plate may provide a rigid fixation and lead to a low rate of dorsiflexion deformity, loss of correction, delayed union, or nonunion in a proximal crescentic osteotomy, although further investigations are required.

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Scarf Procedure and Rotational Scarf Procedure

12

Sarah E. Haller, Brett J. Waverly, and Lowell Weil, Jr.

Background

The scarf osteotomy is based on a structurally stable bone cut fashioned after a long used construction principle. The Jupiter's cut of carpenters was first documented in Aegina, Greece, in the fifth century B.C. within a temple (Fig. 12.1). Described as an oblique cut with two heels, this cut was used initially for lengthening beams (Fig. 12.1), supporting large vaulted cathedrals, and providing implicit long-term structural stability for nautical vessels, homes, and coliseums. The main significance of the scarf configuration is focused around the long interfragmental contact and the double chevron cut on either end, lending itself to the primary stability of the cut. This cut is well known to carpenters, which can be seen throughout history in structural design with an abundance of applications. In foot surgery, the focus is combining the two fragments after performing a transverse osteotomy with reduction of osseous malalignment (Fig. 12.2).

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The debut of the Z-cut osteotomy in 1976 by Burutaran of San Sebastian, Spain, was performed in conjunction with the Keller arthroplasty for primary bunion correction [2, 9]. This osteotomy was revised, by Gudas and Zygmunt in 1982 with a full-length horizontal "Z" cut in the mid-shaft of the first metatarsal with a 50/50 transverse osteotomy [1]. Continued modifications to the initial "Z" lent itself to the scarf osteotomy originally described by Weil, Sr., in 1984. The scarf osteotomy was an evolution of the "Z" and incorporated a more distally cancellous cut in the metaphyseal head of the first metatarsal and more proximal cut at the metatarsal flare. The distal cut was performed at a 70–90° angle to avoid the fragility of a more angular osteotomy and to maintain the cut in the denser and stable metaphyseal bone. The cuts were made distally at the dorsal one-third of the metatarsal and proximally at the plantar one-third of the metatarsal. All of these alterations lead to the ability for increased correction while preventing the most common limitations seen in literature [2, 8, 11]. This powerful osteotomy gained increasing popularity with the publications and long-term follow-up by Barouk and Weil et al. [2, 7].

Frontal plane correction has been discussed since the early 1980s, and recent advancements with frontal plane rotation have altered thoughts and imparted a new component to bunion correction [3–6]. Triplanar deformities can be corrected if deemed necessary, with the preoperative and

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Fig. 12.1 Demonstration of the Jupiter cut in a market in Auvillars (Haute Garonne), France

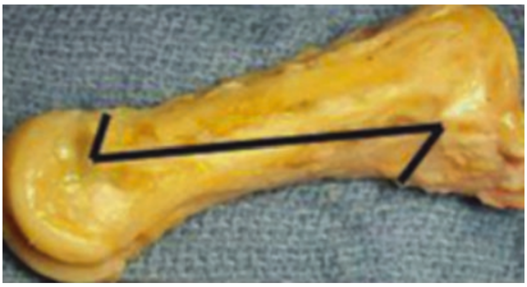

Fig. 12.2 Depiction of the long inter-fragmental contact and the double chevron cut distal dorsal and proximal plantar on a cadaveric model of the first metatarsal

intraoperative confirmation, by performing a rotational scarf osteotomy. By performing this de-rotational osteotomy, there is no loss of corrective power within the transverse or sagittal plane.

Indications

The scarf osteotomy has been shown to correct intermetatarsal (IM) angle up to 23°, proximal articular set angle (PASA) of 10°, and a hallux interphalangeus angle as high as 35° with additional adjunctive procedure of an Akin osteotomy [2, 10]. Indications for the scarf bunionectomy are:

1. IM angle of 12–23°
2. True IM angle greater than 12°
3. Minimal to no arthritic changes at the first metatarsophalangeal joint with at least 40° of dorsiflexion

Preoperative Imaging

All patients are evaluated clinically and corroborated with bilateral weight-bearing radiographs: consisting of anterior-posterior (AP), lateral (LAT), sesamoid axial (SA), and oblique views. All foot radiographs should be weight bearing, especially if evaluating hallux valgus deformity to fully appreciate the pathology. The AP weight-bearing view is utilized to assess the hallux valgus angle (HA), first and second IM angle, metatarsal parabola, metatarsus adductus (MA) angle, and tibial sesamoid position (TSP). Other angles that can be observed on weighting bearing AP radiographs include distal articular set angle and hallux interphalangeal angle (Fig. 12.3). The evaluation of sagittal plane deformity such as declination or metatarsus elevatus is observed on lateral weight-bearing films and should be accounted when determining appropriate surgical care (Fig. 12.4). In conjunction with the TSP on weight-bearing AP films, the sesamoid axial can assist in determining any frontal plane deformity of the metatarsal as well as establish the sesamoid position in relation to the crista (Figs. 12.5 and 12.6). Radiographs, clinical exam, and appreciation of patient's goals are necessary to determine the best treatment and surgical

Fig. 12.3 The AP weight-bearing view is utilized to assess the hallux valgus angle (HA), first and second IM angle, metatarsal parabola, metatarsus adductus (MA) angle, and tibial sesamoid position (TSP). Other angles that can be observed on weight-bearing AP radiographs include distal articular set angle and hallux interphalangeal angle

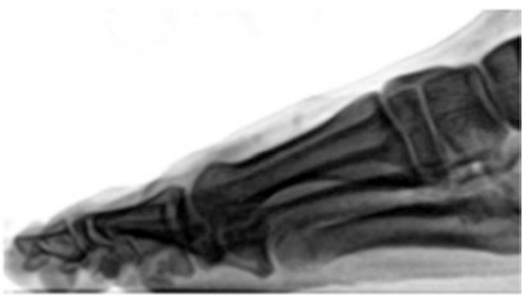

Fig. 12.4 The evaluation of sagittal plane deformity such as declination or metatarsus elevatus is observed on lateral weight-bearing films and should be accounted when determining appropriate surgical care

Fig. 12.5 The sesamoid axial can determine any frontal plane deformity of the metatarsal as well as establish the sesamoid position in relation to the crista; there is no frontal plane deviation in this preoperative weight-bearing X-ray

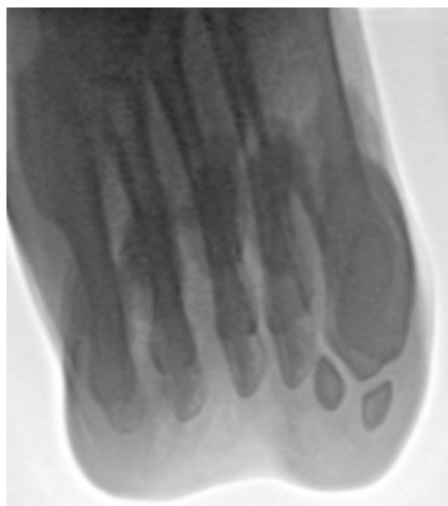

Fig. 12.6 There is a frontal plane deviation in this preoperative weight-bearing X-ray, determined by the position of the crista

intervention. Advanced imaging studies such as MRI and CT provide little additional information to the initial workup, although many have described use of 3D weight-bearing CT imaging as a beneficial imaging exam, and this is an evolving area that may have greater future benefits.

Surgical Technique

The scarf osteotomy is performed through a medial incision. The medial incision is preferred as it is void of neurovascular structures, allows better visualization and leads to better postoperative cosmetic result (Figs. 12.7 and 12.8).

Fig. 12.7 Preoperative clinical image, non-weight bearing showing substantial deviation of the first metatarsal with drifting of the great right toe. Skin markings seen are for adjunctive procedures: plantar plate repair of the second as well as an exostectomy of the IPJ of the hallux

Fig. 12.8 Preoperative clinical image, non-weight bearing. Skin markings demonstrated a 5–7 cm linear marking coursing along the declination of the first metatarsal. This incision is extended over the base of the proximal phalanx if an osteotomy is indicated

The incisional approach is medial at the junction of the plantar and dorsal skin extending 5–7 cm from the base of the proximal phalanx to the mid-segment of the first metatarsal shaft, paying careful attention to the 15-degree declination of the metatarsals (Fig. 12.9).

After the skin incision is deepened through subcutaneous tissue, the great toe is dorsiflexed to reveal a dorsal pocket to allow for dissection deep to the neurovascular bundle allowing for retraction and protection (Fig. 12.10). Next, the great toe is plantarflexed, which exposes a pocket at the most distal plantar aspect of the joint to carefully release soft tissue attachments from the capsule (Fig. 12.11). The use of single prong urologic skin hooks provides less traumatic handling of the dorsal and plantar skin and excellent exposure (Fig. 12.12).

A lenticular capsular incision is then performed, excising a fusiform-shaped portion of capsule at the level of the first metatarsal head (Fig. 12.13). This resection is not performed over the joint in order to prevent postoperative scarring, which could result in limitation of motion. The capsule and periosteum are reflected dorsally and plantarly to expose the metatarsal for osteotomy and fixation. To minimize soft tissue trauma and ensure the osteotomy can be translocated, the handle of the #3 Bard-Parker blade is utilized to free the proximal

Fig. 12.9 The skin incision is deepened through subcutaneous tissue

Fig. 12.10 Using the non-dominant hand, the great toe is dorsiflexed to reveal a dorsal pocket to allow for dissection under the neurovascular bundle to allow retraction without disturbance

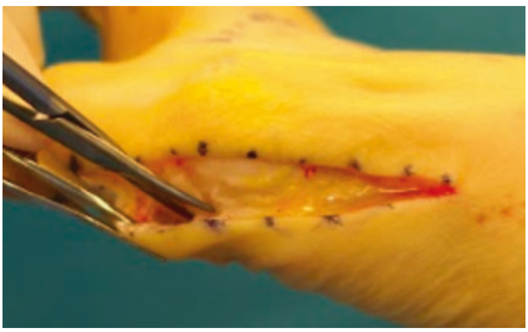

Fig. 12.11 Using the non-dominant hand, the great toe is plantarflexed which exposes a pocket at the most distal plantar aspect of the joint. This pocket demarcates to permit careful release of all soft tissue attachments surrounding the joint capsule

plantar soft periosteum under the proximal first metatarsal (Figs. 12.14 and 12.15) [17, 18].

An intra-articular sesamoid release is performed through the same incision with the use of a McGlamry elevator releasing the lateral suspensory ligament (Fig. 12.16). Through this approach, the blood supply to the first metatarsal and sesamoid apparatus is not compromised, and an adjuvant incision in the first interspace is not required (Figs. 12.17, 12.18, and 12.19) [17, 18]. This technique allows for mobilization of the sesamoid apparatus and preservation of the lateral metatarsophalangeal joint ligament, thereby maintaining stability of the joint. Manual manipulation of the great toe into extreme varus, keeping the metatarsal head within the soft tissue, should be performed to confirm a full ligament release (Fig. 12.20) [2, 12].

Fig. 12.12 Four single prong urologic skin hooks, two dorsal and two plantar, provide less traumatic handling of the dorsal and plantar skin and excellent exposure. They are held taught on the opposing side of the foot with a heavy hemostat

Fig. 12.13 A lenticular capsular incision is then performed with a #15 blade; this ellipse is initiated from proximal to distal and is carefully performed not to extend over the joint

Fig. 12.14 To minimize soft tissue trauma and ensure the osteotomy can be displaced, the handle of the #3 Bard-Parker blade is utilized to free the proximal plantar soft periosteum under the first metatarsal

Fig. 12.15 The orientation is directed from distal medial to proximal lateral along the contour of the base of the first metatarsal

Frontal plane rotation of the first metatarsal is evaluated by assessment of the joint and compared with the preoperative sesamoid axial views. If there is no rotational deformity, a standard scarf osteotomy will be performed; however, if there is a rotational component, an additional step will be added to the standard scarf procedure.

Standard Scarf Osteotomy

Prior to making any osteotomy, a smooth 0.045 Kirschner (K) wire is placed as an apical axis guide. The apical pin is placed in the dorsal one-third to one-fourth of the head of the first metatarsal to safeguard appropriate placement of the

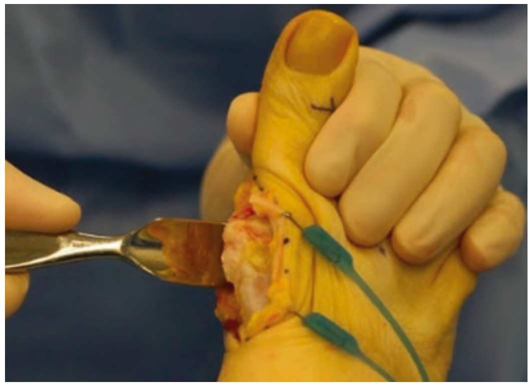

Fig. 12.16 An intra-articular sesamoid release is then performed through the same incision with the use of a McGlamry elevator releasing the lateral suspensory ligament

dorsal apex arm of the osteotomy (Figs. 12.21, 12.22, and 12.23). This ensures that the distal aspect of the osteotomy will be in the cancellous bone and not the more fragile corticomedullary bone, increasing stability and preventing the troughing effect. In addition, the osteotomy is angulated 15–30° plantarly so plantar displacement of the first metatarsal head is achieved with lateral translation and intermetatarsal correction of the capital fragment. This creates increased medial column stability and reduces the possibility of transfer metatarsalgia (Fig. 12.20).

There are three total osteotomy cuts involved in the scarf osteotomy: two vertical arms (distal dorsal and proximal plantar) and one horizontal arm. The first cut is the horizontal or longitudinal osteotomy. A specialized saw blade is utilized to ensure proper depth of cut and ease in the creation of a stable and consistent osteotomy (Fig. 12.24). The longitudinal long arm of the osteotomy is created utilizing an osteotomy guide that is placed over the K-wire previously described (Fig. 12.25). The osteotomy guide can be secured with a second wire at the proximal aspect depending on surgeon preference. Care is taken to ensure the proximal dorsal aspect of the metatarsal that is two-thirds of the shaft prevents dorsal stress fractures at the proximal metatarsal, as the patient will be immediately weight bearing.

Next, the distal dorsal transverse arm of the osteotomy is performed at the metaphysis of the

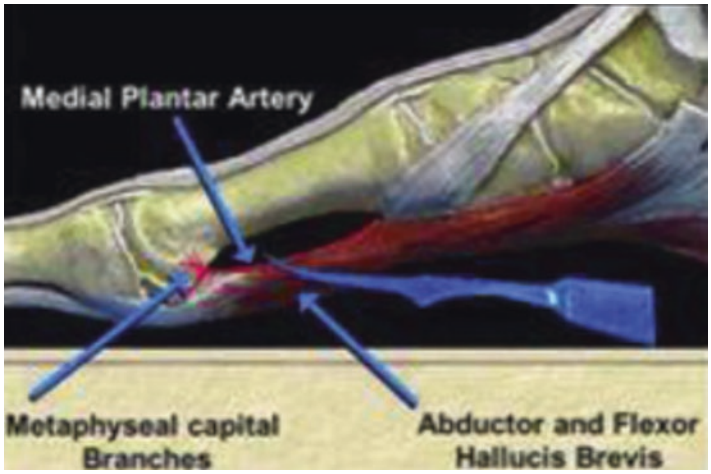

Fig. 12.17 Arterial supply to the first metatarsal head

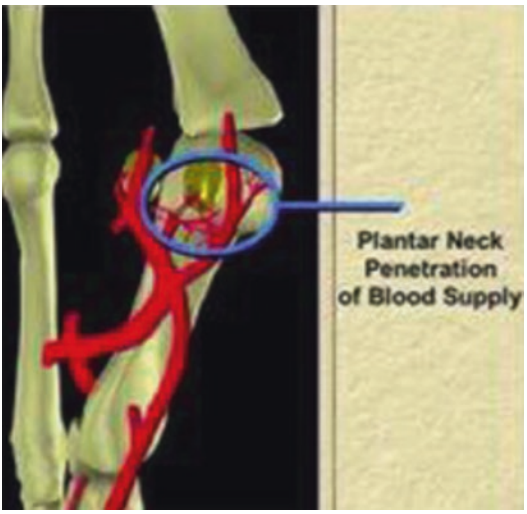

Fig. 12.18 Plantar arterial supply to the first metatarsal head

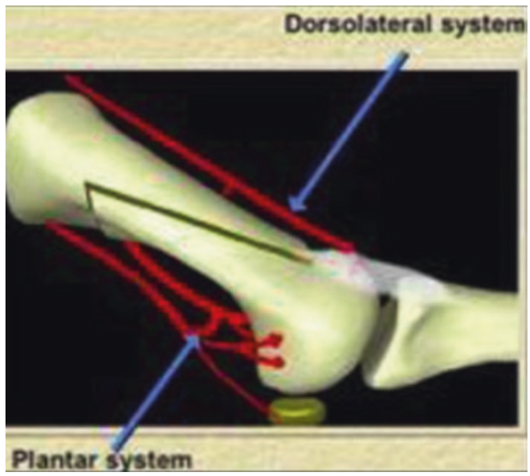

Fig. 12.19 Plantar arterial supply and dorsolateral system of the first metatarsal head

first metatarsal head. The apical axis guide placed at the dorsal distal first metatarsal assists in orienting the cut (Figs. 12.26 and 12.27) and ensuring that all osteotomies are in the same plane, which improves stability and minimizes intraoperative complications. The guide is oriented 70–90° from the longitudinal cut of the first metatarsal, roughly 5 mm proximal to the dorsal articular cartilage of the first metatarsal head. It is important to keep this cut in the metaphyseal bone, which increases stability and further decreases the risk of troughing in the postoperative setting. Care should be taken to retract the extensor hallucis longus and brevis tendons when performing the distal dorsal cut. Direct retraction and passive dorsiflexion of the hallux are used to protect the tendons as the dorsal arm cut is completed. The final cut is the proximal plantar transverse cut. This is typically performed without assistance of an osteotomy guide or K-wire. The saw blade is angled at a 45–60° angle to the longitudinal cut and orientated parallel to the axis of distal horizontal cut (Figs. 12.28 and 12.29). Once all cuts are completed, lateral translation of the osteotomy is then performed utilizing a "push-pull maneuver." A "dart" or small osteotome is used to assist in lateral translation of the

Fig. 12.20 Manual manipulation of the great toe into extreme varus, keeping the metatarsal head within the soft tissue, should be performed to confirm a full ligament release

Fig. 12.21 Dorsal view for neutral placement of 0.045 K-wire that is placed in the metatarsal head

capital fragment. A phalangeal clamp stabilizes the proximal fragment (Fig. 12.30) while gently pulling medially as the capital fragment is pushed laterally to correct the intermetatarsal deformity. It is important to push the capital fragment at the longitudinal osteotomy arm to prevent transverse plane rotation of the metatarsal head (Fig. 12.31).

Once adequate translation and correction are achieved, the hallux should be manipulated into a plantar varus position, manually holding the capital fragment in place while a "scarf clamp" is placed from medial to lateral at the first metatarsal diaphysis to gently compress and stabilize the longitudinal arm of the osteotomy (Fig. 12.32).

After the clamp is placed to secure the osteotomy with desired correction of the hallux valgus deformity, two 2.3 mm partially threaded, headless compression screws are utilized to fixate the osteotomy. The first point of fixation is placed from dorsal central proximal to plantar central distal aimed at the crista of the first metatarsal head, with care not to break through the cartilage or disrupt the sesamoid apparatus. The second point of fixation is placed dorsal proximal central to plantar distal lateral engaging the plantar lateral cortex of the plantar segment of the first metatarsal (Fig. 12.33).

The medial eminence is now removed with a sagittal saw, and the overlying bone shelf is packed into the metatarsal shaft as a cortical strut graft (Fig. 12.34). The dorsal medial metatarsal head and medial cortical rim of the metatarsal are smoothed with an aggressive rotary burr and the joint is inspected and freed of any plications within the joint (Fig. 12.35).

Capsular repair is achieved using 2-0 Absorbable suture. The initial suture is placed at the plantar capsule adjacent to the tibial sesamoid and connecting to the dorsal capsular tissue. The suture is directed distal then return proximally utilizing a locking pulley stitch (Fig. 12.36) with the toe in a corrected position. The suture needle is passed through both sides of the capsule in a continuous locking stitch (Fig. 12.37). This prevents excessive knot absorption and reduces postoperative bleeding and swelling. Skin closure is achieved with a running subcuticular 5-0 absorbable and reinforced with 1⁄2-in. Steri-Strips

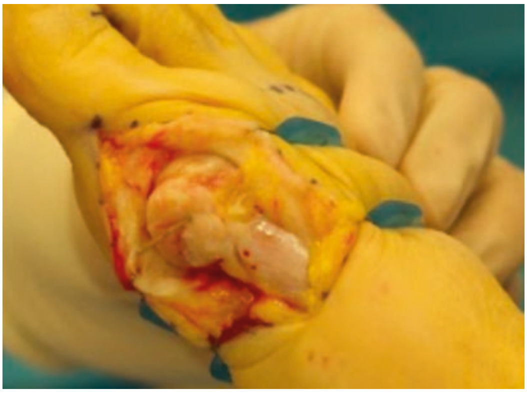

Fig. 12.22 Oblique lateral view for placement of 0.045 K-wire that is placed in the metatarsal head with plantar flexion

Fig. 12.23 Frontal plane view of placement of 0.045 K-wire that is placed in the metatarsal head

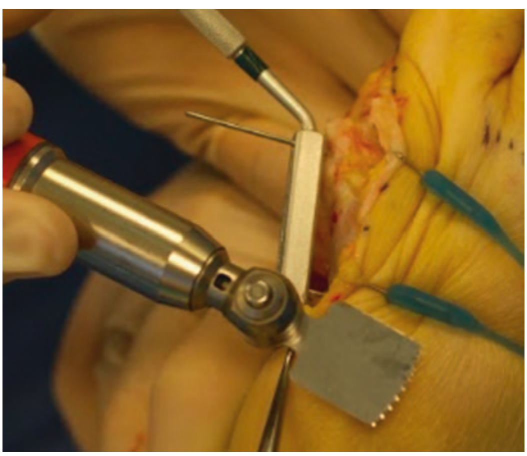

Fig. 12.24 A wide fan blade is used to create the initial transverse osteotomy with the use of the guide

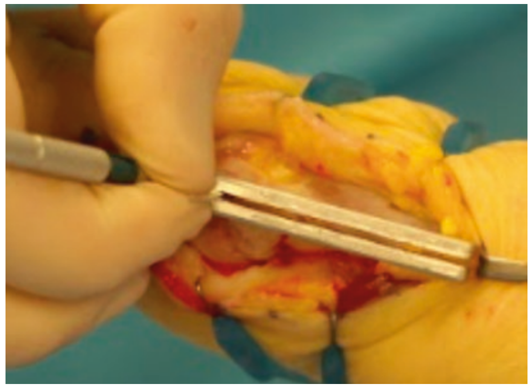

Fig. 12.25 The longitudinal long arm of the osteotomy is created utilizing an osteotomy guide, shown here, that is placed over the K-wire at the dorsal one-third to one-fourth of the head of the first metatarsal and angulated plantar proximally toward the plantar one-third to one-fourth of the proximal first metatarsal shaft

Fig. 12.26 The apical axis guide placed at the dorsal distal first metatarsal assists in orienting the cut; direct retraction and passive dorsiflexion of the hallux are used to protect the tendons as the dorsal arm cut is completed

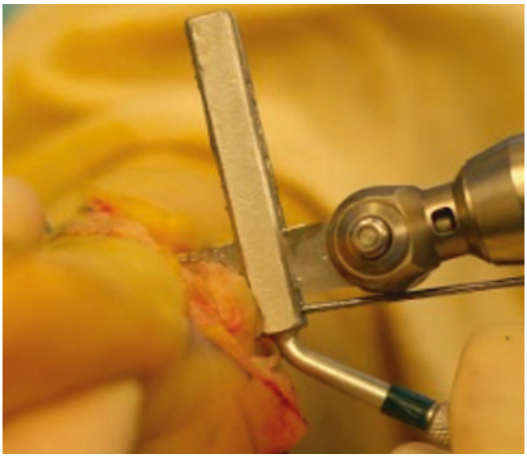

Fig. 12.27 The guide is oriented 70–90° from the longitudinal cut of the first metatarsal, roughly 5 mm proximal to the dorsal articular cartilage of the first metatarsal head

Fig. 12.28 The proximal plantar osteotomy is last; the saw blade is angled at a 45–60° angle to the longitudinal cut and orientated in the same direction of the distal K-wire. The toe is held in varus to allow for direct visualization and separation as the osteotomy is completed

Fig. 12.29 With independent blades inserted into the osteotomies, the scarf cut can be visualized, depicting the maintenance of the dorsal cortical shelf and the obliquity of the dorsal and plantar osteotomies

Fig. 12.30 Lateral translation of the osteotomy is then performed once all cuts are completed utilizing a "push-pull maneuver." A dart or small osteotome is used to assist in lateral translation of the capital fragment in opposition to a phalangeal clamp on the dorsal bone shelf. Additionally, it is important to distract the toe and tissues when shifting the metatarsal head laterally to prevent rotation and allow for maximum correction to be achieved

(Figs. 12.38, 12.39, and 12.40). A bulky compressive dressing of 4×4 gauze, Webril, and Kling is used with the first ray and hallux maintained in the corrected position. A 6-in. (15.3 cm) compressive bandage is applied to the operative extremity from the metatarsal heads to mid-calf, followed by a postoperative shoe. This bandage is left in place for 7–10 days postoperatively with guarded weight bearing in the surgical shoe.

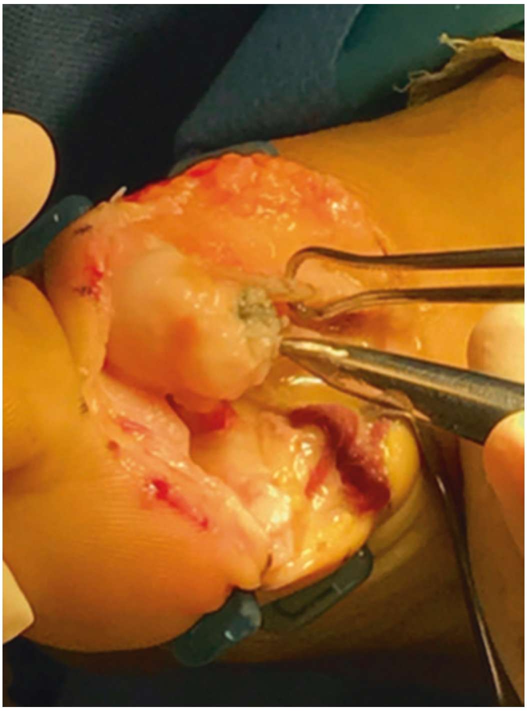

Fig. 12.31 The hallux should be manipulated into a plantar varus position to manually hold the capital fragment in place, while a scarf clamp is placed from medial to lateral at the first metatarsal diaphysis to compress and stabilize the longitudinal arm of the osteotomy

Fig. 12.32 The hallux should be manipulated into a plantar varus position to manually hold the capital fragment in place, while a scarf clamp is placed from medial to lateral at the first metatarsal diaphysis to compress and stabilize the longitudinal arm of the osteotomy

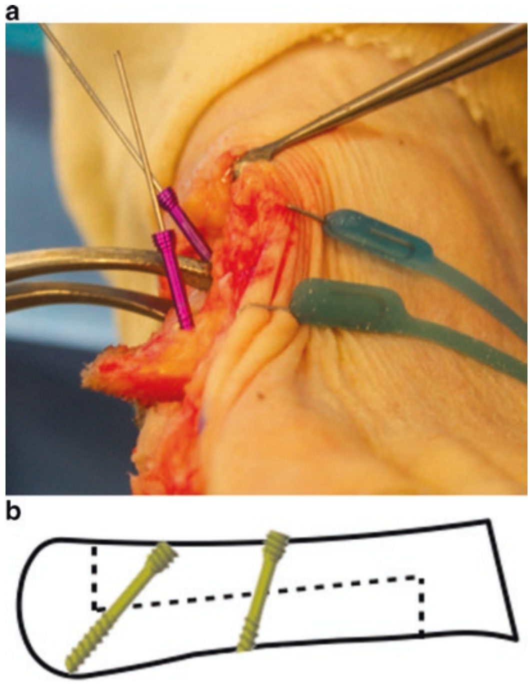

Fig. 12.33 (**a**) Two 2.3 mm partially threaded, headless compression screws are utilized to fixate the osteotomy. (**b**) The first point of fixation is placed from dorsal central proximal to plantar central distal aimed at the crista of the metatarsal head, with care not to break through the cartilage or disrupt the sesamoid apparatus. The second point of fixation is placed dorsal proximal central to plantar distal lateral engaging the plantar lateral cortex of the plantar segment

Fig. 12.34 The overlying medial bone shelf is resected and applied at the most proximal aspect of the osteotomy site as a cortical strut graft

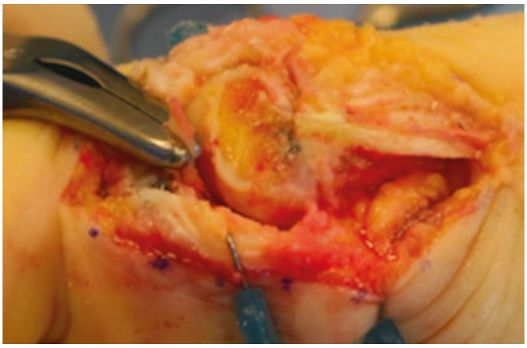

Fig. 12.35 Final contouring and inspection of the joint and osteotomy

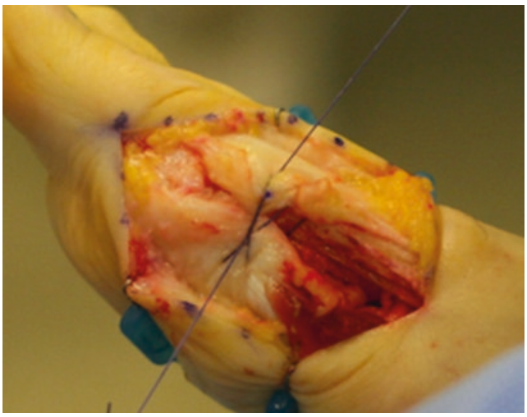

Fig. 12.36 Capsular repair is achieved using 2-0 absorbable suture. The initial suture is placed at the plantar capsule adjacent to the tibial sesamoid and connecting to the dorsal capsular tissue. The suture is directed distal then return proximally utilizing a locking pulley stitch. To evaluate the position of the toe, the skin hooks are removed and the foot is loaded to simulate weight bearing. The capsule is then released or tightened depending on the position of the great toe

Fig. 12.37 The suture needle is passed through both sides of the capsule; the free limb is wrapped around the needle three times in a locking-type fashion that allows for a locking pulley type stitch

Fig. 12.38 Dorsal view of skin closure, achieved with a running subcuticular technique with 5-0 Absorbable

Fig. 12.39 Lateral view of skin closure, achieved with a running subcuticular technique with 5-0 Absorbable

Fig. 12.40 The skin closure is reinforced with pliable 1⁄2-in. (1.27 cm) Suture reinforcement strips

Rotational Scarf Osteotomy

Incision placement and dissection for the scarf-plasty does not differ from the standard scarf osteotomy previously described. Rotation within the frontal plane is assessed on weight-bearing radiographs and sesamoid axial view. Intraoperatively, the frontal plane rotation is best appreciated during the lateral release where the head of the metatarsal is visualized while loading the forefoot. This pronated deformity can be corrected with a scarf osteotomy by resection of a medially based wedge, along the length of the longitudinal osteotomy, allowing for the frontal plane correction from 15° to 25°.

The initial smooth 0.045 K-wire is placed at the dorsal one-third to one-fourth of the head of the first metatarsal and angulated proximally toward the plantar aspect of the fourth metatarsal head (Fig. 12.41). The rotational Reese osteotomy guide (Fig. 12.42) is placed over the distal K-wire. A second smooth 0.045 K-wire is placed proximal at the plantar one-third to one-fourth aspect of the guide and angulated in line with the distal K-wire, as a stabilization point. Again, the placement of the proximal K-wire more plantar on the metatarsal to ensure the dorsal aspect of the metatarsal is two-third of the metatarsal shaft to prevent dorsal stress fractures with immediate weight bearing. The initial longitudinal osteotomy is performed, and the osteotomy guide is removed. Without removing the K-wires, the guide is then repositioned to remove a 15, 20, or 25° wedge. The amount of correction necessary is dependent on the deformity assessed intraoperatively and on preoperative radiographs. The greater angle will provide a greater amount of frontal plane correction. With the guide in place, a second longitudinal osteotomy is created (Fig. 12.43) that produces a medial wedge that is removed providing correction of the pronated rotation of the metatarsal (Figs. 12.44,12.45, and 12.46). Subsequently, the distal dorsal transverse cut is made 5 mm from the articular cartilage of the first metatarsal head at an angle of 70–90° from the longitudinal osteotomy with use of the osteotomy guide. Finally, the proximal plantar transverse cut is performed without an osteotomy guide at an angle of 45–60° to the longitudinal cut and orientated in the same direction of the distal K-wire as the cut is completed. The osteotomy is laterally translocated once all cuts are completed. Once adequate translation is achieved, the hallux should be manipulated into a plantar varus position to manually hold the capital fragment in place, while the scarf clamp is placed from medial to lateral at the first metatarsal diaphysis to gently compress and stabilize the longitudinal arm of the osteotomy. The rotational scarf osteotomy is fixated and closed in the same fashion as a standard scarf osteotomy (Figs. 12.47, 12.48, and 12.49).

Postoperative Protocol

The patient is placed in a postoperative shoe(s) with initial bandages until their first postoperative appointment at day 7–10. Weight-bearing foot radiographs are obtained and reviewed for hardware failure and maintenance of the surgical correction (Fig. 12.49). At the first postoperative visit, all bandages are removed with only the underlying Suture reinforcement strips intact. Minimal swelling should be noted at this point. Patients are allowed to bathe immediately but are instructed not to soak the surgical foot for an additional 2–3 weeks. At this time, the Steri-Strips are fully removed if they have not fallen off on their own.

At the first postoperative appointment, the patient is transitioned to running-type athletic shoes. They are instructed to remain in athletic shoes and to remove only for bathing, sleeping, and doing their physical therapy program. Athletic shoes provide increased support and improved balance compared to a walking boot or postoperative shoe. They also offer continued compression to minimize edema with increased ambulation. Physical therapy is initiated at this first visit with an aggressive home protocol with particular attention directed to flexion strength of the FHL tendon. Activity is limited to roughly one to one and a half hours total on their feet daily. Each week the patient can increase the daily total by 1 h. By the time they are seen for their second postoperative visit, they are on their feet for a total of 6–8 h daily. Patients are also allowed to drive a car as soon as they feel comfortable to do so.

The second postoperative visit is 6–8 weeks following surgery. Radiographs are used to confirm osseous bridging across the osteotomy site with maintained correction (Fig. 12.50). At this time, patients are transitioned into shoe gear of their choice with the restriction to minimize barefoot walking. They are to progress increased activities such as exercise, which includes walking, treadmill, and elliptical machine.

Fig. 12.41 The initial smooth 0.045 K-wire is placed at the dorsal one-third to one-fourth of the head of the first metatarsal and angulated proximally toward the fourth metatarsal head

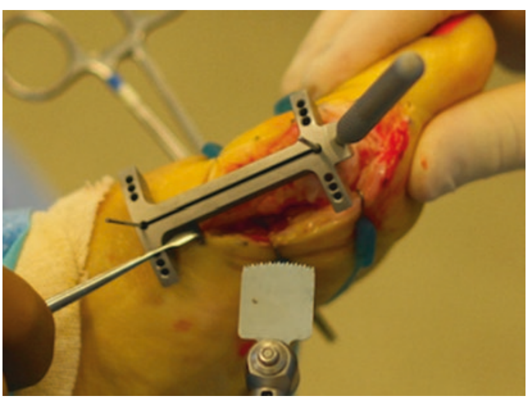

Fig. 12.42 Using a specialized osteotomy guide with predetermined medial wedge of 10, 15, and 20°, the second smooth 0.045 K-wire is placed proximal at the plantar one-third to one-fourth aspect of the guide and angulated in line with the distal K-wire, as a stabilization point

Fig. 12.43 Frontal view of the osteotomy guide placed with K-wires at the distal dorsal one-third and proximal plantar one-third with care taken to allow appropriate medial wedge resection

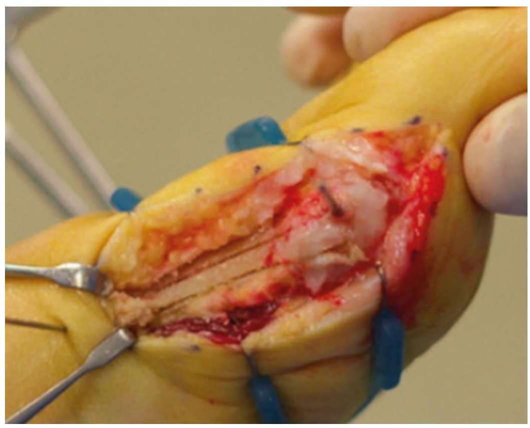

Fig. 12.44 Osteotomy guide placed with K-wires at the distal dorsal one-third and proximal plantar one-third with care taken to allow appropriate medial wedge resection. The osteotomy guide is repositioned based on desired wedge angle

Fig. 12.45 Demonstration of medial wedge to be resected in order to correct frontal plane deformity of the first metatarsal

At the 3 months, patients are able to return to all activities without restriction. Daily stretching is still encouraged daily depending on the patient's strength and range of motion. Edema to the surgical foot should be minimal at this point with the infrequent aches and pain with increased activity. Again, postoperative radiographs are obtained.

Fig. 12.46 The transverse cuts are completed distal and proximal to adequately resect the final wedge

Fig. 12.47 The procedure is completed in same fashion as standard scarf osteotomy; the osteotomy is transposed into a corrected position and subsequently fixated

Fig. 12.48 Six weeks postoperative anterior-posterior weight-bearing view

Fig. 12.49 Six weeks postoperative lateral weight-bearing view

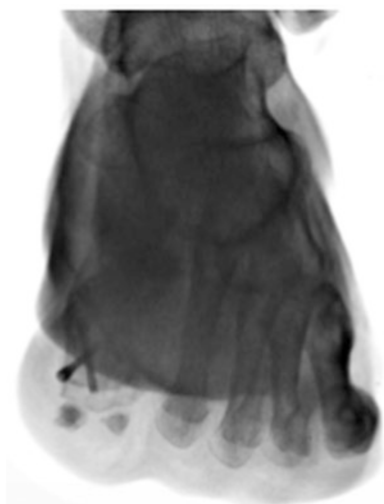

Fig. 12.50 Six weeks postoperative sesamoid axial

Complications

As with all surgery and specifically bunion procedures, the scarf bunionectomy is not without complications. The scarf osteotomy is a demanding bunion procedure with a learning curve in which the complication rate is directly tied to experience. The complications associated with the procedure are well documented and do not differ from other bunion procedures [20]. One complication unique to the scarf bunionectomy is troughing, which occurs at the rate of 1% but was seen at a rate of 35% in one study [13, 14]. Troughing occurs when the first metatarsal cortices fall down into the cancellous bone of the metatarsal, most notably observed during the time of fixation when the cortical bone is compressed into the cancellous portion. This occurrence can lead to malunion, frontal plane rotation deformity, and elevation of the first ray. Troughing is more prevalent in elderly patients and those with osteopenia [19]. Placing a bone graft or strut graft to the plantar proximal aspect of the osteotomy has been shown to minimize troughing in the postoperative period [19]. It has been our experience that when the scarf osteotomy is performed with an osteotomy guide and distally in the cancellous metatarsal head, the incidence of troughing is greatly diminished.

Other complications of the scarf are recurrence (6%) [15], hallux varus (3–5%) [9, 11, 16], stress fractures of the metatarsal (3%) [11], and transfer metatarsalgia (2%) [11]. Despite the steep learning curve, the complications associated with the scarf procedure can be minimized with experience and attention to the surgical technique. Overall, patient satisfaction rates of the scarf bunionectomy, whether unilateral or bilateral, is extremely high with up to 97% of patients stating they would undergo surgical repair of their bunion under the same circumstances [11].

Summary

The scarf osteotomy is a versatile procedure that has been well researched for the correction of hallux valgus deformity in the adolescent and adult populations. It differs from the "Z osteotomy" as the scarf osteotomy's distal cut is within the metaphysis of the first metatarsal head versus the diaphyseal-metaphyseal junction of the distal first metatarsal seen in the "Z osteotomy." The scarf osteotomy is an inherently stable osteotomy, which allows for early weight bearing and timely return to activities of daily living. Surgical indications are wide-ranging and can be applied to the majority of hallux valgus deformities offering reproducibility and a low complication rate. Troughing, while the most documented complication with the scarf osteotomy, is substantially lessened with intraoperative consistency and use of the strut graft presented in our surgical technique. In addition, the procedure can be performed in all age groups (pediatric to geriatric) with the ability to perform concurrent bilateral correction when indicated. It provides long-term predictability and optimal satisfaction and function. Initially, the scarf osteotomy may be technically difficult, but with experience, it is an efficient and reproducible bunion procedure that addresses all severity of deformities.

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Tarsal-Metatarsal Joint Arthrodesis

13

Lawrence A. DiDomenico, Danielle N. Butto, Paul D. Dayton, Daniel J. Hatch, Bret Smith, and Robert Santrock

Background

The procedure was first described by Albrecht et al. [1] in 1911 and later popularized by Lapidus in 1934. Lapidus proposed a first metatarsal–cuneiform arthrodesis paired with arthrodesis of the second metatarsal, resection of the dorsomedial eminence of the first metatarsal head, and distal soft tissue repositioning. He believed that metatarsus primus varus was the result of an underdeveloped atavistic foot type resulting in increased intermetatarsal angle (metatarsus primus varus) and that hypermobility of the first metatarsal–cuneiform joint was a component of the pathology. Lapidus concluded that the apex of the deformity, the first metatarsal–cuneiform joint, needed to be addressed or a "bayonet-shaped" deformity would result [2]. To date, numerous modifications have been made to the original Lapidus procedure; however, all include arthrodesis of the metatarsal–cuneiform joint [3–10].

The first metatarsal–cuneiform joint combined with its surrounding ligaments form a stable segment. The base of the first metatarsal has a lateral joint surface, a medial joint surface, and an inferior joint surface. A mediodorsal and lateroplantar protuberance is commonly found, which adds rotational stability to the joint [11]. In an anatomic cadaveric study by Mason and Tanaka, it was found that the lateral plantar prominence is constantly found on the metatarsal base. The size of the prominence differs greatly and is sometimes referred to as the "lateral flange" [12]. This and other details of the anatomic structure of the first ray have a direct impact on the understanding of resultant deformities and necessary components of correction. New information related to the triplane positions on the segments and the effect that these relationships have on function are beginning to change our understanding of the

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basis and needs for correction of HAV. These anatomic and functional concepts are discussed in detail in Chaps. 2 and 6 and will be referred to in the following procedural overview.

Indications

The first metatarsal–cuneiform arthrodesis has been traditionally performed in patients with a hypermobile first ray as a prime indication. This indication has been challenged recently due to controversy regarding the location of instability, the difficulty in determining the degree of mobility, and the inconsistency of clinical assessment. Root described normal first ray range of motion as equal dorsiflexion and plantarflexion with hypermobility defined as anything beyond equal motion in the sagittal plane. To assess this, he placed the ankle and subtalar joint in neutral position then stabilized metatarsal heads two through five with one hand and the first metatarsal head in the other hand while taking the first ray through range of motion [13, 14]. Roukis et al. described the "dynamic Hicks test" to assess first ray range of motion. They described the placement of the foot and examiner's hands as described by Root. The hallux is fully dorsiflexed at the first metatarsophalangeal joint, and dorsal and plantar pressures are applied to the first metatarsal head. They believe true hypermobility exists when both tests are positive for hypermobility [15].

Further evidence suggesting the presence of first ray hypermobility has been reported based on radiographic findings according to some surgeons on anterior–posterior (AP) X-ray. Cortical thickening of the second is thought to occur secondary to overload [16]. Also diastasis between the base of the first metatarsal and/or the medial cuneiform and the base of the second metatarsal, elevated first metatarsal relative to the lesser metatarsals and painful synovitis at the second metatarsal phalangeal joint, and/or hyperkeratotic lesions under the lesser metatarsals have been identified as possible signs of hypermobility (Figs. 13.1a–d and 13.2).

In reality there is no consensus or consistency in the clinical measurement or definition of first ray hypermobility, and that is why we question the utility of this measure as a primary indication for tarsometatarsal level of correction for HAV. As discussed in Chaps. 2 and 6, the main site of mobility of the first ray is at the naviculocuneiform and talonavicular joints with a minority of motion at the TMTJ. The first metatarsocuneiform arthrodesis in reality is indicated to treat moderate to severe hallux abducto valgus as well as high levels of deformity with or without the presence of hypermobility. The main utility of the procedure is that it has the advantage of providing correction at the apex of the deformity [17, 18]. In addition, TMTJ is a convenient location to address all planes of the deformity concurrently including the transverse, the sagittal, and the frontal plane resulting in complete anatomic correction. Patients with small IMA may have significant frontal plane deformity which is why, like with hypermobility, the degree of IMA is not used as a prime indication. Sesamoid axial radiographs are recommended to assess the overall position of the first metatarsal in the frontal plane. Dayton et al. found in a case study of 25 patients that all patients had a component of frontal plane deformity. Correcting the frontal plane resulted in change in the IMA of 10.1°, hallux abduction angle (HAA) of 17.8°, and proximal articular set angle (PASA) of 18.7° [19]. Dayton et al. reviewed the data on 35 consecutive patients who underwent triplane bunion correction including derotation of the metatarsal. They found the mean amount of varus (supination) rotation performed during correction was 22.1 ± 5.2°. The mean amount of intermetatarsal angle reduction achieved was 6.9 ± 3.0°. The tibial sesamoid position changed by a mean of 3.3 ± 1.2° [20]. DiDomenico et al. evaluated the correction of the IMA and sesamoid position with frontal plane derotation and found by derotating the metatarsal that there is a significant improvement in both IMA and sesamoid position [21]. Other indications for first metatarsal–cuneiform arthrodesis include pes planus correction, treatment of degenerative joint disease (DJD), and revision HAV procedures [10, 16, 22, 23] (Fig. 13.3a–c).

Contraindications include a short first ray, because some degree of shortening is inevitable with resection of the joint, therefore further shortening an already short ray. Additionally, the

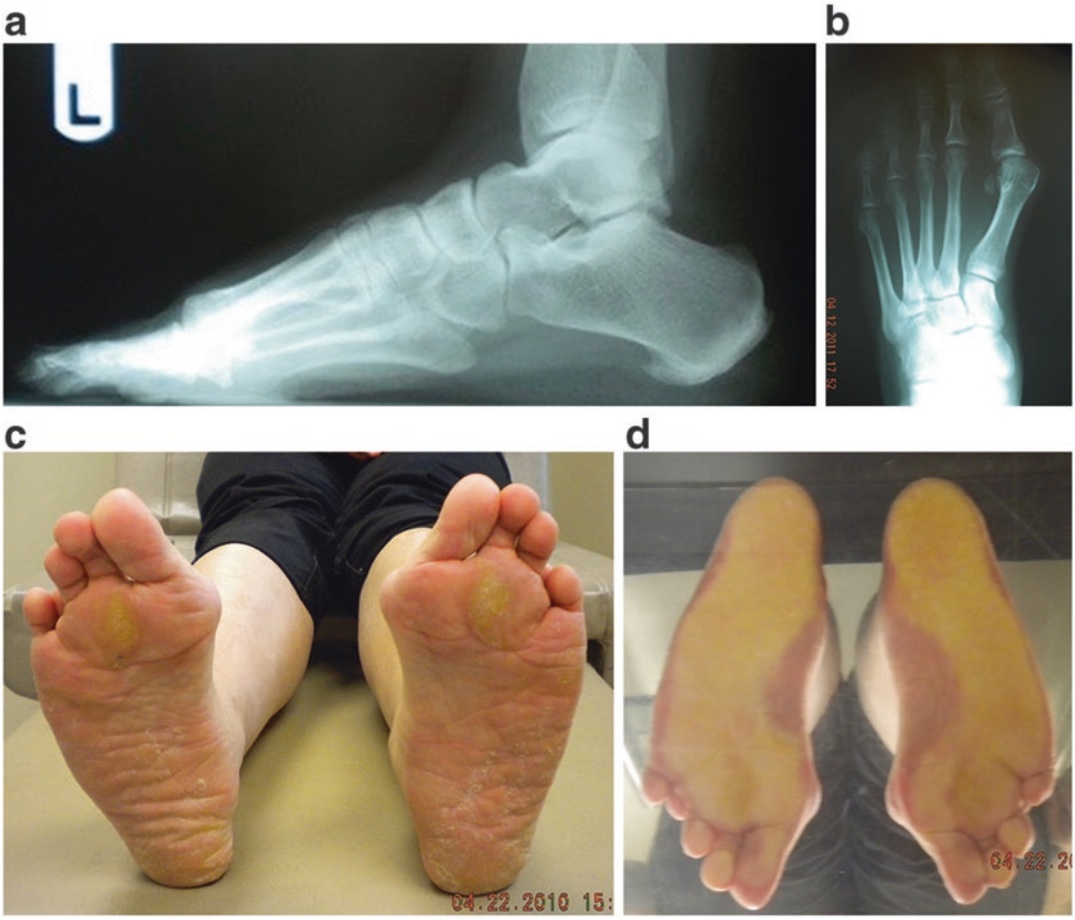

Fig. 13.1 (**a**) A lateral radiograph projection demonstrating a patient who suffers from TMT-1 hypermobility/instability. Note the dorsal cortex of the first metatarsal in comparison to the second metatarsal leading to an elevated first metatarsal. (**b**) An appearance of a "long first metatarsal" on a AP radiograph secondary to the hyper mobility. (**c**) Patient who presents with a HAV deformity bilaterally as well as a sub two callus lesion on both feet. (**d**) Note the lack of weight bearing under the first metatarsal causing the increased pressure to the sub-second metatarsal. The increase in sub-second metatarsal is secondary to the increase in the intermetatarsal (IM) angle, the elevatus of the first metatarsal (the first ray is not bearing the needed weight) along with a tight posterior muscle group increasing the forefoot load to the second metatarsal

procedure should be avoided in individuals with open growth plates.

The authors want to point out that a short first ray is very unusual in feet that have not been affected with trauma or previous surgery. Oftentimes what may appear to be a short first ray on a "single snap shot projection" more likely than not is not truly a short ray. Considerations that must be addressed when evaluating radiographs are what was the patient's position of their foot and was it fully loaded at the time of the X-ray? What was the angle of the beam relative to the foot at the time of the X-ray? Does the patient have more of a flatfoot or a high-arched foot? If a patient has more of a flatfoot, the radiograph projection will more likely than not appear long, and if patient presents with more of a high-arched foot, the first metatarsal will be more plantarflexed and appear relatively short. The surgeon needs to take this into consideration and rely on clinical evaluation as much as the radiographic evaluation.

Fig. 13.2 This is an AP radiograph from a patient who presents with a recurrent hallux abducto valgus deformity who had a previous distal metaphysical osteotomy performed. Note the diastasis of the base of the metatarsals and cuneiforms, a valgus rotation of the hallux and sesamoid complex, a previous stress fracture experienced by this patient from second metatarsal overload because of the increase in intermetatarsal angle (increasing the load to the second metatarsal as the first is not bearing the weight), and hypermobility/instability of the first ray

Technique #1

Preferred Technique: Lawrence A. DiDomenico and Daniell N. Butto

An incision is made over the metatarsal–cuneiform joint approximately 4–6 cm in length. There is no incision at the level of the first metatarsophalangeal joint or in the IM joint space. The tarsal–metatarsal incision is deepened in the same plane using sharp and blunt dissection. All bleeders are identified and ligated as necessary. The incision is carried down exposing the metatarsal–cuneiform joint. The tarsal–metatarsal ligaments are resected using a rongeur exposing the joint. Two mini Hohman retractors are used for the soft tissue retraction. Next the articular cartilage of the metatarsal and cuneiform sides of the joint are resected. The initial joint resection is performed on the first metatarsal articular surface. The first metatarsal articular surface is denuded first as this is the most distal and the most unstable segment. This resection is made perpendicular to the long axis of the first metatarsal and parallel to the existing metatarsal base. There is no correction made within the first metatarsal segment, as there is no deformity in the first metatarsal in typical HAV deformity. Thus, the articular joint resection needs to be kept consistent and parallel with the natural-occurring anatomy. The base of the first metatarsal is concave; therefore, the amount of cartilaginous resection on the base of the first metatarsal will need to be slightly greater than the amount on the convexity of the natural-occurring articular surface of the cuneiform. The corrective articular resection is made at the distal aspect of the convex-shaped cuneiform. The correction is made with a slight change in angular resection in the transverse plane. The frontal and sagittal planes are later corrected via reduction and appropriate positioning of the tarsal–metatarsal joint (Fig. 13.4).

Prior to reducing the joint into the appropriate desired position, a significant amount of time should be spent with joint preparation to ensure good bony healing. The metatarsal base and distal cuneiform as well as the medial aspect of the second metatarsal base are prepared. The authors use a laminar spreader for distraction between the first metatarsal and cuneiform. A pituitary rongeur is used to debride the cortex of the medial wall of the second metatarsal. It is imperative that the surgeon is diligent to ensure that the subchondral plate is penetrated demonstrating good bleeding at both the metatarsal and cuneiform. The joint preparation is extremely important in efforts to obtain a bony union and to avoid a delayed and nonunion (Fig. 13.5).

Next, the frontal plane is addressed. The surgeon derotates the hallux out of valgus (in a varus direction to a neutral anatomic position) in order to get the nail plate to be parallel with the ground. This derotation allows for the entire hallux, sesamoid, and first metatarsal complex to be rotated from a position of valgus and into a neutral

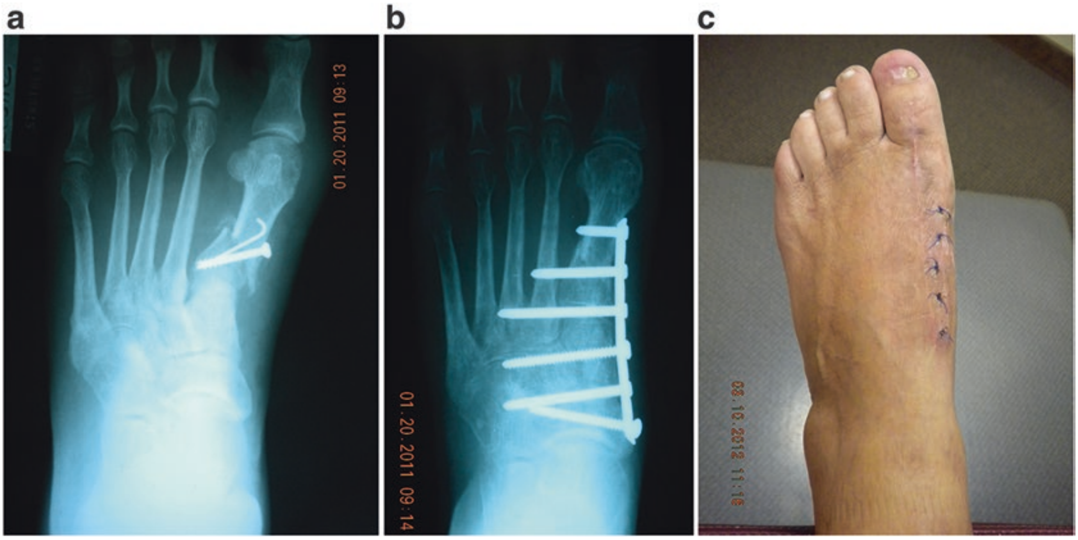

Fig. 13.3 (**a**) This is an AP radiograph of a patient who underwent a closing base wedge osteotomy of the first metatarsal with K-wire and screw fixation. The patient experienced a fracture and displacement of the osteotomy site with malalignment. (**b**) This is an AP radiograph of correction of photo 12 A who underwent a revision Lapidus procedure to correct the malalignment and displacement of the closing base wedge osteotomy. (**c**) A clinical photo demonstrating good anatomical alignment of the recurrent HAV deformity. Note the previous scars from the previous surgeries. There is only an incision at the tarsal-metatarsal joint which obtained good anatomical alignment and reduction of the deformity in all three planes. No dissection (lateral release) or medial eminence resection was performed

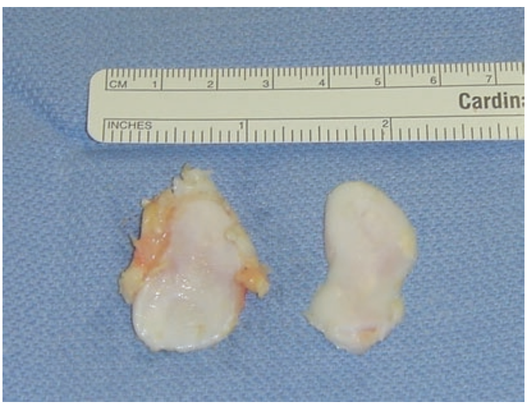

Fig. 13.4 These are the articular surfaces of the base of the first metatarsal and cuneiform following joint resection in preparation of performing a Lapidus procedure

Fig. 13.5 An intraoperative view demonstrating bone debridement of the medial base of the second metatarsal in preparation for fixation of a Lapidus procedure

position as one unit. This results in the sesamoid complex repositioned under the first metatarsal; the hallux is taken out of a valgus position into a anatomic neutral position. This rotation will be clinically evident at the tarsal–metatarsal joint as well as under fluoroscopy. Because there is no dissection at the first metatarsophalangeal joint (medial eminence resection or sesamoidal dissection), the maintenance of the soft tissues allows for the integrity of the hallux, sesamoids, and metatarsal to function as one unit. By maintaining the integrity of the soft tissues, the first metatarsal phalangeal joint maintains stability and allows the surgeon to manipulate and reposition the metatarsal phalangeal joint and the first metatarsal into a corrective anatomical alignment. If the soft tissues are dissected (historically know as a "lateral release" and medial eminence resection), this destabilization of the soft tissues will not allow the surgeon the ability to rotate and position the first metatarsal phalangeal joint and first metatarsal into anatomic alignment. The sesamoid correction can be observed under fluoroscopy at this time. The sagittal plane reduction technique is performed by stabilizing the hind foot, while the surgeon dorsiflexes the first metatarsophalangeal joint initiating the windless mechanism. This hind foot stability allows the surgeon to apply retrograde forces to the plantar tarsal–metatarsal joint and allows for the first metatarsal to plantarflex to a natural-occurring level, parallel with the lesser metatarsals. Once the surgeon has the hallux, sesamoid, and metatarsal rotated to a neutral desirable position (frontal plane reduction), and the first metatarsal sagittal plane corrected, the surgeon can use his or her thumb against the first metatarsal to manually reduce the first intermetatarsal angle in the transverse plane. The primary surgeon must ensure that the first metatarsal is in the desired position, which is essentially rotated out of valgus, and parallel with the second metatarsal in both the transverse and sagittal planes. Next a 2 mm smooth K-wire is used to stabilize the reduction and position. The first K-wire is positioned from the central proximal one-third of the first metatarsal into the cuneiform. Because of appropriate positioning of the tarsal–metatarsal joint, it is not unusual to see dorsal gapping at the tarsal–metatarsal joint. Subsequently, while maintaining position in all three planes, a second K-wire is inserted into the medial first metatarsal head and into the lesser metatarsals; this serves to prevent derotation in the frontal plane, maintains reduction in the transverse plane, as well as maintains confirmed desired position of the first metatarsal parallel to the second metatarsal (prevents elevation of the first metatarsal relative to the lesser metatarsals in the sagittal plane). If the surgeon feels a need to obtain more correction in the frontal plane, the temporary fixation K-wires can be backed out, and an additional K-wire can be inserted into the first metatarsal medial and lateral cortex with the K-wire in the direction of inferior medial to superior lateral. Once the K-wire penetrates the far cortex of the first metatarsal, the K-wire can be used as a rotation device and rotate the metatarsal into more of a neutral position (out of valgus and in a varus direction) and insert the K-wire into the lesser metatarsal to stabilize the position. In many cases, a large Weber clamp may be used to assist, increase, or maintain the reduction. When using the large Weber clamp, the surgeon must be sure not to change the sagittal plane relationship between the first and lesser metatarsals. The position is checked both clinically as well as under fluoroscopy to confirm acceptable alignment (Fig. 13.6a, b).

The recommended fixation options for this technique are three solid long cortical interfragmentary compression screws or a solid cortical interfragmentary compression screw along with a medial plate. Regardless of the construct, the first screw is the most important screw; this is often referred to as the "home run screw" [24]. This screw should be a solid long cortical screw with preference size of a 3.5 or 4 mm. A trough is created into the mid-dorsal side of the first metatarsal approximately in the proximal one-third to one-half of the metatarsal [25]. A high-speed bur is used to create a notch in the cortical bone as described by Manoli and Hansen [25]. The notch allows for drilling difficult angles such as the first metatarsal to the first cuneiform. The first metatarsal has a declination making drilling without the notch difficult, and this technique allows the surgeon to control the screw angle and also allows the undersurface of the screw head to fit better at the level of the cortex or slightly below as well as avoid external pressures such as shoes from the thin skin of the dorm of the foot, help prevent stress risers, and avoid fracturing the cortex.

The first drill is either 4.0 mm for a 4.0-mm cortical screw or 3.5 mm for a 3.5-mm cortical screw and is drilled into the first metatarsal and stopped at the cuneiform. The next drill is either 2.9 mm for the 4.0-mm cortical screw or 2.5 mm for the 3.5-mm cortical screw and drilled into the cuneiform. The drill is aimed for the inferior,

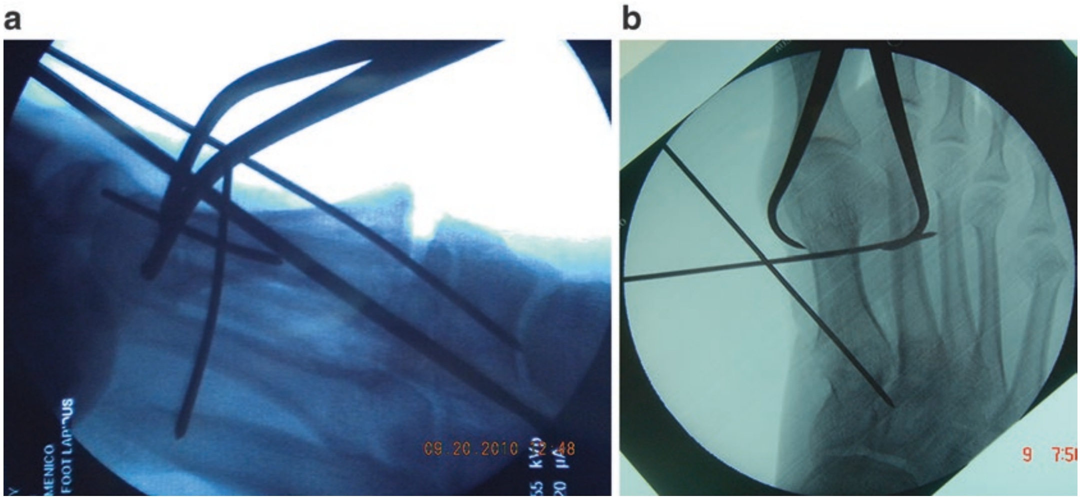

Fig. 13.6 (**a**) An intraoperative lateral radiograph demonstrating temporary K-wire fixation and a large Weber clamp for stabilization and reduction while the surgeon is drilling for the "home run" screw. Note the origin of the drill hole in the first metatarsal is as distal as possible, and it exits at the medial inferior cuneiform inferior to the navicular. The sagittal plane correction is well visualized as there is good bone-to-bone contact at the inferior metatarsal and cuneiform along with dorsal gapping at the metatarsal cuneiform superiorly indicating good sagittal plane correction of the first ray. The dorsal gapping will be backfilled with autogenous calcaneal bone graft. (**b**) An intraoperative AP radiograph demonstrating temporary K-wire fixation and a large Weber clamp for stabilization and reduction of the intermetatarsal angle in the transverse plane

medial aspect of the cuneiform (based on the shape of the cuneiform, the largest cross section of the bone is in the medial cuneiform). This screw should have a bicortical purchase; this screw provides interfragmentary compression at the plantar aspect of the joint or the tension side of the foot, and the long screw provides leverage and resistance to ground reactive forces. This allows for excellent reduction at the base of the tarsal–metatarsal joint most often leaving some dorsal gapping of the tarsal–metatarsal joint. When a three-screw construct is desired, the next screw is inserted from the medial proximal one-third of the first metatarsal into the base of the second metatarsal with the respective drill sizes for a 3.5-mm or a 4.0-mm cortical screw. The initial drill is the oversized drill through the first metatarsal, and the second drill is the undersized drill into the second metatarsal and/or possibly the lesser metatarsals in order to obtain a screw purchase and allow the surgeon to dial in with the desired intermetatarsal angle reduction. Oftentimes a washer will be applied with this screw, which provides greater reduction of the IM angle. The third screw is placed from the most proximal dorsal position of the cuneiform aiming into the medial proximal first metatarsal. This screw also should be as long as possible for obtaining leverage and resistance to ground reactive forces. The longer the interfragmentary screw, the greater the dispersion of forces and more counteraction of the tensile forces. The key to the placement of this screw is to start distally on the metatarsal and aim for the plantar-medial cortex of the medial cuneiform. The construct should be checked under fluoroscopy to confirm adequate reduction. The surgeon should check for intercuneiform instability, and if intercuneiform instability is identified, then intercuneiform joint preparation should be performed, and the medial to lateral screws should be inserted into the intermediate and/or lateral cuneiform for additional stability. It has been the authors' experience that grossly hypermobile feet and flatfoot deformities often present with intercuneiform instability [26] (Figs. 13.7a, b and 13.8).

When a medial-based plate or locking plate is used in conjunction with an interfragmentary

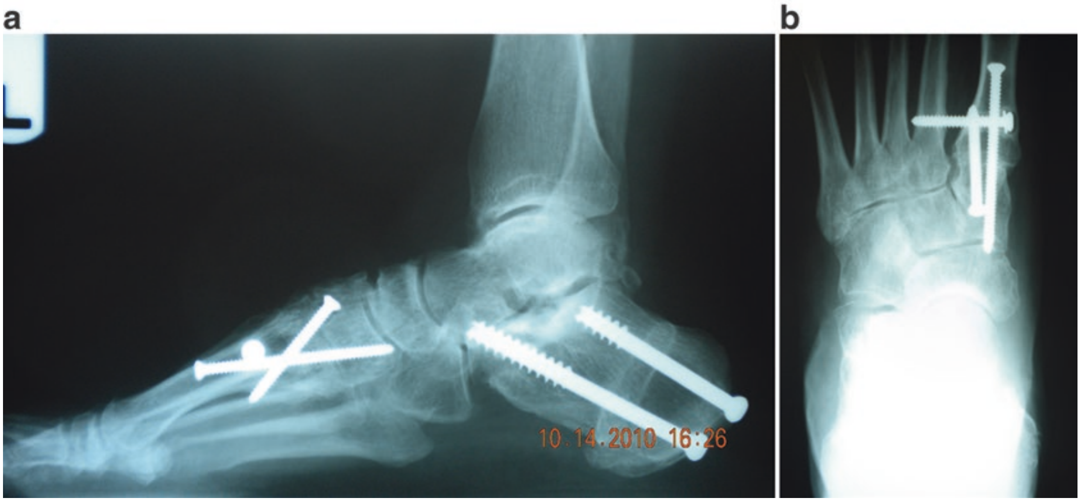

Fig. 13.7 (**a**) This is a postoperative lateral radiographic projection of a patient who had a Lapidus procedure with a three-screw technique and a percutaneous calcaneal displacement osteotomy performed. With respect to the Lapidus fixation, note the "home run" screw is long, it provides interfragmentary compression, and it is parallel to the ground (providing a "beam effect"). The cuneiform to the first metatarsal also is long and provides bicortical interfragmentary compression too, and the medial to lateral screw inserts into the base of the second metatarsal also with bicortical interfragmentary compression. Note the screw heads are countersunk below the cortex because of the thin soft tissue envelop of the skin in the foot and to provide relief from external pressures such as shoes 42. (**b**) This is a postoperative AP radiograph of a patient who had a Lapidus procedure performed with a three-screw technique. Notice the length of the "home run" screw – the authors recommend between 50 and 60 mm of length. The "home run" screws are inserted in the most medial aspect of the inferior cuneiform (area of most bone in the cuneiform). Because of the thin soft tissue envelope of the foot, the transverse screw head is also countersunk to avoid external pressures such as shoe gear. The transverse screw also demonstrates a bicortical purchase. A washer is used with this screw to aid in the reduction of "dialing in" or assisting with the intermetatarsal angle reduction

compression screw, the plate is applied to the medial first metatarsal–cuneiform joint. Following the insertion of the "home run screw," the initial screws are placed proximal in the medial cuneiform of the plate in combination with locking and nonlocking screws. The distal screws are placed into the metatarsal with a combination of locking and nonlocking screws. Similar to the three-screw technique, an interfragmentary compression screw can be applied within the plate from medial to lateral into the second and/or lesser metatarsals. This interfragmentary compression allows the surgeon to reduce the IM angle, and the plate essentially becomes an excellent reduction tool acting similar to a large washer. The plate is placed to span the metatarsal and cuneiform. Screws are placed through the plate and span the cuneiforms proximally, and an intermetatarsal screw is placed at the base of the first and second metatarsals. The medial plate acts as a "large washer" aiding in the reduction of the intermetatarsal angle in the transverse plane. With the proximal portion of the plate anchored well into the cuneiform, the distal portion of the plates mimics a "large washer" as the interfragmentary screws placed at the proximal portion of the first metatarsal allow the surgeon to "dial in" with the reduction of the intermetatarsal angle, and the remaining distal screws lock the reduction in place. Additionally, it provides stability from frontal plane rotation and intercuneiform instability. Often the authors get questioned if the intermetatarsal screw is problematic, painful, or if it breaks/fractures. The authors (unpublished at this time) reviewed 105 cases and found eight cases in which there was a fracture in the screw. Those patients who experienced a fractured screw were clinically/

Fig. 13.8 A hallux varus deformity: this is a patient who had a Lapidus procedure performed with distal soft tissue balancing which lead to a hallux varus deformity. In this chapter, the authors do not recommend distal soft tissue balancing or resection of the medial eminence of the first metatarsal. It has been the authors' experience that this is not needed to obtain an adequate reduction of the hallux valgus deformity and one cannot obtain a hallux varus if the distal soft tissue procedure is not performed

symptomatic insignificant. The construct should be checked under fluoroscopy to confirm adequate reduction (Fig. 13.9a–i).

If supplemental bone grafting is desired, attention is directed to the lateral aspect of the calcaneus where a small stab incision is made in the resting skin line that is posteroinferior to the sural nerve and the peroneal nerves. A Freer elevator is inserted in the incision, freeing the periosteum medially and laterally, exposing the lateral wall of the calcaneus. A 3.5-mm drill was used to penetrate the lateral cortex. With this done, a curette is inserted into the calcaneus, allowing for harvesting of cancellous bone from the lateral aspect of the calcaneus [27]. The dorsal gap of the tarsal–metatarsal is packed tightly with autogenous bone graft and serves as a shear strain-relieved bone graft [24, 28]. The construct is checked under fluoroscopy, and the wound is closed with typical deep and skin wound sutures.

Traditionally a 6–8-week non-weight-bearing period post-modified Lapidus arthrodesis has been recommended [29–31]. With the advent and availability of locking plate constructs that provide more reliable stability and bridging for the fusion, immediate weight bearing is starting to become common [3, 29, 32]. We have allowed immediate, functional weight bearing in a controlled ankle motion (CAM) boot for approximately the past 16 years. A retrospective analysis of the authors' patients identified 376 patients undergoing TMTJ arthrodesis with 74 patients meeting inclusion criteria for immediate weight bearing. Four patients had bilateral procedures performed at separate times for a total of 78 Lapidus procedures. Thirty patients had a three-screw construct, while 48 patients had a medial locking plate with an interfragmentary screw. There were 6 males and 68 females. The average age was 50.2 years old (males 56.7, females 49.7) with a range of 15–86 years. Fifty-five patients had a BMI less than 29, while 16 patients had a BMI greater than 30. BMI information was not available for three patients. Fifteen patients admitted to using nicotine. Additionally, seven patients had type II diabetes mellitus. Autogenous shear-strain relief bone graft was used in 75 of the 78 procedures. Patients who had adjunctive osseous procedures that required a non-weight-bearing post-op course were excluded from the study. Three patients (3.8%) experienced a postoperative nonunion. Interestingly, none of the patients with nonunions were smokers, and only one patient was diabetic.

Technique #2

Preferred Technique: Paul Dayton DPM, MS, Daniel Hatch DPM, Bret Smith DO, and Robert Santrock MD

An alternative procedure for TMTJ level correction is an instrumented system Lapiplasty® procedure (Treace Medical Concepts, Inc., Ponte Vedra Beach, FL) that provides triplane correc-

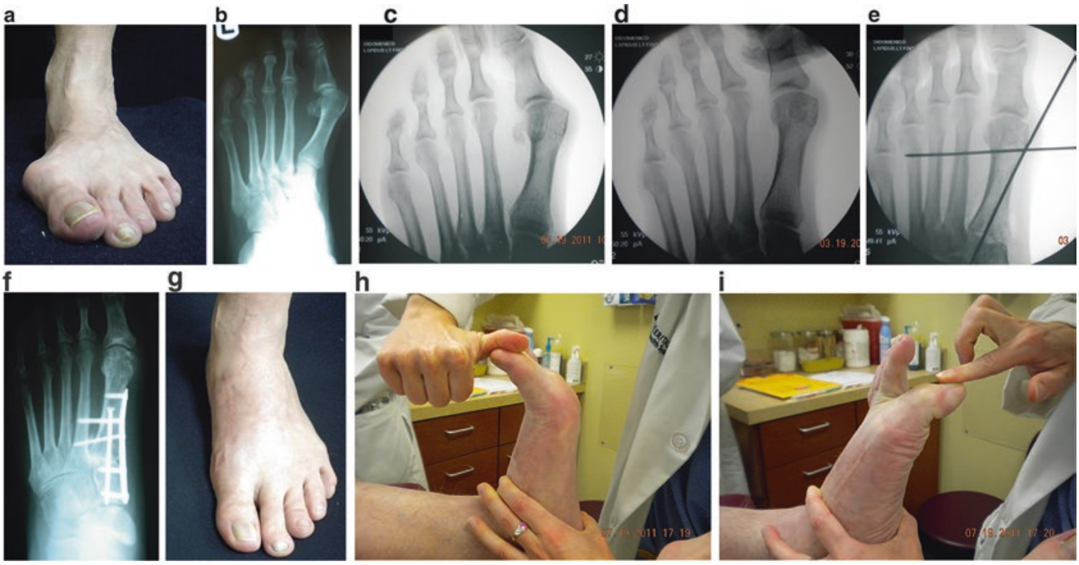

Fig. 13.9 (**a**) A clinical photo of a patient who presents with a painful HAV deformity. Note the valgus rotation of the great toe. (**b**) An AP radiograph of the same patient demonstrating a large IM angle, diastasis of the base of the first and second metatarsal, as well as the cuneiforms. There is a valgus rotation of the great toe, first metatarsal, and subsequently a valgus rotation of the sesamoid complex. (**c**) An intraoperative radiograph of the same patient demonstrating the sesamoid completely in the first interspace and the articular surface of the fibular sesamoid is 90° to the lateral aspect of the first metatarsal. (**d**) An intraoperative radiograph of the same patient demonstrating the great toe in the varus direction to a neutral position rotates the entire first metatarsal, great toe, and sesamoid complex as an entire unit. Note the sesamoid are placed into an anatomic position when a frontal plane rotation is accomplished. This is done without dissection about the first metatarsal phalangeal joint. (**e**) An intraoperative radiograph of the same patient demonstrating temporary fixation following reduction of the IM angle, frontal plane correction, and sagittal plane correction prior to screw fixation. (**f**) A postoperative radiograph of the same patient following reduction of the frontal plane (no dissection about the first metatarsal phalangeal joint), and correction of the transverse and sagittal plane. (**g**) A clinical photo of the same patient with a limited scar at the base of the first metatarsal and cuneiform. Note the reduction of the bunion and anatomical alignment. (**h**, **i**) Demonstration of range of motion of the first metatarsal phalangeal joint following a Lapidus procedure without invasion into the joint

tion at the anatomic apex of the deformity with a stepwise approach. (Note: the authors of this section are consultants and designers for Lapiplasty®.) The system uses a novel surgical sequence, first correcting the deformity with a unique positioning guide before making templated bone cuts and finally fixating with a non-compression biplane plate construct. Indications for this procedure are not based on degree of deformity, presence of hypermobility, or TMTJ angulation. The basic tenants of the procedure are to provide correction in three planes concurrently at the anatomic apex of the deformity and fixate with a construct that tolerates early weight bearing. The technique can be employed in the vast majority of hallux abducto valgus deformities but should not be used when clinically significant first MTPJ arthritis is present. Since this technique relies on the correction of the first metatarsal at the TMTJ and does not employ capsular balancing or distal osteotomies, it is recommended to obtain an anterior-posterior and axial sesamoid views to fully understand the degree of each plane of deformity and to assess whether there is any sesamoid subluxation. The PVB classification system (reviewed in Chap. 5) is used in part to guide decision-making for the need of limited lateral release.

The initial incision is made over the dorsal aspect of the tarsal–metatarsal joint, just medial to the extensor hallucis longus tendon and extends from the proximal pole of the medial

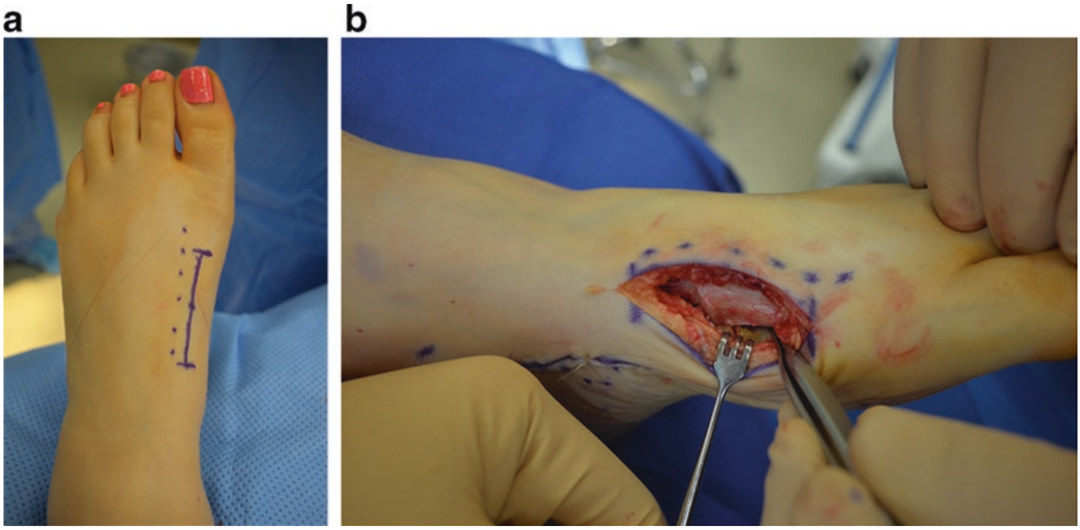

Fig. 13.10 (**a**) Recommended incision place just medial and adjacent to the extensor of the hallux from the proximal pole of the medial cuneiform to mid shaft of the first metatarsal. (**b**) Dissection within intracapsular and subperiosteal pocket exposing the medial ridge of the first metatarsal

cuneiform to the mid shaft of the first metatarsal (Fig. 13.10). It is essential to keep the incision dorsal for this technique to allow the guidance system to work properly. An intracapsular and subperiosteal pocket are developed without subcutaneous undermining to preserve the neurovascular anatomy. Dissection should be carried far enough medial to expose the medial ridge on the first metatarsal.

The TMTJ is released to allow for triplane mobilization of the first metatarsal using a combination of oscillating saw and/or osteotome. Using the oscillating saw technique has the added benefit of plaining any irregularities from the cartilaginous surfaces of the joint making frontal plane rotation more seamless (Fig. 13.11). The fulcrum device is then placed into the space between the proximal first and second metatarsals seating it proximally adjacent to the medial cuneiform (Fig. 13.12). Transverse plane flexibility of the first metatarsal phalangeal joint is evaluated, and if significant soft tissue tightness is noted, a small dorsal first interspace incision is made, and the tight lateral structures at the MTPJ are released until the joint is mobilized out of the abducted position. This step is only necessary if ankylosis is present and preventing correction of the hallux as the positioner device is engaged. A small stab incision is made over the second metatarsal approximately 1.5–2.0 cm distal from the first TMTJ, and the positioner device is inserted over the second metatarsal and onto the medial ridge of the first metatarsal (Fig. 13.13). Engaging the positioner with the fulcrum in place concurrently corrects the metatarsal in all three planes which is confirmed with fluoroscopy. A cut guide alignment tool (termed the "joint seeker") is placed dorsally in the TMTJ; this assures that the cuts are made correctly in the sagittal plane when the cutting guide is then placed and temporarily fixed in place (Fig. 13.14). The joint seeker is then removed, and the cuts on the base of the metatarsal and cuneiform can be completed. Once all of the cut bone has been removed, the joint is prepared for arthrodesis by aggressive metaphysis drilling on both sides of the joint using a 2-mm drill bit not a K-wire. The joint is axially compressed and held in the corrected position and pre-compressed with a terminally threaded olive wire (Fig. 13.15). When satisfactory triplane correction is obtained, final fixation can be applied with a biplanar mini-plate construct (Control 360® System, Treace Medical Concepts, Inc., Ponte Vedra Beach, FL) that

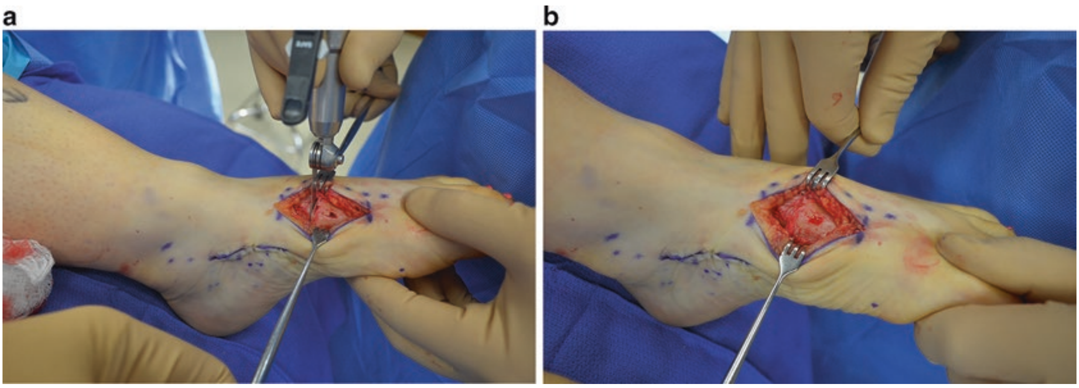

Fig. 13.11 (**a**) Use of the sagittal saw for release of the TMTJ and concurrent planning of the irregular cartilaginous surface to allow for free frontal plane rotation. This step is not aimed at joint preparation for fusion, just mobilization. (**b**) Manual testing of inversion component of frontal plane rotation required for correction

Fig. 13.12 Placement of the fulcrum device between the first and second metatarsal bases (Note the proximal position adjacent to the medial cuneiform)

offers stability and allows for physiologic micromotion to promote callus healing. This fixation design was found to be biomechanically stable in cantilever bending mechanical tests up to 250,000 cycles of bending underload [33]. The initial plate is applied dorsal across the first TMTJ with the screw angle purely sagittal. A second plate is applied medially with the screw angle 90° to the dorsal plate (Fig. 13.16). When complete triplane correction has been obtained, it is generally not necessary to use any fixation from the first metatarsal into the lesser metatarsal or cuneiforms. Anatomic and rotational alignment prevents deforming forces to pull the hallux lateral and buckle the first metatarsal medially. Further incision and dissection at the first MTPJ is generally not needed as the eminence is normalized through rotation (the effects of frontal plane rotation are reviewed in detail in Chap. 6).

The priority for this technique is complete triplane correction and maintenance of normal medial column kinematics. Because we have noted the importance of maintaining the windlass mechanism of the medial column for normal function, we do not advocate transfixation of the first and second metatarsals with additional screws. Similarly, we do not prepare the interval between the bases of the first and second metatarsals for fusion. Fixation of the first and second metatarsals severely curtails sagittal plane motion of the medial column and prevents the normal windlass mechanism for plantarflexion of the first metatarsal during gait. Decreased weight bearing of the first ray can in many cases lead to lateral weight transfer and lesser sub-metatarsal pain. It is not intuitive to many surgeons that medial column motion is maintained after TMTJ fixation because of the prevailing thought that robust motion occurs at the TMTJ and that blocking this motion prevents sagittal plane mobility. As discussed in Chap. 6, the majority of medial column motion occurs at the naviculocuneiform and intercuneiform joints and to some degree at the talonavicular joint. Medial column mobility is maintained in all three planes after TMTJ fusion. Using transfixation to prevent recurrence is not necessary with this technique since the deformity forces that produce recurrence are removed with derotation and complete angular correction.

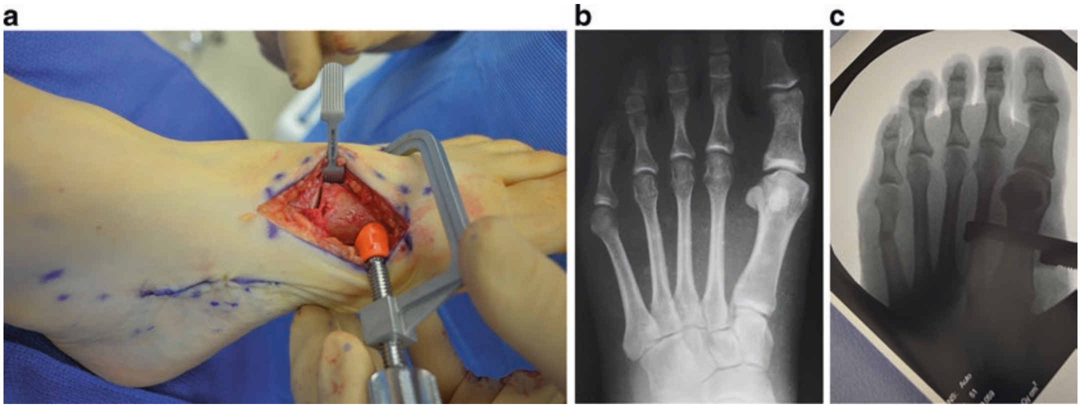

Fig. 13.13 (**a**) Placement of the positioner device. (**b**) Deformity before engaging the device. (**c**) Correction of deformity after engaging the action of the positioner device

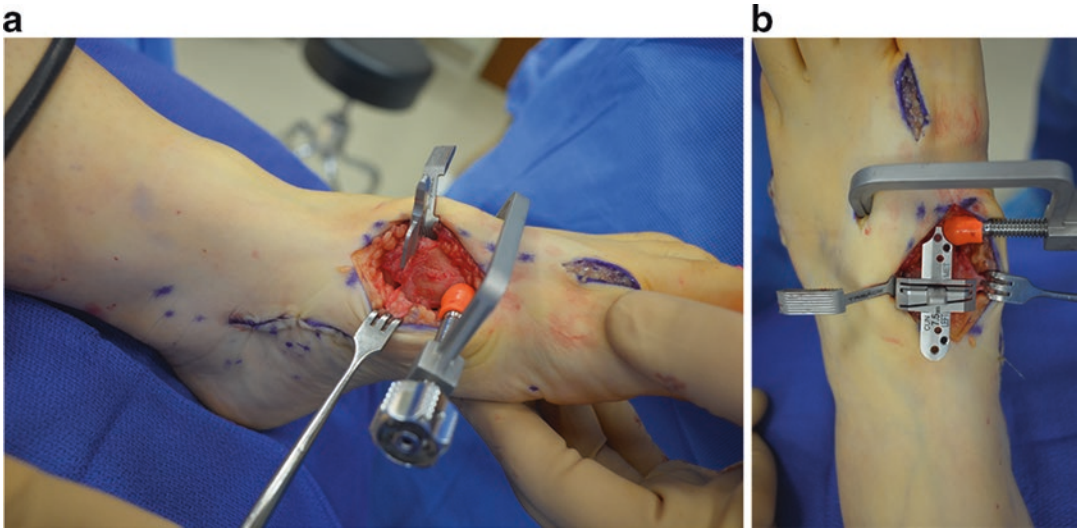

Fig. 13.14 (**a**) Placement of joint seeker device to align cut guide properly with the sagittal plane of the joint. (**b**) Cutting guide placed of the joint seeker device allowing accurate triplane cuts

It has become common to include lesser metatarsal osteotomy procedures with TMTJ fusion because of the concern for lesser metatarsal pain. We find this to be unnecessary when complete correction of metatarsal eversion is carried out and sagittal plain mechanics are normalized. Additionally, maintaining the medial column motion improves first MTPJ mechanics and offsets the slight shortening effect of resection of the TMTJ joints surfaces for fusion. Despite the small amount of shortening of the first ray with this procedure, we rarely see patients develop lateral metatarsal overload. In other words, accurate triplane alignment at the TMTJ improves medial column function thereby making associated procedures unnecessary. As discussed in Chap. 6, complete correction makes recurrence much less likely because the deforming forces on the first ray are removed.

The recommended postoperative course for this technique is protected weight bearing in a tall cast boot with avoidance of any high-impact activity starting several days after the procedure. Initial bandages are removed at 4 days, and no

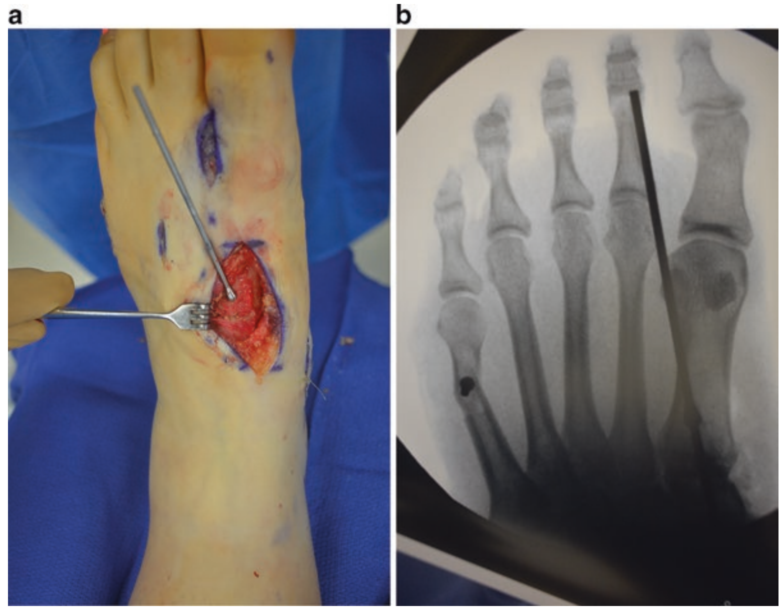

Fig. 13.15 (**a**) Corrected position maintained and compressed joint surface apposition maintained with a terminally threaded olive wire inserted into the lateral flare of the metatarsal based into the medial cuneiform (Note incision for lateral capsulotomy of the first MTPJ. Note MTPJ and hallux position is anatomic without the need for capsulorrhaphy, distal metatarsal or hallux procedures). (**b**) Radiographic evaluation of the corrected position

further digital splinting or bandaging is needed; showering is also allowed at this time. The range of motion activities are allowed for the foot and ankle when the initial pain subsides and are encouraged several times daily. Patients are returned to normal shoe gear around 6–8 weeks and are allowed to pursue high-impact activity when the fusion is consolidated around 3 months.

The traditional Lapidus procedure has undergone a progressive evolution to now include a new understanding of the 3D deformity anatomy. Currently we use the term triplane tarsometatarsal corrective arthrodesis as a more complete description for this procedure. Additionally, traditional indications which limit the procedure have been abandoned by the authors. That is, we do not require the presence of hypermobility, high IMA, or TMTJ arthrosis to select the procedure. As has been discussed throughout this textbook, our traditionally held ideas regarding the anatomy and function of the first ray both with and without HAV deformity may not be entirely accurate. The thought process for selection of TMTJ triplane arthrodesis also includes the identification of an intrinsically straight first metatarsal and the anatomic apex of the deformity at the TMTJ. Using this definition metatarsal osteotomies are not desirable. Although the initial results are extremely promising for 3D correction, this is an extremely new philosophy and technique which requires further study of patient outcomes.

As discussed in other chapters in this book, there is a lack of quality outcome studies reporting on validated PROM for bunion surgeries of all types, including the traditional Lapidus procedure. Review of the literature reveals mostly comparison studies for fixation techniques and evaluation of the safety of weight bearing in the early postoperative period. Recurrence rates have been discussed in Chap. 7. MacMahon et al. [34] assessed return to sports and physical activity following a modified Lapidus procedure in 48 patients with a mean age of 37.3 years old at 2.8 years mean. Patients completed a sports-specific, patient-administered questionnaire and had FAOS scores, and these were compared to sports outcomes. Postoperatively patients rated 29% of activities as less difficult, 52% as the same, and 19% as more difficult and rated participation levels as improved in 40%, the same in 41%, and impaired in 19% compared to

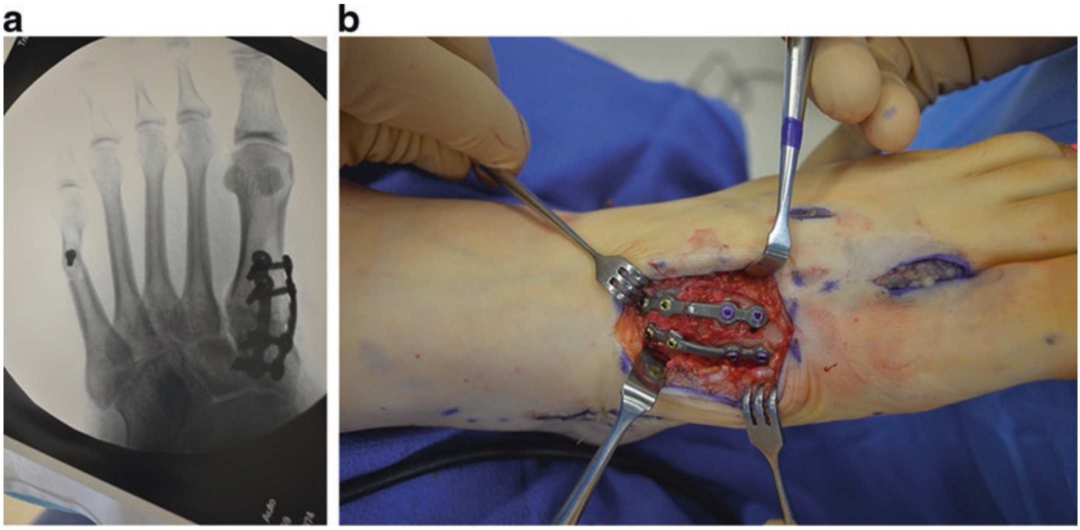

Fig. 13.16 (**a**) Final correction after fixation applied. (**b**) Biplane construct with two small flexible locking plates at 90° angles to each other

preoperatively. Eighty-one percent of patients were pleased with the outcome of their surgery in terms of physical activity. FAOS score improvements were highly associated with improvements in physical activity. Their conclusion was that 80% of patients were able to participate in their previous sports/physical activities at a similar or better level than before surgery. Robinson et al. [35] looked at footwear modifications after the Lapidus procedure footwear-specific questionnaire 18.5 months after surgery in 65 patients. Eighty-six percent of patients were able to wear comfortable footwear postoperatively, and 62% were able to wear fashion heels 21.4 weeks after surgery. Of the patients returning to heels, 77% were able to tolerate wearing heels better than before surgery. No change of foot size was noted following surgery. Taylor et al. [36] reviewed surgical outcomes of 18 modified Lapidus patients using the validated Foot Health Status Questionnaire (FHSQ). All FHSQ domains improved, with the greatest change coming in the category of foot pain. All 18 patients had union with one having poor pain control and another having postoperative bleeding. IMA improved by 7.8°, and HAV improved by 22.9°.

Other Considerations

Concomitant deformities and biomechanical abnormalities such as equinus [37] need to be addressed when performing this procedure. If other deformities are not corrected, biomechanical compensations may occur that hinder the primary surgical correction [38]. As we have highlighted here and discussed in other chapters, the bunion deformity is triplanar, and we feel that reduction of all three planes is a priority. Some surgeons suggest plantarflexing the metatarsal by sliding the metatarsal plantar which we recommend against. This practice decreases the bone surface area and changes the axis relationships within the first ray which we feel reduces the predictability of the procedure. Not only does metatarsal derotation from an everted position results in complete and consistent correction, it also gives the surgeon greater bone-to-bone contact and surface area for fusion which affects mechanical characteristics such as stress and strain at the fusion site. Stress to an area is calculated by dividing force by area ($\sigma = F/A$). Having the metatarsal derotated provides a larger area and therefore a larger denominator resulting in decreased stress per unit area of the surface. The load the construct can withstand is calculated by multiplying stress and area ($F = \sigma A$). Again, the larger the area, the more force that the area can withstand. A larger surface area allows for dispersion of ground reactive forces hence not concentrating force in one area [39]. When the metatarsal is in a neutrally rotated or anatomic position, there is a more uniform transmission of force from the metatarsal to the cuneiform. Further, stiffness is dependent on area. Stiffness (k) is how a material resists deformation in response to an applied force. It is found by multiplying the area (A) times the Young's modulus (E) of the bone and dividing that by the length ($k = A\mathrm{E}/L$). It is advantageous to have uniform stiffness across the fusion site [39].

Surgeons have also discussed resection of the lateral flange of the first metatarsal base to aid in reduction of the intermetatarsal angle. In an anatomic cadaveric study by Mason and Tanaka, it was found that there was a constant lateral plantar prominence found on the metatarsal base. The size of the prominence differed greatly between specimens [12]. We believe this plantar prominence is what surgeons refer to as the "lateral flange." In many cases this flange appears lateral only because the metatarsal is in an everted position. We argue that this bony block is eliminated once the metatarsal is adequately inverted during correction and does not need to be resected. Once this frontal plane is reduced, the lateral flange is now plantar and provides increased bone contact with the medial cuneiform rather than a hindrance to reduction.

Complications

Shortening of the first metatarsal is a potential complication of the Lapidus procedure which can lead to transfer lesions plantar to the second metatarsal head along with decreased hallux purchase. As we noted previously, a plantarflexed first metatarsal can give the appearance of a short ray and must be considered in evaluation. The goal is to achieve a natural plantarflexion angle of the first metatarsal parallel to the second metatarsal, and we recommend against offsetting the first metatarsal by sliding it in a plantar direction because it alters the axis relationship of the first ray. Excessive plantarflexion of the first metatarsal can cause sesamoid pain as well as a joint contracture at the first metatarsal phalangeal joint**.** Also as discussed in Chap. 6, when the first ray is corrected in all three planes, the normal windlass mechanism of the first ray is restored fully, and this improves the weight-bearing function of the MTPJ and medial column reducing the tendency for lateral transfer symptoms. In our experience this normalization of the first ray mechanics protects against lateral weight transfer.

Delayed unions and nonunions are certainly a consideration for this procedure, with delayed unions occurring more frequently in literature [40]. A review of the literature reports nonunion rates between 5% and 33% after modified Lapidus with 6–8 weeks of non-weight bearing [29, 32, 41]. The diversity of joint preparation techniques, fixation techniques, and postoperative protocols makes it difficult to draw accurate conclusions regarding healing rates. The advent of more stable techniques and grafting are an advantage, and we are seeing many reports of excellent healing and low complications even with early weight bearing. The authors' combined experiences highlight a very low healing complication rate with the techniques presented. Malunions associated with the procedure can be avoided with intraoperative radiographs to establish correct positioning in all three planes of the deformity. Malunion of the first ray in an elevated position may give rise to a dorsal bunion, decreased range of motion, and decreased purchase of the first ray, which could lead to transfer metatarsalgia [16]. Likewise, care must be taken to not overly plantarflex the first ray as sesamoiditis could result. Neuritis, while uncommon, can be encountered with the close proximity of the medial dorsal cutaneous nerve to the surgical site. Depending upon dissection techniques and incision planning, the saphenous nerve may be involved as well as the deep peroneal nerve of the first interspace [16, 42, 43]. Cases of complex regional pain syndrome have been reported [40].

Summary

Despite our enthusiasm with this procedure, especially with the triplane modifications, we are fully aware that further outcome studies must be done to understand the overall benefits to the patient and comparison to other procedures. All of the authors perform modifications of the Lapidus with high frequency, and we are rarely performing metatarsal osteotomy procedures due to our analysis of the observed power of the anatomic correction and our empiric results. We are actively collecting data and analyzing results to add to the body of knowledge of this subject.

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First MTPJ Arthrodesis

14

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and Paul D. Dayton

Background

One of the primary questions that arises when discussing the choice of a first metarsophalangeal joint (MTPJ) arthrodesis for correction of a bunion as an index procedure is the ability of the procedure to correct all components of the deformity. It is readily intuitive that all three planes of the hallux component of the deformity can consistently be corrected and maintained with an arthrodesis. Less intuitive is the ability of a MTPJ arthrodesis to correct the first intermetatarsal angle (IMA), especially in large deformities. It has been noted by multiple authors that correction of metatarsus primus adductus (MPA) or IMA occurs in conjunction with first MTPJ arthrodesis. Although the vast majority of studies looking at IMA correction following first MTPJ arthrodesis maintain that there is no need for additional procedures such as a proximal osteotomy to correct the IMA, there are isolated reports advocating the need for additional procedures [72].

IMA Reduction Evidence

A systematic review examining the deformity correction outcomes following first MTPJ arthrodesis for hallux valgus sheds light on this topic [20]. The review identified 15 studies specifically reporting on deformity correction of IMA and hallux valgus angle (HVA) after isolated primary first MTPJ arthrodesis. Eight studies reporting a mean preoperative IMA of less than 15° showed a pooled mean IMA reduction of 3.70° (Table 14.1). The remaining seven studies, which evaluated deformities with a pooled mean IMA greater than 15°, showed a mean IMA reduction of 5.42° (Table 14.2). This systematic review clearly shows reduction in preoperative IMA can be expected following first MTPJ arthrodesis and supports the argument against the need for additional procedures to correct the IMA, even in cases with a large deformity. Figure 14.1 highlights the robust IMA and HVA correction that can be achieved with a first MTPJ arthrodesis.

A brief review of the studies included in the systematic review provides pearls for decision-making regarding first MTPJ arthrodesis. Sung et al. [83] reviewed 58 cases of hallux valgus and/or hallux rigidus and rated the deformities as

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Table 14.1 Change in mean IMA with a preoperative IMA less than 15°

Author	Number	Pre-IMA	Post-IMA	Change in IMA
Sung et al. [83]	*N* = 58	14	9.7	4.3
Pydah et al. [70]	*N* = 69	13.1	8.6	4.5
Goucher and Coughlin [35]	*N* = 54	13	10	3
Nicholas et al. [66]	*N* = 76	10.9	8	2.9
Lombardi et al. [53]	*N* = 21	10.6	8.5	2.1
Agoropoulos et al. [1]	*N* = 62	12.9	8.5	4.4
Coughlin [14]	*N* = 47	11	8	3
Mann and Katcherian [58]	*N* = 47	12.7	8.3	4.4
	Total number	Pooled mean pre-IMA	Pooled mean post-IMA	Mean change in IMA
	N = 434	12.40	8.70	3.70

Table 14.2 Change in mean IMA with a preoperative IMA greater than 15°

Author	Number	Pre-IMA	Post-IMA	Change IMA
Feilmeier et al. [33]	*N* = 94	15.32	9.88	5.44
Besse et al. [8]	*N* = 36	16.1	10.4	5.7
Cronin et al. [18]	*N* = 20	16.7	8.7	8
Coughlin et al. [16]	*N* = 21	17.3	11.2	6.4
Dayton et al. [23]	*N* = 22	17.3	10.9	6.1
Tourne et al. [84]	*N* = 42	15	11	4
Gregory et al. [36]	*N* = 32	16.2	12	4.2
		Pooled mean pre-IMA	Pooled mean post-IMA	Mean change in IMA
	267	15.90	10.48	5.42

mild, moderate, or severe depending upon the preoperative radiographic findings. Following fusion, the mean IMA decreased from 14° to 9.7°, and the mean hallux abductus angle (HAA) decreased from 31.9° to 13.4°. Their analysis showed the degree of IMA reduction increased in more severe hallux valgus deformities. The findings of Feilmeier et al. [33] in their radiographic review of 94 cases of first MTPJ arthrodesis were similar, reporting a mean reduction in IMA of 5.44° for the entire study group. When patients were broken into subsets of low preoperative IMA (11–15°) and high preoperative IMA (16–24°), the respective mean IMA reductions were 4.21° and 6.83°.

Besides a significant reduction in IMA and HVA with first MTPJ arthrodesis, Pydah et al. [70] also noted that the mean tibial sesamoid position was improved by an average of one grade. Similar to Sung et al. [83] and Feilmeier et al. [33], they remarked that a more severe preoperative IMA correlated with a larger IMA reduction and that additional procedures to correct IMA were not needed.

Newer works by McKean et al. [62] and Dalat et al. [19] are consistent with previous literature and highlight outcomes of first MTPJ arthrodesis in patients with a preoperative IMA greater than 15°, noting significant reduction in IMA and HVA following first MTPJ arthrodesis. Dalat et al. [19] reported on 33 procedures with a preoperative IMA ≥20° and were able to achieve satisfactory IMA correction, with a mean postop IMA in this subgroup of 8.1° (3–12°).

The Case for MTPJ Arthrodesis over Implant Arthroplasty

The decision to replace or fuse the first MTPJ is an age-old argument among foot and ankle surgeons. Proponents of arthrodesis maintain that

Fig. 14.1 Two series highlighting the correction of bunion deformity, including IMA and HVA reduction, achieved with first MTPJ arthrodesis. Comparisons highlighting preoperative clinical appearance to postoperative clinical appearance and preoperative radiographs to postoperative radiographs

fusion provides excellent pain relief and a stable first ray that is functional in nearly all aspects of average daily ambulatory function and that the results are long lasting with low revision rates. Proponents of joint replacement cite preservation of ROM as the primary and necessary goal when treating first MTPJ pain and arthrosis. However, the long-term durability and complication rates with implants have been discussed by many researchers [9, 10, 34]. Both procedures are joint destructive, so an appropriate differentiating description of implant arthroplasty versus arthrodesis would be motion preserving versus motion sacrificing. Inherent in this discussion of motion-preserving and motion-sacrificing procedures is the benefit that each class of procedure provides for the patient with painful first MTPJ deformity and arthrosis. Both procedures provide a decreased level of pain compared to preoperative values in short- and midterm patient series. The question at the forefront of the argument is whether it is restoration of motion that produces positive outcomes or whether it is simply pain relief resulting from resection of the diseased joint during both arthrodesis and implant arthroplasty.

If restoration of range of motion (ROM) is the mechanism by which implant arthroplasty restores function and results in pain relief and satisfaction, one would expect outcome studies to highlight robust postoperative ROM measurements as a long-term benefit of the procedure as is noted in hip and knee replacements. With respect to pain relief and patient function, review of the favorable outcomes following first MTPJ arthrodesis seems to contradict the premise that it is improved ROM producing the positive outcomes in implant arthroplasty and support the idea that these results are achieved simply by removing the arthritic joint, thereby allowing the patient to ambulate and function better with less pain. With this dichotomy in mind, it is helpful to understand the real differences and similarities between replacement and arthrodesis. We undertook a detailed review of the published literature for first MTPJ implant arthroplasty to specifically quantify expected first MTPJ ROM values following replacement arthroplasty and therefore better understand the variables that drive positive patient outcomes.

We performed a systematic review of first MTPJ ROM after implant arthroplasty (Dayton et al. unpublished work). A total of 90 studies were identified in a systematic search of the databases. After the abstract review and application of the inclusion criteria, we identified 35 studies, 22 prospective studies that reported total preoperative and postoperative ROM without specifying dorsiflexion and plantarflexion ROM, and 13 studies that reported both dorsiflexion and plantarflexion ROM individually. The demographic information was not consistently reported among the included studies and therefore could not be analyzed. From the studies included, the mean follow-up duration was 44.7 months. For analysis, we divided the studies into two sets, one that reported only total preoperative and postoperative ROM without specifying dorsiflexion and plantarflexion ROM and a second set of the studies that specified the components of ROM. The results are listed in Tables 14.3 and 14.4.

Table 14.3 Includes all prospective studies that presented preoperative and postoperative total ROM of the first MTPJ

Prospective studies reporting total first MPJ ROM $n = 22$			
	Number of procedures	Pooled mean ROM (°)	Change in pooled mean
Preop ROM	906	29.10	
Postop ROM	906	46.24	+17.14

Table 14.4 Includes only prospective studies that report pre-op and post-op total ROM, dorsiflexion, and plantarflexion of the first MTPJ

Prospective studies including specific measurements for first MPJ dorsiflexion and plantarflexion $n = 13$			
	No. of procedures	Pooled mean ROM (°)	Change in pooled mean
Preop total ROM	510	28.24	
Postop total ROM	510	49.28	+21.04
Preop dorsiflexion	510	18.78	
Postop dorsiflexion	510	34.82	+16.04
Preop plantarflexion	510	9.42	
Postop plantarflexion	510	14.42	+4.99

Our review for MTPJ implant arthroplasty found that little consistency exists between studies. Reports of subjective satisfaction with decreased pain after joint replacement are undeniable and comparable to arthrodesis. However, one must ask if this finding is the product of the preservation of joint motion or if this finding is merely a result of the removal of a painful pathologic joint. The data of this review would point to the latter as there appears to be a relatively low net gain in first MTPJ ROM after implant arthroplasty, consistent with what Gibson and Thomson [34] noted in their comparative series of arthrodesis versus implant arthroplasty. These findings contradict the premise that there is robust motion after replacement; in fact, these average postoperative values fall into stages of hallux limitus/rigidus based on some classifications [17]. The end ROM measurements and hallux positions are also arguably not significantly different from the standard position of the hallux after a first MTPJ arthrodesis. Typically, the hallux is positioned in 10–15° of dorsiflexion relative to the first metatarsal axis. As Fig. 14.2 depicts, when this position is combined with the average first metatarsal declination angle of 20–25°, this provides a functional platform of approximately 30–40° of first MTPJ dorsiflexion relative to the first metatarsal declination. This is functionally the same position the hallux would be in during push-off following an implant arthroplasty that produces 35–45° of dorsiflexion. The fused hallux is in a functional position in the sagittal plane and maintains weight-bearing function despite the loss of range of motion. This functional position of the hallux is similar to the average dorsiflexion of

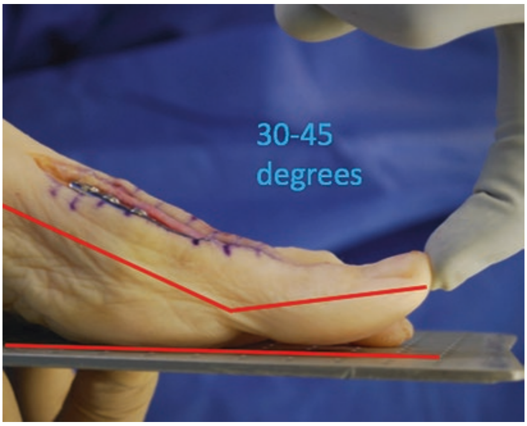


Fig. 14.2 Proper sagittal plane hallux position for arthrodesis represents the same average dorsiflexed position achieved in normal gait of 42°. Typically the hallux is positioned in 10–15° of dorsiflexion relative to the first metatarsal axis when this position is combined with the average first metatarsal declination angle of 20–25°; this provides a functional platform of approximately 30–40° of first MTPJ dorsiflexion relative to the first metatarsal declination. This is also nearly the same degree of dorsiflexion achieved following implant arthroplasty. The fused hallux is in a functional position in the sagittal plane and maintains weight-bearing function despite the loss of range of motion

42° achieved in normal gait as identified by Nawoczenski et al. [65].

Procedure Technique

The approach to a first MTPJ arthrodesis begins with a skin incision located dorsally, just medial to the extensor hallucis longus (EHL) tendon and central to the long axis of the first metatarsal and proximal phalanx as shown in Fig. 14.3. The length of the incision will vary based on the hardware utilized for fixation but generally starts just proximal to the neck of the first metatarsal and extends to a point just proximal to the head of the proximal phalanx. The incision is deepened through the subcutaneous layers directly without wide subcutaneous undermining, taking care to avoid damaging neurovascular structures and maintaining full-thickness soft tissue flaps medial and lateral. Once the dissection is completed through the subcutaneous layers, an incision through the periosteum and dorsal joint capsule begins the development of the surgical pocket. The periosteum and joint capsule are carefully elevated from the distal metatarsal shaft, the head of the first metatarsal, and the base and proximal aspect of the proximal phalanx along the full extent of the incision. The osseous resection is carried out within this intracapsular and subperiosteal pocket with the neurovascular structures protected and maintained within the medial and lateral full-thickness flaps.

Joint resection should be aggressive and remove all osteophytes, cartilage, and subchondral bone from the entire head of the first metatarsal, including the plantar aspect, and all cartilage and subchondral bone from the entire base of the proximal phalanx. There are often degenerative changes and fibrosis present within the sesamoid complex, making it imperative to complete a plantar sesamoid release relieving any lateral contracture or ankylosis to allow the metatarsal to move laterally and the IMA to reduce. Complete release of the soft tissue attachments to the metatarsal head will also allow appropriate positioning of the proximal phalanx in all three planes. The plantar sesamoid release can be completed bluntly with a large key or similar elevator between the plantar metatarsal head and the superior surface of the sesamoids until the hallux is able to move freely and there is no longer any ankylosis remaining. Removal of the plantar contours of the head, including the crista, also acts to decompress the joint plantarly and reduces the chances of plantar pain postoperatively. We do not specifically prepare the sesamoids for fusion to the metatarsal; rather this is to decrease the cubic content of prominent bone plantarly.

Preparation of the bone surfaces can be completed by several methods, including rongeur and burr, specialized cup and cone reamers, or planar cuts. Planar cuts tend to be utilized for revision surgery rather than for a primary fusion procedure and do not provide as much bone-to-bone surface area for healing or as much fine-tuning ability, making satisfactory positioning more difficult to achieve. The cup and cone preparation allows robust maneuverability and adjustability for appropriate positioning in all planes. The authors' preparation of choice is manual resec-

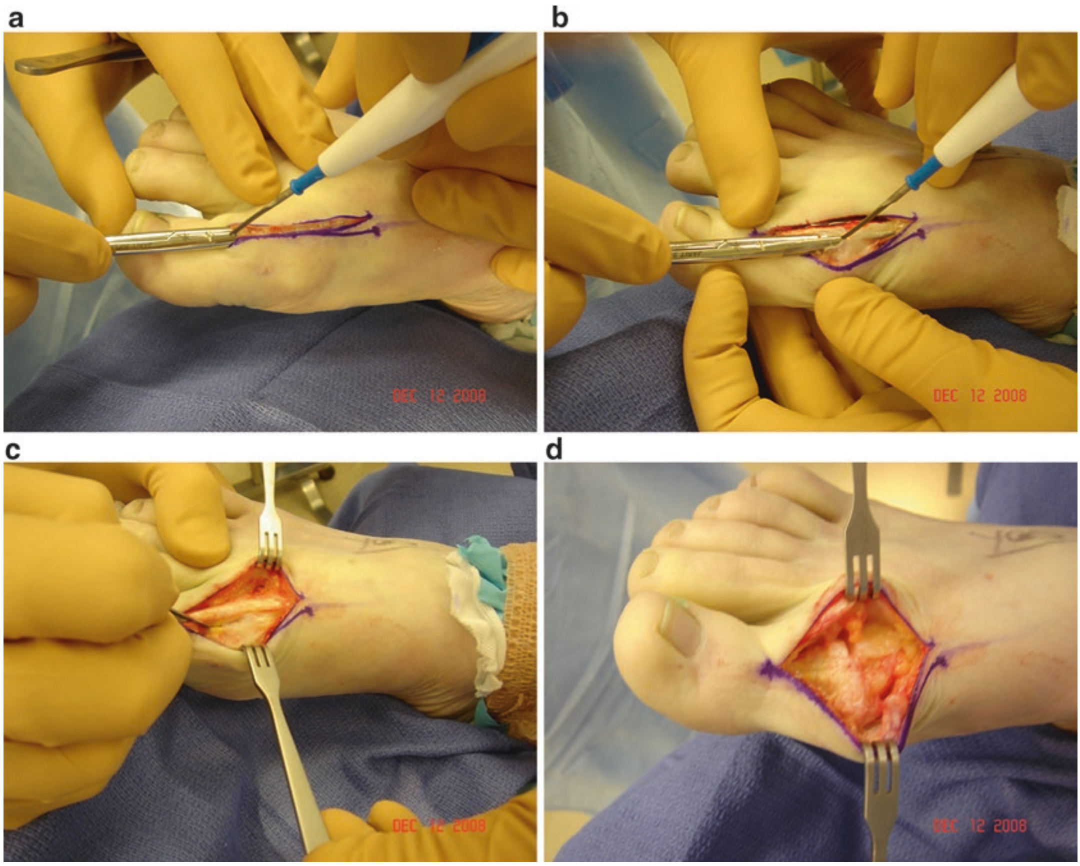


Fig. 14.3 Each step of incision and tissue dissection is shown here: (**a**) incision planning, (**b**) skin incision and dissection of first layer, (**c**) capsular and periosteal incision medial to EHL, (**d**) dissection of deep tissue and creation of full-thickness flaps

tion of the cartilage and all subchondral bone on the metatarsal head with a rongeur and preparation of the phalanx base with a round or oval high-speed burr as noted in Fig. 14.4. This allows the surgeon complete control of the bone shape and allows efficient and adequate removal of all subchondral and peripheral bone. Issues we have seen with power reamers include failure to resect the subchondral plate completely and fracture of the bone segments, especially in osteoporotic bone and when degenerative cysts are present.

To promote robust healing, we strongly recommend removal of all cartilage and the entire subchondral plate from the first metatarsal head and phalanx, down to bleeding trabecular bone. As the head is being prepared, the shape and size will be predicated on the size of the proximal phalanx base. The peripheral cortex of the base is left intact for stability, and the central portion of the base is deepened to sit on the head of the first metatarsal in a cup and cone (ball-and-socket) fashion. Care should be taken to keep the walls of the proximal phalanx cup steep and to keep the depth of the site equal throughout, avoiding any areas of varying depth which could limit good bone-to-bone apposition and cause instability.

Once the opposing surfaces are adequately prepared and a stable fit between them is present, the area should be irrigated and care taken to ensure there is no soft tissue within the arthrodesis site. Temporary fixation of the arthrodesis site is then performed. The authors' temporary fixation is performed with a 0.062 k-wire in a manner similar to a hammertoe with the pin started in the

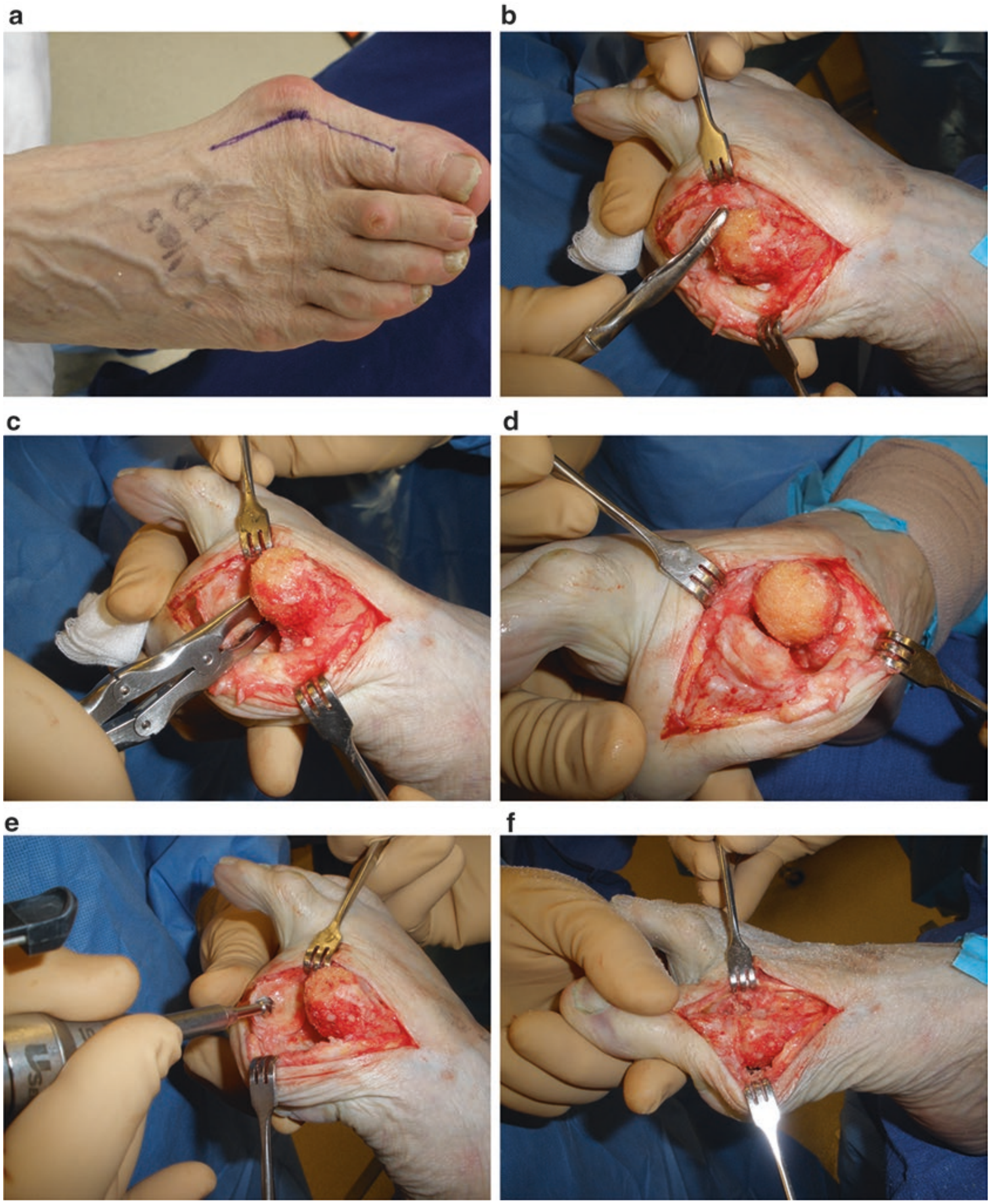


Fig. 14.4 Joint preparation steps are shown here in a patient (**a**) preoperatively, (**b**) with partial head preparation, (**c**) preparation of the plantar head, (**d**) with complete head preparation, (**e**) preparation of the base of the proximal phalanx, (**f**) with prepared surfaces positioned for arthrodesis

central base of the proximal phalanx and driven distally out the tip of the hallux. The hallux is then positioned onto the first metatarsal head with appropriate hallux position in all three planes, and the pin is driven proximally into the first metatarsal head and shaft, as shown in Fig. 14.5a. With this technique, if repositioning is necessary, the pin can be pulled back out of the

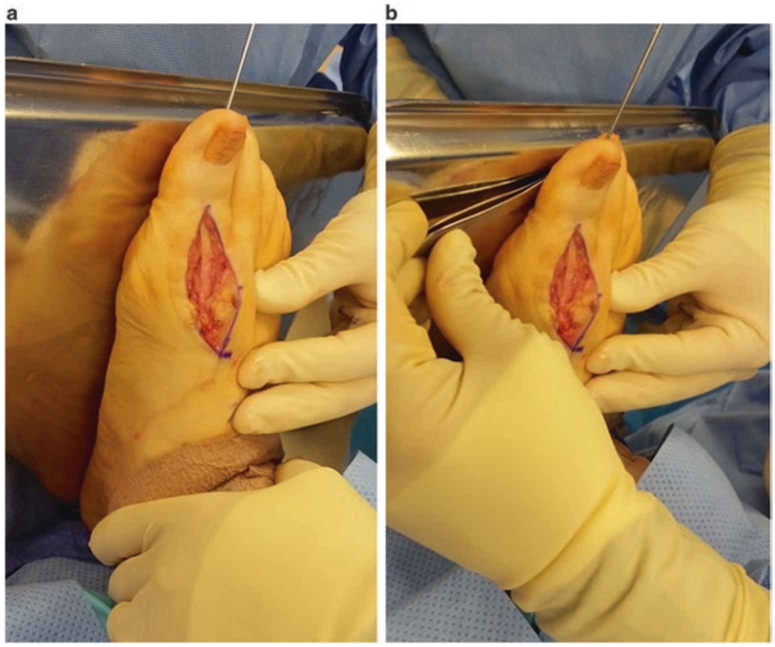


Fig. 14.5 (**a**) K-wires are inserted for temporary fixation and assessment of arthrodesis position, with (**b**) depicting the handle of the forceps inserted under the head of the proximal phalanx to ensure appropriate sagittal plane position

metatarsal and then advanced again after repositioning without the need to fully remove the temporary pin.

Positioning is evaluated clinically and radiographically with the temporary fixation in place. Key components of the position are the transverse, sagittal, and frontal plane position of the hallux. The hallux nail should be facing straight up to ensure the appropriate frontal plane position. Residual valgus rotation can cause irritation at the medial condyle of the proximal phalanx. The transverse plane position should be approximately 10–15° abducted relative to the first metatarsal shaft and sit in a well-aligned position relative to the second digit. There are several nuances that should be considered with respect to the transverse plane positioning of the hallux. If there is a high hallux interphalangeal angle (HIA), the proximal phalanx may need to be positioned with less abduction than is normal to ensure that the distal tuft of the hallux doesn't irritate the second digit.

The sagittal plane position is evaluated with a flat surface placed against the entire plantar surface of the foot and loading of the forefoot with the rearfoot in neutral position. The authors have found the best result with the proximal phalanx head positioned just barely off the surface of the plate with the rearfoot in neutral and the forefoot loaded. This is verified by a scalpel handle or the end of a forceps being able to just slide in under the distal aspect of the proximal phalanx, as shown in Fig. 14.5b. When evaluating position, one must identify if the hallux interphalangeal joint (IPJ) is pinned in a dorsiflexed or plantarflexed position and account for that.

The positioning in all three planes and the apposition at the arthrodesis site is first confirmed clinically, modified until appropriate, and then confirmed with intraoperative c-arm. Figure 14.6 shows a hallux that is positioned too high, with the head of the proximal phalanx well off of the weight-bearing surface. In this case, the pin wound be pulled out of the first metatarsal and the hallux repositioned in a lower position until it was just barely off of the surface as seen in Fig. 14.5. Once the positioning is confirmed, the site can be fixated. The authors' fixation of choice is biplanar locking plates; however there are many different fixation options that have been described in the literature. Many of these fixation options and the subsequent healing rates associated with each are presented later in this chapter. Biplanar plating, shown in Fig. 14.7, allows the surgeon to easily manipulate the plates to fit the patient and the arthrodesis site, rather than having to fit the site to the plate. Biplanar plating has been shown to be stronger than certain anatomic plates [22] and is a more biologic form of fixation, providing a stable but not rigid fixation construct and allowing for micromotion to promote healing [67]. Biplanar fixation allows the surgeon to control all planes of motion and creates a very stable construct to aid in healing. Once the site is fixated in an acceptable position, the incision is closed in a layered fashion, and a dry sterile bandage is applied along with a light compression wrap.

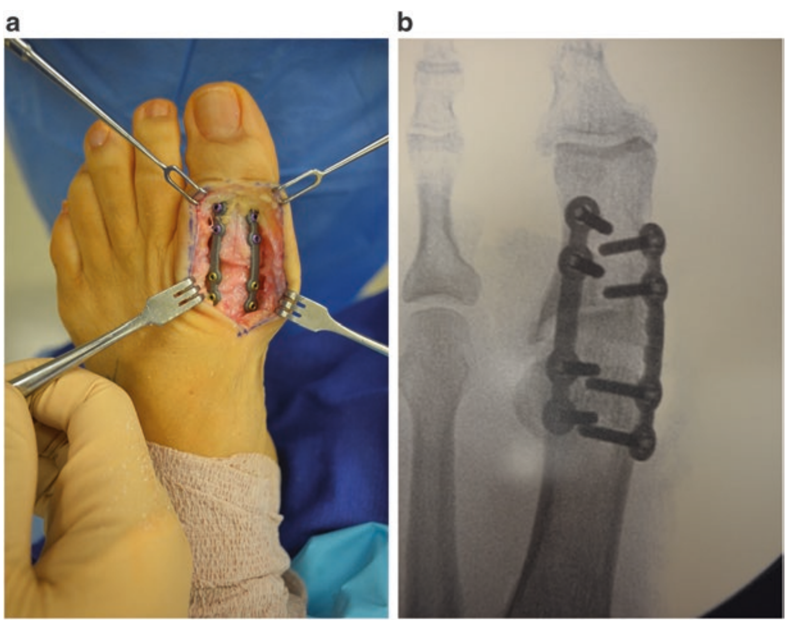
Fig. 14.6 The position of the hallux shown is too high, with the head of the proximal phalanx well off of the weight-bearing surface, and may result in poor function and potential complications

Fusion Position Evidence

Successful clinical outcomes of a first MTPJ arthrodesis are not only related to a successful union but also the union position, which affects overall foot function. If poorly positioned, additional pathologies and symptoms may result, potentially requiring additional revision surgery [35]. In a systematic review of union rate, Roukis [73] found a malunion rate of 6.1% (with 87.1% dorsal malunion and the remainder valgus rotation) and hardware removal rate of 8.5%. The author concluded that while the union rate was good, the malunion and hardware removal rates are inappropriately high and need further investigation for improvement. These results highlight the importance of appropriate fusion position and hardware selection and placement.

There are variations of recommended position in the literature; however the consensus appears to be approximately 10–15° abducted and between 10° and 25° dorsiflexed relative to the

Fig. 14.7 The stable, functional fixation construct created by biplanar plating is shown (**a**) intraoperatively, demonstrating dorsal and dorsal medial positioning, and (**b**) by c-arm, utilized to assure appropriate plate position intraoperatively



weight-bearing surface [14, 35, 46]. If the proximal phalanx dorsiflexion angle is too high, there is a resultant flexion contracture of the hallux IPJ and inability of the hallux to purchase the ground as noted in Fig. 14.8. The authors have found that excessive hallux dorsiflexion with the arthrodesis can result in severe pain to the plantar first metatarsal head and sesamoid complex. This results from increased weight-bearing pressure to the plantar first metatarsal head from the non-purchasing hallux and can lead to subsequent callus formation. Additionally, too much dorsiflexion is cosmetically unappealing, can also lead to hallux IPJ arthrosis form the contracture, and may result in pain to the distal hallux and shoe gear irritation from the dorsal hallux rubbing on the shoe. Similar to other authors [79], we have found the best position to be that noted previously in the description of the procedure, with the hallux positioned just barely off of the weight-bearing surface.

Alentorn-Geli et al. [2] have also reported that the dorsiflexion angle of the hallux post-arthrodesis plays a significant role in the pressure sub-first metatarsal head and hallux during gait. They reported that patients with a clinical dorsiflexion angle >15° and radiographic dorsiflexion angle >30° had more pressure under the first metatarsal head and those with a clinical dorsiflexion angle <15° patients had more pressure under the hallux. They recommended that in order to prevent increased plantar pressures under first metatarsal head, the arthrodesis dorsiflexion angle should be below 15° clinically and 30° on radiographs. This position allows the hallux IPJ room to plantarflex just slightly to contact the ground, without producing a flexion contracture. By using the scalpel or forceps handle technique previously described, the surgeon is also able to prevent the hallux from being positioned too low, which can result in dorsal jamming of the hallux IPJ with subsequent arthrosis. Additionally, if the hallux is positioned too low, there is a potential for lateral weight transfer during forefoot push-off, resulting in metatarsalgia.

The selected fixation construct can also play a role in malposition of the hallux. DeOrio [27] highlighted potential reasons for excessive dorsiflexion, including the use of pre-bent plates, and due to the anatomic configuration of the proximal phalanx. The author noted that a plate with no bend is actually able to provide approximately 15° of hallux dorsiflexion at the first MTPJ due to the conical configuration of the proximal phalanx. Since the plantar and dorsal surfaces of the proximal phalanx are not parallel but rather form an angle of approximately 30° to each other, a flat plate positioned over the joint after removal of the dorsal prominences and joint surfaces is able to form a functional dorsiflexion position. Therefore, as the bend of the plate increases, the dorsiflexion angle of the hallux will increase beyond 15°, potentially resulting in too high of a dorsiflexion angle. We have found this phenomenon to be common with pre-contoured locking plates and recommend removing the dorsiflexory bend from the plate prior to application to prevent hallux malposition. It is necessary with many of the available plates to bend the plate past 180° to fit over the convex contour of the dorsal first MTPJ and prevent excessive dorsiflexion position of the hallux. Similarly, Marsland et al. [60] found that the dorsiflexion angle of the first metatarsal and hallux measured by the dorsal cortices was significantly smaller than the intramedullary angle, with the dorsal cortices angle being 10.8° smaller. They concluded that since a pre-contoured dorsal plate for first MTPJ fusion uses dorsal cortices for the dorsiflexion angle, it may lead to excessive clinical dorsiflexion. Lewis et al. [51] evaluated the effect of plate position and type on the dorsiflexion angle in cadaveric specimens. They found that the more proximal the plate was placed, regardless of type, the greater the resultant dorsiflexion angle. This resultant change in angle was greatest for the pre-contoured plates, which highlights the importance of proper hardware selection and positioning for obtaining the ideal fusion position. Using the biplane construct described above, the plates do not participate in positioning of the site but are simply contoured to the fusion site after satisfactory position is achieved, thus avoiding the pitfalls of many “anatomic” plates.

Postoperative Protocol

The authors' postoperative protocol consists of immediate protected weight bearing in either a surgical shoe or removable cast boot. The patient is usually encouraged to use an assistive device for the first 2–4 days postoperatively for balance and pain control. As tolerated, the patient may discontinue the use of the assistive device and bear full weight to the heel in the shoe or boot. The dressing is left in place until the first postoperative visit, typically 3–4 days after surgery. At that time, the dressing is removed, and the patient is instructed that they may get the surgical site wet in a shower [21, 32, 33]. A light dressing may be employed if needed, with compression from either an ace wrap or a compression stocking. The patient is encouraged to perform ankle joint range of motion without resistance daily. Radiographs are typically taken at 3 and 6 weeks postoperatively, and if clinical and radiographic signs of healing are present at 6 weeks, the patient is transitioned into a stable athletic shoe with flat-footed walking for 1–2 weeks, followed by gradual return to heel-to-toe walking at 6–8 weeks postoperatively. The average patient is released to all activity between 10 and 12 weeks.

Outcomes Evidence

Union Rate

Studies consistently show a high union rate with first MTPJ arthrodesis, regardless of fixation construct. Most studies support a time to union between 6 and 9 weeks [7, 24, 73–77, 86]. There are studies looking at overall healing rate as well as studies evaluating union rates relative to specific forms of fixation, early weight-bearing status, type of joint preparation, male versus female sex, and pathology, among others.

With respect to overall union rate, Roukis [73] performed a systematic review of the available literature at that time, which included 37 studies and 2,818 first MTPJ arthrodesis procedures. The mean time to union was 64.3 days with an overall nonunion rate of 5.4% and a symptomatic nonunion rate of 1.8%. Mahadevan et al. [56] investigated the effect of joint preparation on union rate comparing flat-on-flat configuration and ball-and-socket configuration and also analyzing joint preparation techniques of rongeur, rongeur and burr, and conical reamer. They found an overall union rate of 93.5% and found no difference in union rate based on joint configuration or

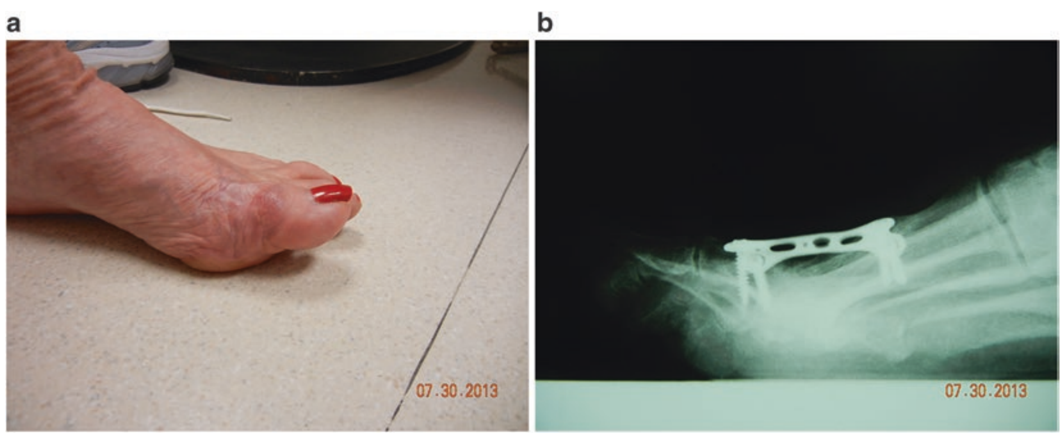


Fig. 14.8 The position of the hallux is shown (**a**) with excessive dorsiflexion postoperatively clinically and (**b**) radiographically

preparation technique. Bass and Sirikonda [3] evaluated the nonunion rate based on gender and between locking and non-locking plating systems. The study included 172 consecutive first MTPJ arthrodeses for various pathologies, including HAV, hallux rigidus, and revision procedures. The overall nonunion rate was 6.9% (12 feet). They found a statistically significant difference in the nonunion rates between the males (17.5%) and females (3.8%). They did note a difference in the healing rates between the plating constructs; however this was not statistically significant.

Korim and Allen [48] described differences in nonunion rate based on patient pathology (hallux valgus, hallux rigidus, inflammatory arthropathy, and salvage surgery). In 134 first MTPJ arthrodeses, the overall union rate was 91.8%, with a significantly higher nonunion rate in the hallux valgus pathology group. The authors concluded that hallux valgus may need a stronger construct. Grimes and Coughlin [37] specifically reviewed 33 first MTPJ arthrodeses performed for failed hallux valgus surgery and reported a 12% nonunion rate, with only one being symptomatic. Of note, however, is that the AOFAS and patient satisfaction scores were significantly reduced compared to that which has been noted for primary arthrodesis.

If symptomatic, a nonunion may require revisional surgery. A full discussion of revision is beyond the scope of this chapter. However, an interesting point to note, however, is the work of Gross et al. [39]. They reported on the outcomes of first MTPJ arthrodeses performed for failed implant arthroplasty. In their series of 12 revisions, there was a 42% delayed union, with a mean time to union of 6.9 months, compared to the 6–9 weeks identified in most studies of primary fusion, a 17% nonunion rate, and a 58% complication rate. This work highlights the difficulty in revising an implant arthroplasty to an arthrodesis if the implant fails. Hope et al. [42] noted that some patients may do well with hardware removal without revision in the face of nonunion; however, this was a small series, and we would not advocate this for most patients at this time.

Effect of Early Postoperative Weight Bearing

Historically, patients undergoing first MTPJ arthrodesis were prevented from weight bearing in the early postoperative period out of fear of increased risk of nonunion and delayed union complications. In recent years, however, there has been overwhelming evidence to not only disprove the notion that early weight bearing increases the rate of nonunion but also to highlight the causative relationship between immobilization and postoperative complications [40, 80]. Further, in literature pertaining to union rate following first MTPJ arthrodesis, there is a growing emphasis on adequate joint preparation techniques and stable fixation constructs, rather than time to weight bearing. Immediate weight bearing following a first MTPJ arthrodesis has been shown to be a safe, effective postoperative protocol with no evidence to support increased rates of nonunion or delayed union. The immediate weight-bearing protocols also appear to result in high union rates without a notable difference based on fixation type. Table 14.5 highlights most of the recent literature available evaluating union rate for specific fixation constructs and also highlights the outcomes with early or immediate weight-bearing protocols.

Fixation and Union Rate

There are many ways to fixate a first MTPJ arthrodesis, including single and crossed screws, k-wires, staples, locking and non-locking plates, anatomic pre-contoured plates, biplanar constructs, and a combination of hardware. As shown in Table 14.5, the literature overall demonstrates a high union rate, largely regardless of the fixation construct used. However, a single oblique screw and a combination of a non-locking dorsal plate with a lag screw appear to have the lowest union rates.

One significant outlier is Gross et al. [38], with a very low union rate of 68.8% in their series of 16 procedures performed with a dome-shaped reamer and an anatomic plate with PocketLock fixation. Of note is the fact that they left the subchondral plate intact and fenestrated it rather than removing it. Mayer et al. [61] retrospectively evaluated the outcomes of non-locking semitubular plates and pre-contoured locking plates for first MTPJ arthrodesis in 128 patients and found no difference between union rate, complication rate, time to radiographic healing, MTPJ angle, and Visual Analog Scale (VAS) score. They did find that clinical time to healing was shorter and the radiographic angle from the proximal phalanx to the floor was smaller in the noncontoured group. Further, in patients with inflammatory arthropathy, they found increased time to healing in the noncontoured plate group. Dening and van Erve's [26] review of 72 MTPJ arthrodesis procedures directly compared the fusion rates between three different fixation constructs: one oblique screw, two crossed lag screws, and plate with plantar lag screw. They found significantly fewer nonunions with the plate and plantar lag screw fixation construct than with a single oblique screw. Bennett et al. [5] evaluated lag screw and dorsal plate fixation construct for fusion rate, hardware failure, and patient satisfaction. In 107 procedures, they found an 86.9% fusion rate with all 14 nonunions resulting from a broken screw, plate, or both. They concluded that a non-locking modular handset applied in only one plane is not strong enough for first MTPJ arthrodesis fixation.

Cadaveric Fixation Studies

Several first MTPJ fixation constructs have been evaluated for biomechanical stability by utilizing cadaveric specimens. The utility of such evaluation is determination of stiffness and load to failure for specific fixation constructs without the inherent risk of in vivo testing. Forces applied to cadaveric fixation constructs can, however, simulate the forces applied to the first MTPJ arthrodesis site during gait. This information can help guide surgeons in their decision-making process for hardware selection; however, as noted in Table 14.5, most common forms of fixation demonstrate good union rate radiographically and clinically when applied with appropriate joint preparation. The greater concern may be malunion or poor positioning with certain constructs, rather than an effect on union rate. In cadaveric studies, an interfragmentary screw with dorsal plating has been shown to be stronger than crossed screws [13], crossed k-wires, or a dorsal plate alone [69]. Further, there has been evidence in support of locking plates over non-locking plates [43], triple-threaded headless screws over partially threaded lag screws [54], and intramedullary screws over crossed interfragmentary screws [64].

Satisfaction and Function

Beyond union rate and healing outcomes, surgeons must prioritize evidence regarding patient satisfaction and ambulatory function after a surgical procedure. Many surgeons have a fear of performing a first MTPJ arthrodesis because of unsupported claims that the patient will not be able to be active and participate in exercise or sporting activities or will be limited in what they can do after a first MTPJ arthrodesis. The literature, however, is clear that there is a high satisfaction rate with a first MTPJ arthrodesis [49], and most patients can return to their presurgical level or are even better than their presurgical level, with respect to activity and function. Despite many of the published reports evaluating patients with preoperative hallux rigidus rather than HAV, they remain highly relevant for this discussion due to their ability to address questions regarding postoperative function and satisfaction following a first MTPJ arthrodesis. van Doeselaar et al. [85] used the Dutch Foot Function Index (FFI) to identify changes in patients undergoing first MTPJ arthrodesis for either hallux rigidus or hallux valgus. They found the FFI improved significantly in both groups, without any significant difference between the two groups. Evaluation and comparison of literature with respect to outcomes and satisfaction can be difficult due to researchers failing to use validated outcome measures and due to the wide variability of measures used. In order to improve our understanding of

Table 14.5 Union rate of first MTPJ arthrodesis with various forms of fixation with associated weight-bearing protocol

Author and year	Fixation	Number	Weight bearing	Union rate
Bass and Sirikonda (2015) [3]	Locking *Anchorage*™ plate	$N = 76$	Immediate heel weight bearing in a post-op shoe	97.4%
	Non-locking *Charlotte*™ plate	$N = 76$		88.2%
	Non-locking *Hallu-fix*™ plate	$N = 20$		95%
Bennett et al. (2005) [5]	Lag screw and dorsal plate	$N = 107$	Non-weight bearing for 1 week, walking boot with heel only for 5 weeks	86.9%
Bennett and Sabetta (2009) [6]	Accutrak™ pre-contoured plate with 3.5 mm cortical screws and/or 4.0 mm cancellous screws	$N = 233$	Heel walking in walking boot at 1 week	98.7%
Besse et al. (2010) [8]	Three titanium staples	$N = 54$	Immediate weight bearing in "clog"-type foot cast	94.4%
Brodsky et al.(2005) [12]	Parallel screws	$N = 60$	Weight bearing at 4 weeks in post-op shoe	100%
Coughlin and Abdo (1994) [15]	Dorsal Vitallium plate, with or without k-wires	$N = 58$	Protected immediate weight bearing in post-op shoe	98%
Dalat et al. (2015) [19]	Dorsal titanium non-locking plate with oblique compression screw through plate	$N = 208$	Immediate weight bearing in a walking boot	97.1%
Dayton and McCall (2004) [24]	2 crossed screws	$N = 30$	Immediate heel or lateral foot weight bearing in post-op shoe	100%
	Single screw plus one k-wire	$N = 12$		
	2 or more k-wires	$N = 5$		
Dening and van Erve (2012) [26]	Oblique screw	$N = 24$	Immediate weight bearing in forefoot-relieving post-op shoe	71%
	Two crossed lag screws	$N = 21$		90%
	Dorsal plate alone	$N = 13$		100%
	Dorsal plate with plantar lag screw	$N = 14$		93%
Doty et al. (2013) [29]	Pre-contoured dorsal plate	$N = 48$	Immediate weight bearing with foot flat, no toe off	98%
Ellington et al. (2010) [30]	Lag screw with plate	$N = 107$	Immediate heel weight bearing in post-op shoe	87.85%
Goucher and Coughlin (2006) [35]	Low-profile dorsal titanium plate	$N = 49$	Immediate weight bearing in post-op shoe with heel and lateral foot walking	92%
Gross et al. (2015) [38]	Plate with PocketLock fixation	$N = 16$	Immediate weight bearing in a post-op shoe or short walking boot as tolerated	68.8%
Hyer et al. (2008) [44]	Crossed screws	$N = 14$	Immediate heel weight bearing in post-op shoe	92.9%
	Dorsal plate	$N = 31$		90.3%

(continued)

Table 14.5 (continued)

Author and year	Fixation	Number	Weight bearing	Union rate
Hyer et al. (2012) [45]	Static plate	$N = 43$	Non-weight bearing in splint for 1 week followed by weight bearing in walking boot for 6 weeks	95.35%
	Static plate with lag screw	$N = 14$		85.71%
	Locked plate	$N = 36$		91.67%
	Locked plate with lag screw	$N = 45$		95.56%
Korim and Allen (2015) [48]	Crossed screws	$N = 124$	Non-weight bearing or heel bearing for 6 weeks	91.9%
	Dorsal plate	$N = 10$		90%
Kumar et al. (2010) [49]	Dorsal plate and compression screw	$N = 46$	Immediate weight bearing in post-op shoe	98%
Leaseburg et al. (2009) [50]	Low-contour titanium plate with or without lag screw	$N = 35$	Immediate heel weight bearing in post-op shoe	100%
Mah and Banks (2009) [55]	K-wire (except for 2)	$N = 22$	Immediate weight bearing with padded surgical shoe	90.9%
Mann et al. (2013) [57]	Low-profile titanium plate with either crossed k-wires or 1 or 2 compression screws	$N = 21$	Non-weight bearing for 6 days followed by heel weight bearing in walking boot	95.24%
Mahadevan et al. (2015) [56]	Crossed compression screws	$N = 45$	Did not report	93.8%
	Dorsal plate and oblique compression screw	$N = 122$		90.9%
Mayer et al. (2014) [61]	Non-contoured non-locking plate	$N = 102$	Progressed to protected weight bearing at 3–6 weeks	92.2%
	Pre-contoured locking plate	$N = 26$		92.3%
Mohammed and Gadgil (2012) [63]	Differential pitch cannulated crossed screws	$N = 23$	Immediate heel weight bearing in heel wedge shoe	91%
Poggio et al. (2010) [68]	Memory compression staples	$N = 49$	Did not report	95.9%
Roukis et al. (2012, 308–311) [76]	Crossed flexible titanium intramedullary nails and a dorsal static staple	$N = 51$	Immediate protected weight bearing	100%
Roukis et al. (2012, 191–194) [77]	Crossed flexible titanium intramedullary nails and a dorsal static staple	$N = 95$	Immediate protected weight bearing	96.8%
Roukis et al. (2012, 433–436) [75]	Crossed flexible titanium intramedullary nails and a dorsal static staple	$N = 195$	Immediate protected weight bearing	97.4%
Roukis et al. (2012, 12–16) [74]	Flexible titanium intramedullary nails alone or with static staples	$N = 148$	Immediate protected weight bearing in post-op shoe	97.3%
Shah et al. (2012) [78]	Single lag screw	$N = 16$	Plaster walking cast for 6 weeks	81.3%
	Lag screw and cerclage wire	$N = 15$	Immediate heel weight bearing without a cast	73.3%
	Memory staples	$N = 15$	Immediate heel weight bearing without a cast	93.3%

(continued)

Table 14.5 (continued)

Author and year	Fixation	Number	Weight bearing	Union rate
Storts and Camasta (2016) [82]	Buried crossed k-wires	$N = 48$	Immediate protected weight bearing in post-op shoe	97.9%
	Crossed screws	$N = 49$		95.9%
van Doeselaar et al. (2010) [85]	Crossed screw	$N = 62$	Immediate heel weight bearing in post-op shoe	95.2%
Wassink and van den Oever (2009) [87]	Single compression screw	$N = 109$	Heel touch with crutches for 2 weeks, WB in post-op shoe or BK cast at week 2	95.4%
Wanivenhaus et al. (2017) [86]	Compressive locking plate	$N = 31$	Immediate full weight bearing in stiff-soled post-op shoe	90.3%

patient outcomes following first MTPJ arthrodesis, it is prudent that researchers agree upon a standard measurement tool that is valid and objective.

DeSandis et al. [28] recently reviewed the functional outcomes after first MTPJ arthrodesis. In their retrospective review of 56 feet in 53 patients, the average preoperative SF 36/12 score was 65.7 and increased to 81.3 postoperatively. The FAOS score improved from 54.4 to 82.6, and the daily activity subscale improved from 73.2 to 89.9. Eighty-five percent of their patients were either satisfied or highly satisfied, and 89% stated that they either had improved ability to perform daily activities or had no decrease in function. Of note is that 23% and 24%, respectively, stated that they were able to run and jog without as much limitation, and 68% stated they could walk with less limitation compared to preoperatively. The majority of patients were all able to continue with their other sporting activities at the same or improved level as they did preoperatively, including yoga, hiking, tennis, and biking. The most common complication in their series was symptomatic hardware, and all of those requiring removal had a dorsal non-locking plate with screw fixation construct. They noted that this did not lead to any significant difference in subjective outcome scores.

Goucher and Coughlin [35] reported a 96% satisfaction rate in their series of 49 patients, with an AOFAS score of 82 postoperatively compared to 51 preoperatively and a VAS that improved from 6.3 to less than one. Coughlin et al.'s [16] review of 21 first MTPJ arthrodesis procedures in 16 patients with moderate-to-severe hallux valgus found patient satisfaction be excellent in 17 feet (80%) and good in 4 feet (20%). No patient had first metatarsal cuneiform pain postoperatively, and all patients maintained an equal or increased activity level compared to preoperatively, with an average AOFAS-HMI score of 84 out of a possible 90 points. They also found a significant reduction in pain and metatarsalgia of the lateral metatarsals with all patients reporting the ability to wear conventional or comfort shoe gear. Consistently, studies evaluating patient satisfaction and AOFAS scores have similar findings to the studies highlighted [19, 25, 63, 68], with most reporting satisfaction in the mid-80th to upper 80th percentile.

Because we are evaluating first MTPJ arthrodesis for HAV with associated degenerative changes, it is imperative to discuss the outcomes with respect to function and satisfaction of a first MTPJ arthrodesis compared to that of implant arthroplasty, which is typically the other procedure a surgeon is deciding between. Stone et al. [81] reported on one of the longest follow-up studies to date, at 15 years, comparing outcomes of first MTPJ arthrodesis to implant arthroplasty. In their series, patients that had a first MTPJ arthrodesis had statistically significant less pain based on the Visual Analog Scale (VAS) and higher satisfaction, though, interestingly, there was no difference found in the VAS-Foot and Ankle, a validated subjective questionnaire for pain and function. Of note is that the patients who had a primary arthrodesis fared better than those with a revision arthrodesis for a failed arthroplasty. Brewster [10] performed a systematic review comparing first MTPJ arthrodesis versus joint replacement and found that arthrodesis achieves better functional outcomes than total joint replacement, citing a median revision rate of 0%, compared to 7% for the implant group, and a median postop AOFAS-HMI score of 82 for the arthrodesis group and 83 for the implant group. Kim et al. [47] conducted a multicenter trial comparing fusion, hemi-implant, and resection arthroplasty for first MTPJ arthritis and found that all were successful in improving patient pain and no statistically significant difference was noted in the subjective outcomes among the three groups. Gibson and Thomson [34] reported in their series on the subject that at 12 and 24 months postoperatively, the arthrodesis was more effective at reducing pain and produced better functional results than joint implant, citing a 16% failure rate of implant arthroplasty and 82% overall satisfaction for the arthrodesis group versus 45% for arthroplasty. Additionally, only 3% (1 patient) of the arthrodesis patients versus 40% (12 patients) of the arthroplasty patients would not elect to undergo the same surgery again. Raikin and Ahmad [71] also compared arthrodesis and metallic hemiarthroplasty of the first MTPJ, and the investigators concluded that arthrodesis was more predictable for reduction of pain and restoring function than the implant arthroplasty group. Erdil et al. [31] compared three groups: first MTPJ arthrodesis, resurfacing hemiarthroplasty, and total joint replacement of hallux rigidus. They found that the VAS pain scores decreased significantly postoperatively in all three groups and the AOFAS-HMI increased significantly in all groups. The decrease in the VAS was the most significant in the arthrodesis group at a mean of 0.5 postoperatively compared to 1.58 and 1.36 for the other two groups. However the AOFAS-HMI score was lower for the arthrodesis group compared to the other two groups due the lack of motion of the first MTPJ, which results in a maximum score of 90 out of 100. The mean postoperative score for the total joint replacement was 92.67, the resurfacing hemiarthroplasty was 86.14, and the arthrodesis was 76.08. It must be noted that using physician rater scoring systems such as the AOFAS score artificially assigns significance to factors such as ROM which may not actually affect patient function and satisfaction. Therefore, these rating scales may give erroneous results. This is why many researchers strongly recommend using patient-reported outcome measures (PROMs) and standardization of our outcome tools so that procedures within a study and between studies can be compared more accurately.

Foot kinematics and weight-bearing distribution of the foot during gait are critical factors that drive both patient satisfaction and gait function. While metatarsalgia is also a complication of arthrodesis that is quoted in the literature, this is not supported by evidence. In fact, the literature clearly highlights that there is improvement in the weight-bearing function of the hallux and first metatarsal after an arthrodesis, if appropriately positioned, when compared to an implant arthroplasty [4, 11, 34, 41]. Mann and Schakel [59] noted that first MTPJ arthrodesis results in a functionally longer first ray with decreased great toe contact time during gait, resulting in earlier lift-off and subsequent decrease in the dorsiflexion forces across the lesser MTPJs. While Kim et al. [47] did find metatarsalgia to be their most common complication after a first MTPJ arthrodesis at 9.8% in their case series, this was compared to 14.5% for the resectional arthroplasty and 7.7% for the hemi-implant. They also identified more types of complications overall and a greater incidence of complications in the other two groups at short-term follow-up. Brodsky et al. [11] prospectively analyzed the gait of patients undergoing a first MTPJ arthrodesis for hallux rigidus. They completed the gait analysis of 23 patients from preoperative to 1 year postoperative, finding increased ankle push-off power, increased single-limb support time on the side of arthrodesis, and decreased step width postoperatively. The authors concluded that a first MTPJ arthrodesis improves several aspects of gait including propulsive power, weight-bearing function, and stability. While DeFirino et al. [25] found conflicting evidence with some loss of ankle plantarflexion power on the fused limb, they did note a restoration of the weight-bearing function of the first ray with greater maximum force carried by the distal hallux at toe off, as well as an associated increase in AOFAS scores from 38 preoperatively to 90 postoperatively.

The redistribution of weight-bearing forces on the foot following resection or implant arthroplasty has been shown to cause postoperative metatarsalgia of the lesser digits. Henry et al. [41] used footprint analysis in 170 patients who had undergone either a first MTPJ arthrodesis procedure or a Keller procedure for hallux valgus. They found the hallux to bear weight in 80% of arthrodesis patients, as compared to 40% of Keller patients. Further, the authors identified a correlation between a non-weight-bearing hallux and the presence of metatarsalgia of the lesser metatarsal heads. Beauchamp et al. [4] used 16-point pedobargraph readings to assess weight bearing during gait in rheumatoid arthritis patients following either first MTPJ excisional arthroplasty or a first MTPJ arthrodesis. When compared to the arthroplasty group, patients in the arthrodesis group achieved increased weight bearing of the medial ray, including the hallux, improving balance and reducing risk of metatarsalgia. Beverly et al. [9] evaluated changes in gait following silastic implant arthroplasty of the first MTPJ. They found the peak load under the second and third metatarsal heads to be increased by 65% as compared to the patient's non-operative foot, which correlated with a third of the patients reporting discomfort in this area. Further, there was a 43% decrease in the peak load under the hallux and a 23% decrease in the peak load under the first metatarsal head, as well as a reduction in normal pronation during gait. Gibson and Thomson [34], discussed earlier, also found that implant patients bear more weight on the lateral foot as compared to patients with a first MTPJ arthrodesis. The redistribution of weight-bearing forces commonly seen after forefoot arthroplasty is consistently eliminated or reduced to a subclinical level in patients with a first MTPJ arthrodesis. Lombardi et al. [52] assessed the effects of a first MTPJ arthrodesis on the sagittal plane and medial longitudinal arch on radiographic evaluation. They measured the first metatarsal declination, talometatarsal, talar declination, calcaneal inclination, and talocalcaneal angles pre- and postoperatively. Significant postoperative changes were identified for the first metatarsal declination, talometatarsal, and talocalcaneal angles. They concluded that this supports Hicks' windlass theory that fixed hallux dorsiflexion will cause first ray plantarflexion, therefore increasing the medial longitudinal arch.

Shoe gear options after surgical intervention can also play a role in patient satisfaction and perceived outcomes. Difficulty wearing shoes other than orthopedic or comfort shoes has been noted in the literature along with limitation of shoe height; however this must be looked at in relative terms. While shoe styles may be more limited than in a rectus foot with pain-free first MTPJ ROM, the patients we are discussing have a painful HAV deformity and, in most cases, associated degenerative changes of the first MTPJ. Due to this, the authors have found that most of the patients that present with this scenario have already had limitation of shoe gear and do not have a goal of getting into a high-heeled shoe, so for that reason, this is not a limiting feature or complication with the procedure. Additionally, in the authors' experience, we have found that most patients can wear casual dress shoes with a slight heel without any difficulty. Coughlin et al. [16] noted that their patients were largely able to wear conventional or fashion shoes, though some did require inserts or comfort wear, and no patients in their series required custom shoes. DeSandis et al. [28] commented that 55% of the patients in their review did have some limitation in the ability to wear high-heeled shoes postoperatively, though they did not report on what height of heel or how many had this problem preoperatively. The issue of shoe height and style can and should be addressed with the patient preoperatively so they have the appropriate expectations for their outcomes. It is imperative to understand the significant role that patient education and expectations play in satisfaction.

Conclusion

An evidenced-based review of first MTPJ arthrodesis for a bunion deformity confirms consistent deformity correction, patient satisfaction, and healing characteristics. In addition, patients can safely ambulate early or immediately in the postoperative period, making this a very patient-friendly procedure. In order to obtain the high satisfaction and excellent function associated with the procedure, appropriate positioning of the hallux, especially in the sagittal plane, is imperative. The literature is clear that improvement in patient ambulatory function can be relied upon with patients returning to the same or improved activity level postoperatively. When specifically compared against implant arthroplasty, the evidence demonstrates that a first MTPJ arthrodesis has the same or better patient satisfaction and better functional outcomes with less complications and fewer revisions required.

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Juvenile Hallux Valgus

15

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Background

Multiple terms have been used to describe this deformity in the young population. Adolescent hallux abductovalgus is a commonly used term; however juvenile hallux abductovalgus may be the more appropriate term, as the age of onset may be earlier than typically recognized [9]. In a long-term retrospective study, 40% of juvenile bunions were shown to have occurred by the age of 10 or earlier [7]. Multiple studies [7, 23, 40, 41] support this early onset, reporting 46–92% of patients had the deformity in their juvenile years before skeletal maturation [9]. These reports show the deformity begins prior to the age of 20 with an average clinical onset at 12 years.

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Hallux valgus is the most common pathology that affects the great toe. The prevalence of this deformity is similar regardless of the age, affecting 3.5% of the juvenile population and 2–4% of adults [8, 37, 42]. The bilaterality of the deformity, however, is unknown mostly due to unreported contralateral evaluation. Hand dominance may be influential but is also lacking consensus [8]. Yet, one study reported 84% incidence of bilateral deformity with more right foot than left foot surgical corrections. Even though 91% were right handed, the correlation of hand dominance was not significant statistically [8].

The incidence of juvenile hallux valgus tends to increase if associated with metatarsus adductus [2]. In a randomized, controlled study, 35% with metatarsus adductus had hallux valgus compared to 13% of the control group having no bunion deformity [2]. Another report showed similar values with an 18% prevalence of metatarsus adductus without hallux valgus versus 55% with concomitant deformity [14, 33]. Also identified was the significant relationship between the degree of metatarsus adductus and the degree of hallux abductovalgus in male and female subjects [14].

Several studies have shown marked female preponderance of hallux abductovalgus with rates ranging from 3:1 to as high as 15:1 in the adult population [14]. Coughlin supported these statistics in juvenile patients with 88% female association in his series, which does not differ significantly from the adult population [7]. Pique-Vidal et al. in a study of 350 patients observed an

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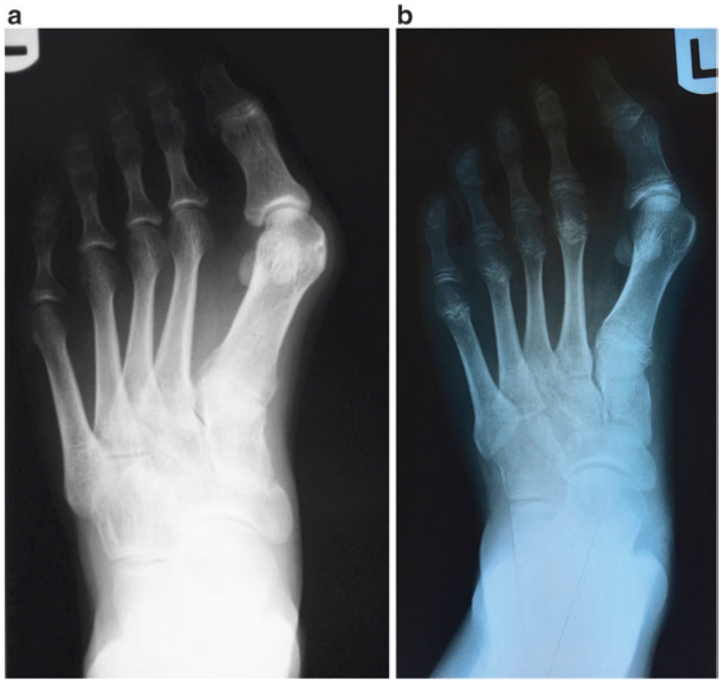

Fig. 15.1 (**a**) A 15-year-old female who reached skeletal maturity. Note the large intermetatarsal angle, diastasis between the base of the first and second metatarsal and the medial and intermediate cuneiform. Additionally, the hallux valgus angle is large, and this typically incorporates pathological sesamoid position with a frontal plane rotation of the hallux. This patient underwent a Lapidus (arthrodesis of the TMT-1 (first tarsal-metatarsal) bunionectomy. (**b**) A juvenile HAV deformity in a patient who has not reached skeletal maturity with a triplane abnormality. Note the increase in the intermetatarsal angle, the increase in the hallux valgus angle, and the rotation into valgus of the hallux as well as the sesamoid position indicating first ray valgus rotation

even higher male-to-female ratio of 1:14.9 [42] (Figs. 15.1 and 15.2).

Although the etiology of juvenile hallux valgus is unclear, there is evidence of familial involvement. Pique-Vidal et al. showed that in 90% of patients, bunion deformities were present in at least two members of the family with a vertical transmission through three generations [42]. Incomplete penetrance of the bunion deformity was noted in 56% of patients. Coughlin similarly reported that 72% of subjects displayed maternal transmission with variable penetrance and concluded the disorder was more severe in these patients [8]. This trait was associated with an X-linked dominant transmission, autosomal dominant transmission, or polygenic transmission [7]. These findings indicate a high likelihood that hallux valgus is hereditary, with probable autosomal dominant transmission. Hardy et al. described 77% of his subjects reported bunion deformities in their mothers and only 16% implicated their fathers [23]. Subsequently, Johnston et al. led a trial based on family history where 94% of the females had a pattern of inheritance consistent with maternal transmission with only two noting paternal involvement [25]. All three males in the study exhibited positive family history through maternal transmission. This in-depth study concluded that juvenile hallux abductovalgus was autosomal dominant with incomplete penetrance.

Extrinsic factors may not affect juvenile hallux valgus as much as adult onset deformities. In the adult population, ill-fitting shoes affected 24% of patients [42]. However, tight shoe gear and high heels play a small role in the etiology of juvenile hallux valgus [7, 42]. This also supports the conclusion that bunions in children younger than 10 years of age are likely inherited [42]. In contrast, Sim-Fook and Hodgson reported 33% of shod individuals displayed hallux valgus compared with a 2% incidence in unshod subjects [49]. Others

Fig. 15.2 An AP radiograph of a young patient who has reached skeletal maturity demonstrating a met adducts deformity who demonstrates a mild HAV deformity clinically

Fig. 15.3 A clinical photo of a juvenile HAV abnormality with a flatfoot deformity

(Pique-Vidal, McGlamry) shared similar observations that hallux valgus is more common among shoe wearers [37, 42]. Yet, Kilmartin et al. noted hallux valgus increases in children regardless of whether they wear biomechanical orthoses or well-fitting shoes [29]. Footwear may be responsible for the correlation between metatarsus adductus and juvenile hallux abductovalgus in that lateral forces of shoe gear may displace the great toe [14, 44].

There have been many causative factors suggested in previous literature. Hohmann notably penned the phrase, "Hallux valgus is always combined with pes planus, and pes planus is always the predisposing factor in hallux valgus" [32]. Kalen and Brecher noted there was an 8–24 times greater incidence of pes planus in juveniles with hallux valgus [28]. Scranton et al. reported 51% of subjects had concomitant pes planus [7, 47]. These studies support Hohmann in that a flatfoot deformity was a predisposing factor for juvenile hallux valgus, yet current literature supports otherwise for the juvenile onset deformity.

Kilmartin and Wallace noted that the incidence of pes planus is as common in the normal population as in those with hallux valgus [32]. Coughlin showed that only 17% of juveniles with hallux valgus had moderate or severe pes planus [7]. In one cohort, they found the calcaneal inclination angle was not significant statistically and suggested pronation may not be related in the development of juvenile bunions [37]. In fact, there is a very low incidence of advanced pes planus in patients with hallux valgus, which does not increase occurrence of juvenile hallux valgus or recurrence following surgical correction [6, 7, 32, 39]. Kilmartin concluded that pes planus was not a significant etiologic factor [32] (Fig. 15.3).

Metatarsus adductus has been associated with juvenile hallux valgus. Early literature noted linear correlation between increasing juvenile hallux valgus and increasing metadductus [2, 43] as well as increased recurrence rates of bunion deformity following a hallux valgus repair when metadductus was present [35]. Using Engel's criteria, Coughlin measured metatarsus adductus angle in juvenile with hallux valgus and reported 100% of subjects with angles greater than 15° and 22% measuring above 21° [9]. This strong association between juvenile hallux valgus and metatarsus adductus, however, had no increased recurrence rates postoperatively. Coexistent hallux valgus with significant metatarsus adductus may exaggerate the deformity and make surgical treatment difficult [52].

McCluney and Kilmartin have reported the metatarsus adductus angle was not statistically significant and only a causal association of metatarsus adductus in the development of juvenile hallux valgus [30, 37]. Yet neither could exclude metatarsus adductus as a possible predictor of juvenile hallux valgus. Ferrari et al. noted distribution of hallux valgus is significantly different between males and females with and without metatarsus adductus [13]. With normal metatarsus adductus angle, males also had a normal hallux abductus angle, whereas half the females displayed a bunion deformity. In both groups, the rate of hallux valgus increased with abnormal metatarsus adductus angles. Actually, 100% of females with abnormal metatarsus adductus angles had abnormal hallux valgus angles. This study found that when metatarsus adductus was present in females, hallux valgus always accompanies it. Therefore, this coexistence should be assessed during surgical consideration [14] (Figs. 15.4).

Fig. 15.4 An AP radiograph demonstrating a mild metatarsus adductus with congruent first metatarsal phalangeal joint and a pes planus deformity. Note the dorsal talar-first metatarsal angle

Radiographic Evaluation

A distinct characteristic of juvenile hallux valgus is congruent joints [8]. Piggott in his adult series noted <10% had a congruent metatarsophalangeal joint [41]. However, later studies revealed 47–68% of juveniles with hallux valgus had congruent joints [7, 52]. Hardy and Clapham coined the term "critical angle of hallux valgus" or the point at which the hallux abuts the second toe, pushing the first metatarsal into varus [23]. The intermetatarsal angle was found to be stable until this point, at which the intermetatarsal and hallux abductus angles increased more rapidly [31].

Plain radiography of the deformity will aid in deciding corrective procedures as well as detecting coexisting abnormalities. Dorsoplantar, lateral, and sesamoid axial X-rays will project all three cardinal planes for evaluation. Commonly evaluated are the intermetatarsal, hallux abductus, and distal metatarsal articular angles, sesamoid position, and metatarsal length. An increased distal metatarsal articular angle (DMAA) may be the defining characteristic of juvenile hallux abductovalgus [8, 9]. Early recognition of an increased distal metatarsal articular angle will aid in avoiding excessive lateral tilt after bunion repair [52]. A relatively high distal metatarsal articular angle occurs with concomitant metadductus [20, 52]. Normal values for distal metatarsal articular angle are 8° or less [4, 20, 37, 46]. Interestingly, the literature shows much variability when measuring the distal metatarsal articular angle. Vittetoe et al. observed that 1 out of 20 times measurements of the angle would be off more than 5° [51]. Amarnek et al. found preoperative measurements averaged 7° below the intraoperative value and recommended distal metatarsal articular angle be determined intraoperatively [1]. The distal first metatarsal articular angle is considered to be one of the main intrinsic factors responsible for the early onset, heritable nature, and severity of the hallux valgus deformities in juveniles [39].

Metatarsus primus adductus is a significant radiographic deformity in hallux valgus and may exaggerate the bunion deformity [2]. The metatarsus adductus angle is the line bisecting the second metatarsal and the longitudinal line bisection of the lesser tarsus on standard weight-bearing dorsoplantar radiographs [14]. Engel determined a metatarsus adductus angle greater than 21° is abnormal [12]. Though some authors believe the increase in intermetatarsal angle is a result and not a cause of hallux valgus, obtaining the true intermetatarsal angle is important in the presence of metatarsus adductus. This is defined as the sum of the intermetatarsal and metatarsus adductus angles and subtracting 15° [11] (Fig. 15.5).

The presence of a long first metatarsal has been indicated in the development of juvenile hallux valgus [37]. Hardy and Clapham observed differences in protrusion distances compared to controls and concluded that subjects with a long first metatarsal are likely to develop hallux valgus [23]. Coughlin noted the preoperative hallux valgus angle averaged 5° more with a long first metatarsal, but it did not directly increase the risk for postoperative recurrence [7]. A hallux abductus angle greater than 15° is considered pathologic [23, 37]. The authors do not believe that long and short first metatarsals exist in cases of feet without previous trauma or surgery except in cases of brachymetatarsals. Often when short and long first metatarsals are discussed, it is the given position of a snapshot view of the first metatarsal. At the time of the radiograph, one needs to ask was the patient full weight bearing, was the patient fully loaded on their foot, was the angle and base of gait accurate, and did the X-ray technician have the appropriate angle at the time of the X-ray? It has been the experience of the authors that when a first metatarsal appears long on an AP X-ray, the metatarsal is elevated or more parallel to the ground (often seen with a flatfoot deformity). When it appears short, the first metatarsal is positioned more in a plantar-flexed position (often seen with a cavus foot) (Fig. 15.6).

Fig. 15.5 This is an AP radiograph of a patient who suffers from a met primus varus deformity

Fig. 15.6 This is an AP radiograph of a juvenile HAV abnormality that demonstrates a "long first metatarsal." Except in cases with brachymetatarsal and other congenital defects or in cases with previous history of trauma or surgery, the authors have noted that there is not a true long first metatarsal. It is a positional abnormality at the time of the "snapshot" of a radiograph. Rather than a "long first metatarsal," the authors submit it is a positional issue demonstrating instability of the first metatarsal. With instability and hypermobility, the first metatarsal is more parallel to the ground, and it appears long; hence it is not physically long, but the position of a fully weight-bearing X-ray gives this impression. Opposite of a long first metatarsal is a short appearing metatarsal radiographically. This occurs in conditions of a stable and plantar-flexed first metatarsal in conditions of a pes caves deformity

In an extensive review by Ferrari et al., a sexual dimorphism was observed, predominantly proving male bones and joints were larger than females [13]. Articular surface measurements suggested high potential for adductory movement in females, which could produce a more adducted first metatarsal than in males [13]. Women also demonstrated greater curvature in the first metatarsal head, which is related significantly to the degree of hallux valgus. This allows for decreased stability at the metatarsophalangeal joint and increased abduction of the proximal phalanx. Ferrari reported that if an abductory force were equal between men and women, the female hallux would buckle more easily than in men. Females are known to be more flexible than males and may lead to greater hallux valgus deformity [14]. This hypermobility is may be due to ligament laxity, but the joint laxity may precede soft tissue influence. The talar head also had larger functional angles in females in which greater motion can occur. Both the first metatarsal head curvature and talar functional angle in females are postulated to increase occurrence of hallux valgus [13]. A full clinical and radiographic assessment including rearfoot deformities or triplanar abnormalities must be considered to determine effective treatment options.

Nonsurgical Treatment

Though controversial, nonsurgical measures may not be helpful in moderate-severe juvenile hallux valgus with progressive deformity. A prospective trial of foot orthoses for juvenile hallux valgus questioned the role of pronation as a causative factor in juvenile hallux valgus [37]. Kilmartin et al. found that orthoses should not be used to treat juvenile hallux valgus as they appear to increase the rate of deformity progression. Interestingly, several of the contralateral normal feet developed hallux valgus despite orthotic use. Hallux valgus increases in children regardless of whether they wear biomechanical orthoses or well-fitting shoes [29]. However, nonsurgical treatment may be amenable in patients with neuromuscular disorders, ligamentous laxity, or inability to remain non-weight bearing (Groiso). Non-operative treatment options that include wider shoe gear, bunion pads, orthotics, and bracing may relieve symptoms of deformities that are mild, minimally painful, and flexible. Although the patient population is generally not compliant with these modalities, they should be attempted given the high rate of recurrence from surgery and are effective in treating other compounding deformities like metatarsus adductus, pesplanovalgus, and equinus [21].

Operative Considerations/ Approach/Procedures

Surgery should be discussed when conservative measures have failed or when these measures are determined to be unlikely to be effective. Additionally rapid progression of the deformity with visible joint adaptation is a reasonable indication for correction in younger patients. The goals of surgery are to relieve pain, restore function, prevent worsening deformity, and improve cosmesis. Value of these factors should be placed in this order. If cosmesis is the main focus, reassessment should be performed and directed toward conservative measures given the high rate of recurrence [53].

Several important factors must be evaluated in the preoperative period. These include the patients' age, growth plate status, coexisting deformity, progression of deformity, family history, functional impairment, and expectations. Severe impairment with pain and dysfunction and progression of the deformity despite conservative measures are clear indications for surgical correction.

Ideal timing for surgical correction is between the ages of 11 and 15 years as the patient approaches skeletal maturity. It is important that growth plates should be closed to allow procedures that can produce optimum deformity correction.

Surgical correction options are vast and include head procedures, base procedures, soft tissue procedures, epiphysiodesis, and first metatarsocuneiform fusion. The decision as to which procedure or procedures is warranted depends on several factors: the severity of the deformity, correction needed, growth plate status, and patients' capacity. Frequently, definitive surgical planning doesn't finish until intraoperative evaluation can be performed of the articular surface of the first metatarsophalangeal joint [41]. Soft tissue procedures are generally insufficient in treating the deformity successfully. It is this authors' approach to not violate the joint unless completely necessary to avoid potential risks of AVN, arthritis, or adhesions. The exception of any abnormal soft tissue contractures contributing to the deformity should be addressed.

Distal metatarsal osteotomies are typically performed on juveniles with only mild to moderate deformity. The most commonly used are the Austin, Kalish, and Reverdin along with its various modifications [6]. The Reverdin and its modifications are especially useful given its ability to not only correct the IM but also for PASA correction [3]. Given this flexibility, it is often combined with more proximal procedures for patients with severe deformity where there have been adaptive changes to the metatarsal head. In these cases, the proximal osteotomy is performed first, followed by the distal procedure to assure proper alignment of the articular surface and joint function. Relocating the sesamoid apparatus beneath the metatarsal head and aligning the FHL restore normal sagittal plane motion of the first MPJ decreasing long-term arthritis risk [22, 45].

Base procedures include opening or closing wedges and the Lapidus fusion. These procedures are generally utilized in those juveniles with more severe deformity and higher IM angles [50]. The goal of these procedures is to correct the severe deformity and restore the parallel relationship between the first and second metatarsal while avoiding plantar or dorsiflexion of the metatarsal. The OBWO and CBWO are typically performed more distal to avoid open growth plates [34]. The OBWO is less often used given its predisposal to lengthening the first metatarsal thus exacerbating the deformity at the first metatarsophalangeal joint [5]. Additionally the results from OBWO have not been as favorable as other procedures. The CBWO on the other hand has proven quite useful and when combined with a head procedure as necessary has shown long-lasting results [24] (Fig. 15.7).

There is little reported use of cuneiform osteotomies in surgical repair of juvenile hallux valgus deformity. The first use was by Riedl in 1908 in which he described a closing wedge osteotomy of the medial cuneiform to reduce the “atavistic” joint surface. This procedure was followed by Young in 1910 who advocated an opening wedge of the medial cuneiform. In 1935,

Fig. 15.7 This is AP radiograph of a patient who presents with a reoccurrence of an HAV deformity. Years earlier, when the patient's growth plate was open (skeletal immature), a transverse closing base wedge was performed demonstrating the deformity is much more complex and needs to be addressed

Cotton described an opening wedge osteotomy of the medial cuneiform dorsally to address sagittal plane deformity in the correction of medial column depression seen in pes planus deformity [54]. This led many physicians to use this procedure in combination with the CBWO or OBWO to address the juvenile hallux valgus deformity. In 1986, Bicardi and Frankel reported on the use of a biplane cuneiform osteotomy in which a dorsal medial-based graft was inserted. The thought was that this procedure addressed the apex of the deformity, which was the obliquity of the metatarsocuneiform joint. Additionally, it preserved length of the first metatarsal and by increasing inclination of the joint surface in the sagittal plane enhanced the durability of the correction. Overall, it was proved to be a safe procedure that allowed the surgeon to address the deformity in multiple planes while preserving the growth center [55] (Fig. 15.8).

Fig. 15.8 It has been the experience of the authors that Cotton osteotomies have not been successful in complete/overall correction of HAV deformities alone. The authors have experience inadequate reduction of the transverse plane. The authors do advocate using the Cotton osteotomy in juvenile HAV surgery in the sagittal plane to enhance stability if the patient cannot have a Lapidus procedure due to skeletal immaturity

Fig. 15.9 This is a patient who had a Lapidus procedure performed at skeletal maturity

Lapidus fusion is ideal for patients with severe deformity and in patients with a high true IMA and metatarsus adductus. This procedure has received negative connotations due to its potential for shortening and growth plate compromise or sacrifice [16]. When performed correctly, it has been shown to have the lowest incidence of recurrence among all other procedures through elimination of hypermobility and addressing the deformity at its apex [19]. Given its ability to correct large deformities, and improvement in stability of the first ray, its long-term benefit should be considered in all candidates where it's a feasible surgical option (Fig. 15.9).

Epiphysiodesis is a different approach to hallux valgus correction. The principle is based on utilizing the patients' inherent growth ability to aid in correction of the deformity. By arresting the lateral portion of the physis, the medial physis continues to grow thus correcting the IM angle and reducing the deformity. Due to this procedure causing possible irreversible physeal arrest, very careful planning and timing must be performed to assure an acceptable reduction of the deformity [10, 15]. Surgery should be performed between ages 10–12 for females and 11–14 in males, although radiographic age dictates specific restrictions. Upon determining skeletal age, potential growth must be calculated utilizing Nelson's growth chart [38]. Timing for the procedure is determined when the amount of anticipated growth is equivalent to the amount of correction needed. Recent fixation technology, such as staples, has now allowed for correction of the deformity, without compromise of the growth center. This allows for earlier surgical correction, although it remains to be seen and studied if this is beneficial in the long term [15].

Authors' Experience and Recommendations

Based on many discussions with family members and in the authors' experience, HAV deformity appears to have a direct correlation with the parents and/or grandparents in terms of similar conditions demonstrating this is a congenital, inherited deformity. In most cases, foot deformities are no different than a parent being tall and the children also being tall, the parents having light eyes and the children also having light eyes, etc., The authors have found in juvenile HAV pathology that distal metaphysical osteotomies have not been successful long term as it does not address the underlying pathology. The authors have experienced a high rate of reoccurrence. Also, the authors no longer advocate performing a lateral release or a medial eminence resection as this has been found to be ineffective long term as well.

The authors challenge the thought of a long and short metatarsal. In the authors' experience, no such thing exists outside of patients who truly suffer from a congenital deformity or patients who have experience previous surgery or trauma at the site. The appearance of a long metatarsal or short metatarsal radiographically is a radiographic instant projection of the position of the first metatarsal. For instance, in a patient who experiences instability of the first ray (often associated with a flat foot), oftentimes the first metatarsal will be more parallel to the ground suggesting there is an appearance of a "long metatarsal"; however it is merely the position and not the anatomic finding. The same issue exists for what appears to be a "short metatarsal." What may appear as a "short metatarsal" on an AP radiograph is a patient who demonstrates a more plantar-flexed metatarsal. For example, a patient with a cavus foot type will often appear to have a short metatarsal.

The authors advocate a thorough evaluation in order to appropriately evaluate and treat the entire lower extremity. This includes having the patient evaluated both standing and seated. A Silfverskiold test is a must in order to determine if the patient suffers from an equinus deformity. If there is a contracture, the surgeon must address this by performing the appropriate posterior muscle lengthening. Additionally, X-rays of the foot, ankle, and calcaneal axial should be obtained in order to provide a complete assessment. Furthermore, the stability or instability/hypermobility of first ray should be evaluated. It is the authors' experience that nearly all HAV deformities have a form of instability/hypermobility. Often associated with instability/hypermobility of the first ray and a HAV deformity are pes planus (flatfoot) conditions. In the author's experience, stabilization of the first ray is imperative in order to obtain a more predictable and long-term outcome (Fig. 15.10).

The authors recommend delaying surgery as long as possible in hopes the patient can have a tarsal metatarsal arthrodesis for a correction in all three planes (Lapidus procedure) once the patient has reached skeletal maturity. It has been the author's experience that the deformity can be corrected in all three planes with a Lapidus procedure, and by stabilizing the first ray and an achieving anatomic alignment, the long-term results are superior to other procedures.

As long as the reduction of the Lapidus is parallel or close to parallel, the clinical results have been pleasing to the patient and patient's family. In performing more aggressive procedures to address the metatarsal adducts deformity, it is not as predictable, and it is much more invasive for the patient and much more difficult for the

Fig. 15.10 A weight-bearing photo demonstrates the first ray insufficiency (instability/hypermobility) of both feet in a pediatric patient who has been diagnosed with juvenile HAV

surgeon to obtain an excellent reduction. In essence the authors do not perform these procedure except in very specific scenarios and have found them to be unnecessary.

It has been the author's experience to address a notable flatfoot deformity if it does in fact coexist with an HAV condition. When the authors have failed to address a flatfoot deformity with an HAV condition, we have identified a high rate of reoccurrence. The patient continues to pronate through the corrected HAV deformity subjecting the patient to a reoccurrence.

The authors recommend, evaluate, and address all deformities that are present when the patient is symptomatic and all non-operative care has failed. Start proximal and address the posterior muscle lengthening as determined by the Silfverskiold test. If a unstable and flatfoot deformity is present, the authors urge the correction of the flatfoot with calcaneal osteotomies (single or double as indicated) as well as stabilization of the first ray and medial column. In cases of where a juvenile HAV deformity that has not responded to non-operative care and skeletal immaturity, the authors have used the Cotton osteotomy to provide increase stabilization in the sagittal plane. In addition, a closing base wedge osteotomy just distal to the growth plate can be performed to address the HAV deformity. The surgeon should aim to make the first metatarsal as parallel to the second metatarsal. The Cotton osteotomy enhances the stabilization of the first ray and addresses the transverse plane to correct the HAV. Please note this cannot correct the deformity in all three planes (Fig. 15.11).

Complications from juvenile hallux valgus include recurrence of the deformity and pain. Although previously associated with recurrence rates over 30%, accurate procedure selection has decreased this rate to more acceptable levels [17]. Additionally, correction of contributory deformities such as pesplanovalgus, equinus, and metatarsus adductus has also been shown to decrease recurrence rates and improve overall pain and function [1, 18, 27, 48, 53]. Underestimation by the provider or selection of the wrong corrective procedure generally is at the root of complications.

Careful preoperative planning is paramount in addressing the deformity accurately. Ideally, one surgery should be performed to correct the deformity and provide long-standing correction and prevention of recurrence. The authors have found that distal metaphyseal osteotomies do not work long term and therefore do not perform this type of procedure. It has been the experience of the authors that improved results are expected when both the primary deformity and secondary mechanical problems such as instability and flatfoot deformity are globally addressed. The authors have found that the Lapidus procedure provides the best long-term and most predictable results as this can address the deformity in all three planes and corrected at the site of pathology. If the patient has not reached skeletal maturity and is symptomatic, the authors typically perform a transverse closing base wedge osteotomy with a Cotton procedure. A Cotton procedure is utilized to provide stability to the medial column (sagittal plane) – to "stiffen" the hypermobile foot. The transverse closing base wedge osteotomy can address the transverse plane deformity closing down the intermetatarsal angle. Because it is well known that recurrence rates are high with osteotomy procedures, patients must be advised of the possibility of recurrence and need for further surgery (Figs. 15.12, 15.13, and 15.14).

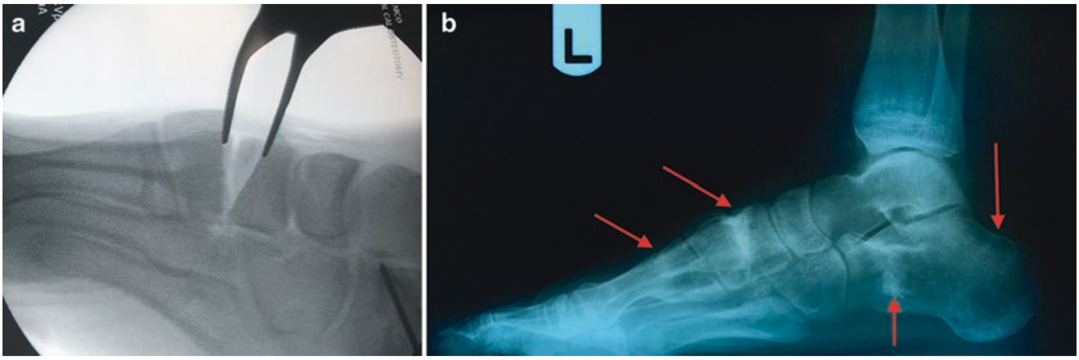

Fig. 15.11 (**a**) This is an intraoperative lateral view of a Cotton osteotomy demonstrating the sagittal plane correction gained through a Cotton osteotomy. Note the plantar flexion of the first metatarsal relative to second metatarsal. (**b**) A lateral radiographic projection of a patient who had not reached skeletal maturity prior to surgery. Preoperatively, the patient was diagnosed with a pes planus deformity as well as an HAV deformity. This patient had an endoscopic gastrocnemius recession, a double calcaneal osteotomy, a Cotton osteotomy, and a closing base wedge osteotomy to address all the pathologies

Fig. 15.12 This is a postoperative AP view of a pediatric patient who preoperatively had a flatfoot deformity associated with a HAV condition. This patient had an endoscopic gastrocnemius recession, a double calcaneal osteotomy, a Cotton osteotomy, and a closing base wedge osteotomy

Fig. 15.13 An AP radiograph of a patient who had a closing base wedge osteotomy prior to skeletal maturity. The HAV deformity reoccurred

Fig. 15.14 (**a**) An AP radiograph of an 16-year-old skeletal mature patient who had a painful, symptomatic HAV deformity. The patient was able tolerate the symptoms until she reached skeletal maturity. The patient had a concomitant flatfoot deformity. The surgical procedures included an endoscopic gastrocnemius recession, a percutaneous calcaneal displacement osteotomy, and a Lapidus bunionectomy. (**b**) This is the lateral X-ray projection of the patient who had an endoscopic gastrocnemius recession, a percutaneous calcaneal displacement osteotomy, and a Lapidus bunionectomy once skeletal maturity has occurred

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16 Arthroplasty with and Without Replacement

Emily Cook and Brandon Barrett

Background

Hallux valgus and hallux rigidus are progressive disorders that result in degenerative changes to the first metatarsophalangeal (MTP) joint surfaces. This is often characterized by limited range of motion, stiffness, and joint pain. The success of conservative treatment options for advanced stages of first MTP joint arthritis is limited as little to no cartilage remains in many cases. In severe cases, the pain may cause the patient to shift more body weight off the medial column onto the lateral foot resulting in an altered gait pattern [1, 2] and concomitant lateral foot pain. Stiff shoe gear (possibly with a steel shank) and joint injections may offer the patient some relief, but this is most often only a temporary result. When a patient with end-stage painful arthritis elects surgical intervention, a joint destructive procedure is often employed as the procedure of choice curing the painful bone-on-bone contact through either a resection arthroplasty, implant arthroplasty, or MTP joint arthrodesis [3–5].

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First MTP joint resection arthroplasty was originally described as a treatment option for hallux valgus by Riedel in 1886 by resecting the base of the proximal phalanx [6]. One year later, in 1887, Colley-Davies described this same technique for the treatment of hallux rigidus [7]. It was not until the early 1900s that this procedure became popularized by Dr. William L. Keller. He published his results in 1904 and 1912 showing this technique as a viable surgical option to relieve painful symptoms from hallux rigidus and hallux valgus [8, 9]. In 1908, Mayo also described arthroplasty of the first MTPJ as a treatment option, but with resection of the head of the metatarsal rather than the base of the proximal phalanx [10]. Unlike Keller, however, Mayo's technique did not grow in popularity. The Keller arthroplasty remained popular for the first half of the twentieth century as it was a technically simple procedure to perform. Keller's early results showed a quick postoperative recovery and good functional outcomes as it maintained the "tripod" structure of the foot [9]. His technique included a resection of the proximal one-third of the proximal phalanx with remodeling of the metatarsal head, producing decompression of the joint and relaxation of the capsule and surrounding joint structures. As this technique became widespread, MTPJ resection arthroplasty became known as the "Keller arthroplasty."

The initial indications for the Keller arthroplasty were relatively broad and included patients of all ages and activity levels. As long-term results

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became available, complications in the younger and more active demographics were reported, and the indications narrowed to include only the elderly with lower ambulatory demands. After several decades of widespread usage, surgeons began to shy away from the Keller arthroplasty as long-term studies reveled complications including short toes, floating toes, loss in push-off power, and difficulty in salvage if the procedure failed [11, 12].

By the mid-1950s, the first MTP joint implant arthroplasty was developed as an alternative to arthrodesis or the Keller arthroplasty. The interest in implant arthroplasty grew as a result of the success in joint replacements being performed in the hip and knee. Implant arthroplasty of the first MTP joint was developed to provide the patient with an alternative solution to joint arthrodesis or resection arthroplasty with the goal of restoring pain-free, stable motion at the joint. As with other joint replacements throughout the body, this alternative option was met with great enthusiasm.

The first implant design was created from a combination of bone cement and acrylic methacrylate in 1951 and made to recreate the base of the proximal phalanx [13]. By the following year, Swanson further modified the implant by creating a cap for the metatarsal head, but this was ultimately unsuccessful [14, 15]. Multiple modifications of this design continued until the 1970s when the use of the total joint silicone implant became popularized. This served as a soft spacer and preserved some of the range of motion of the joint. However, by the 1980s the use of the silicone implant was significantly declining as results showed high complication rates including fracture of the silicone components and host reactions [16–20]. Other early first MTP joint prosthetic designs were patterned off of the designs used in the hip and knee including use of a metallic component with a constrained polyethylene component. The results from this early two-part implant design were not favorable, and high failure rates were reported [21]. Use of other materials, such as acrylics and various metals, had similar failures. Rapid adoption of first MPJ implant arthroplasty ensued before a thorough understanding mechanical implant design tailored for the first MTPJ, material flaws relative to this anatomic area, and an appreciation for selection of appropriate candidates for the procedure. Over time, it became clearer that certain implant designs, implant materials, and patient characteristics were associated with poorer outcomes [3–5]. The mechanical demands, biomechanical complexity, and material interactions relating to the first MPJ have been continuously addressed [22–24]. Implant designs and materials have therefore undergone continuous revisions over the years to address new understandings in biomechanics and physiology. Today, there are a variety of options ranging from hemi-implants to bipolar implants.

Despite attempts to improve implant design, material and patient selection controversy remains as critics question whether it should be considered as a viable treatment option [25]. The first concern is that confusion related to earlier materials and implant design has persisted. Deformity correction was rarely addressed in early studies resulting in mechanical failures based on local mechanical forces. This ignorance regarding the role of first ray biomechanical abnormalities leads to inappropriate implantation and increased failure rates. The second concern is that despite widespread clinical use, there are few high-quality controlled trials available to assist surgeons in making an informed decision regarding first MTP joint implant arthroplasty. With that said, new implant designs continue to enter the market as many patients continue to seek alternatives to joint fusion and maintain joint motion.

Reasoning and Philosophy

There are two basic groups into which surgical procedures for which first MTP joint arthritis can be categorized: joint salvage and joint destructive. Joint salvage procedures attempt to preserve the native cartilaginous surfaces by addressing any periarticular abnormalities and/or cartilage defects. These procedures are commonly performed in the earlier stages of degenerative joint disease (DJD) where the majority of the cartilage is not diseased.

Joint destructive procedures of the first MTP joint are reserved for the late stages of DJD where the joint cartilage is too diseased or too eroded to reasonably expect that a salvage procedure will achieve satisfactory results. The options for a joint destructive procedure can be subcategorized into either arthrodesis (motion eliminating) or arthroplasty (motion preserving). Arthrodesis continues to remain the gold standard for end-stage arthritis [1, 26, 27]. It also remains the more common procedure for definitive treatment as the evidence historically has shown relatively good outcomes and patient satisfaction rates [28]. In multiple comparison studies, arthrodesis has shown better overall postoperative scores, better gait analysis outcomes, and lower complication rates to arthroplasty. Despite these findings, each of these studies contains significant study design flaws making it difficult to draw definitive conclusions [28–32]. Although good success has been reported with first MTP joint arthrodesis, some studies show that an arthrodesis results in a shorter stride length, less ankle plantar flexion at toe-off, and weaker push-off power during gait [33]. Additional complications include patients feeling too stiff and experiencing pain from hardware and dissatisfaction with limitation in their shoe wear options. The limitation in shoe wear options can be especially problematic for women that want to wear high-heeled shoes. Many patients also need to maintain some ROM of the MTP joint for additional occupational or recreational reasons.

The Keller arthroplasty and modified resection arthroplasty can be considered as treatment options, but there continues to be a variability of reported techniques and weak evidence in the literature [34]. However, there is a growing interest in implant arthroplasty as patients are seeking other options that allow for the ROM of the joint to be preserved or regained while maintaining stability. Much of the interest in first MTP joint arthroplasty follows from successes seen in joint replacement in the hip and knee. While implant arthroplasty of the first MTP joint has not demonstrated the same levels of success as other joints, improvements in design and materials show promise.

The primary goals of implant arthroplasty are to alleviate pain, restore or regain ROM, preserve stability, minimize the loss of plantarflexion strength, and improve the overall function of the foot during gait. A meta-analysis in 2010 found greater patient satisfaction after first MTP joint implant arthroplasty [35, 36], while a more recent study showed similar outcomes between implant arthroplasty and arthrodesis [36]. Although these studies show encouraging outcomes, the choice to proceed with implant arthroplasty should take into account the patient's individual characteristics, physical demands, personal preferences, and expectations. More detail concerning patient selection can be found later in the chapter.

Anatomic Considerations

There are multiple tendons and structures that insert onto base of the proximal phalanx and influence the balance and stability of the first MTP joint complex. Maintaining balance of the joint is important as the first MTP joint can bear up to 90% of the body's weight during non-pathologic gait [37]. Tendons that insert onto the proximal phalanx base include the flexor hallucis brevis, extensor hallucis brevis, abductor hallucis, and adductor hallucis. Additional anatomic contributors to joint stability include the collateral ligaments, plantar plate, and sesamoid complex. Joint articulations involve the base of the proximal phalanx with the metatarsal head and the sesamoids with the plantar metatarsal head. Any disruption in the joint stability may result in abnormal motion and uneven force and wear across the joint surface. Cartilage deterioration can then lead to further joint imbalance with progression of arthritis.

Understanding the insertion of the soft tissue structure into the base of the proximal phalanx can help guide the level of surgical resection. While the goal of the traditional resection arthroplasty is to eliminate the deforming forces of these structures, the goal of both the modified Keller arthroplasty and implant arthroplasty is to preserve these structures to allow for continued active stability. Two cadaveric studies showed that by resecting 8 mm and 9.5 mm off the base of the proximal phalanx, in woman and men, respectively, the stabilizing structures are completely removed, and the joint becomes destabilized. However, resecting no more than 3 mm off the base of the proximal phalanx ensures that all the attachments are left intact [38, 39].

Patient Selection

The primary indication for first MTP joint arthroplasty is painful end-stage DJD that involves too much of the joint as to reasonably consider a joint salvage procedure [40]. The ideal patients who would benefit from a Keller arthroplasty include elderly patients with low ambulatory demands with painful end-stage DJD with or without a hallux valgus deformity that have failed conservative management. However, if an implant is used, it is recommended to address any underlying deformity to prevent increased stresses being placed on the implant. Joint arthroplasty can also be considered after joint preservation procedures have failed to provide adequate pain relief. This procedure is contraindicated in younger, active individuals as it significantly impacts gait [41] and because increased failure rates are expected in active individuals. Contraindication for Keller arthroplasty with an implant includes the presence of significant osteopenia or osteoporosis that would be unable to hold an implant. Inadequate bone stock is at a high risk of failure if using an implant secondary to a fracture, implant loosening, or subsidence. A comprehensive list of indications and contraindications for arthroplasty is listed in Table 16.1.

Choosing the appropriate patient for implant arthroplasty plays a large role in predicting the success and durability of the implant. In the early birth of implant arthroplasty, there were several errors made with regard to patient selection. Many of the early failures of silicone implants occurred because of inappropriate placement in individuals that were too active and in patients that were young. It has been postulated that in the early adoption period, the excitement for the promise of the technique leads to implantation in patients whose joints were likely not arthritic to a degree that would justify a joint destructive procedure [42].

Table 16.1 Indications/contraindications for first MTP joint arthroplasty

Indications
Stage II–IV end-stage arthritis of first MTPJ (HL/HAV)
End-stage arthritis of the hallux IPJ or hallux IPJ fusion
Good neurovascular supply
Adequate soft tissue coverage
Adequate bone length
Elderly
Apropulsive gait
Low ambulatory demands
Lifestyle requiring motion at the MTPJ
Increased IMA
Inflammatory arthritis (RA, gout)
Failed joint-sparing surgery
Osteoporosis (resection arthroplasty)
History of bone or joint infection (resection arthroplasty)
General contraindications
Young[a]
Active[a]
Participation in high-impact activities[a]
Lesser metatarsalgia
Lesser metatarsal stress fracture or evidence of lateral overload
Implant-specific contraindications
Allergy to implant material
Previous bone or joint infection[a]
Inadequate bone stock
Insufficient bone length
Large cystic formation[a]
Advanced sesamoid arthritis
Inadequate vascular supply
Peripheral neuropathy
Poor soft tissue coverage

HL hallux limitus, *HAV* hallux abductovalgus, *IPJ* interphalangeal joint, *IMA* intermetatarsal angle, *RA* rheumatoid arthritis

[a]Relative contraindication

Whether considering a joint resection or an implant arthroplasty, it is important to discuss with the patient that this is a joint destructive procedure, not a cure for their underlying process. They need to have a clear understanding of what the goals of surgery are and the risks involved and a true picture of the expected postoperative functional limitations. The patient needs to be well educated on the alternative treatment options and demonstrate an understanding that either technique will not return the joint back to normal function. If the surgeon does not take time to ensure that the patient has the appropriate expectations, then the surgeon increases her risk that the patient will experience a less than optimal outcome. The allure of restoring motion is attractive to both patients and surgeons, and we must be careful to not inappropriately advocate for the benefits without addressing the significant limitations.

Preoperative Clinical and Radiographic Evaluation

Clinical presentation is most often painful hallux valgus or painful hallux rigidus which is having a negative impact on the patient's lifestyle. They may state that their activities of daily living are becoming increasing more difficult as the duration of the disease progresses. Coughlin and Shurnas [43] found that the average age of onset of symptoms is approximately 43 years old with a surgery occurring most commonly around 50 years.

Visual examination often reveals a first MTP joint that appears enlarged secondary to prominent periarticular osteophytes or a pronounced metatarsal head. Rubor is also seen in association with irritation from shoe gear or from degenerative synovitis. Osteophyte formation and joint maladaptation can become irritating to the dorsomedial cutaneous nerve as it courses over the joint causing shooting pain into the toe. The patient may elicit a positive Tinel's with percussion of the nerve. These symptoms can also become worse with tighter fitting shoe gear and activities that increase motion at the MTP joint. Pain may be described as deep aching to sharp and radiating depending on nerve involvement and extent of cartilage damage. Patients may sometimes present with the primary complaint of lesser metatarsalgia in the setting of hallux rigidus as the patient does not perceive that they are shifting their body weight laterally to prevent motion passing through the MTP joint [44]. A diffuse callus under the lesser metatarsals and hammertoe deformities may be evidence of this shifting to the lateral foot.

Limited motion in the sagittal is a common objective finding. In patients with existing hallux valgus deformities, the hallux is often found to be track bound and may not easily reduce into a rectus position. Crepitus is often present in later stages of DJD and may be a sign of significant joint damage, especially if there is pain with midrange of motion [43, 45]. This is best assessed by firmly holding the base of the proximal phalanx and applying axial pressure into the joint while placing the hallux through dorsiflexion and plantar flexion. A catching, grinding, or popping sensation may be felt, suggesting the extent of damage to the joint surfaces.

Anteroposterior (AP), oblique, and lateral weight-bearing radiographs can be helpful in correctly staging the level of osteoarthritis and aid in choosing the correct procedure. In the AP radiograph, the metatarsal head is often found to be flattened and widened with excessive osteophyte formation, joint space narrowing, joint mice, and subchondral eburnation. Cysts may also be readily apparent as lytic areas in the metatarsal head and hypertrophy of the sesamoids may be likely findings in late stages. The lateral radiograph best demonstrates the formation of a dorsal osteophyte off the head of the metatarsal and can further aid in determining the stage of disease (Fig. 16.1). Care should be taken to look at both the AP and lateral radiographs to ensure proper staging of the severity of osteoarthritis. A large dorsal osteophyte may give a false impression on severity as it can obstruct or even falsely distract the joint space [28, 46].

Multiple classifications have been proposed for first MTP joint arthritis [47, 48]. The majority of these have been based on radiographic evaluation such as the three-stage classification proposed by Hattrup and colleagues in the 1980s [49]. Coughlin and Shurnas [43] later developed a more comprehensive classification that is based on the remaining range of motion and radiograph and clinical findings. This classification takes these findings to grade the severity of the disease (Table 16.2). As we have noted above, surgeons should look beyond the radiographic grade of severity and focus on important patient factors such as age, activity level, and patient expectations when selecting the most appropriate surgical technique.

Fig. 16.1 AP (*left image*) and lateral (*right image*) weight-bearing X-rays of end-stage arthritis of the first MTP joint with joint space narrowing and periarticular osteophytes in 86-year-old community ambulatory. A large dorsal joint mouse is noted on the lateral X-ray

Table 16.2 Coughlin and Shurnas [44] clinical-radiographic system for grading hallux rigidus

Grade	Dorsiflexion	Radiographs[a]	Clinical
0	40–60°	Normal	Painless; stiffness and limited passive ROM
	10–20%[b]		
1	30–40°	Dorsal bossing, minimal joint space narrowing	Occasional mild pain with EROM in DF/PF
	20–50%[b]		
2	10–30°	Global osteophytes; mild to moderate narrowing; normal sesamoids	Nearly constant moderate to severe pain just before EROM
	50–75%[b]		
3	<10°	Severe narrowing; cystic changes in metatarsal head; sesamoid changes	Constant pain and stiffness
	75–100%[b]		No mid-ROM pain
4	Same as grade III	Same as grade III	Grade III + mid-ROM pain

[a]Based on standing AP and lateral radiographs
[b]Percentage loss compared with normal motion of the first MTP joint (65°)

Surgical Considerations

The incisional approach is similar whether performing a resection or implant arthroplasty. A linear or curvilinear incision is made dorsally just medial to the extensor tendon over the distal first metatarsal and first MTPJ and extending halfway down the proximal phalanx. This approach works well as this allows good access to the medial, lateral, and plantar structures. Care should be taken to identify and retract the medial dorsal cutaneous nerve as well as the extensor hallucis longus.

Resection/Interpositional Arthroplasty There are several important modifications for the resection arthroplasty that help prevent poor toe purchase and transfer metatarsalgia. First, a medially based "U" capsulotomy is prepared which is ultimately used to wrap around the first metatarsal head from medial to lateral in order to serve as a biological spacer (Fig. 16.2). The base of the "U" is left attached proximally (Fig. 16.3). The distal

Fig. 16.2 Proximally based U capsulotomy *(marked dotted line)*

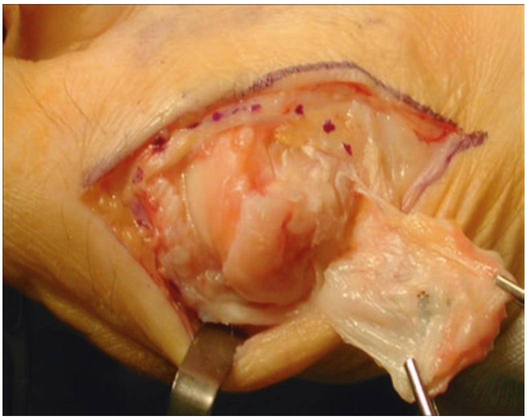

Fig. 16.3 Medial capsule reflected *(prior to medial eminence resection)*

aspect of the "U" must extend as distally as possible onto the proximal phalanx in order to ensure that there is enough capsule to wrap around the metatarsal head after resection of the base of the phalanx is performed. The capsular interposition may also be flipped and reflected with a distal base with reported benefits of purposely denervating the capsule to prevent postoperative pain [50]. We have had good success with the former "U" capsulotomy approach as we feel that the repair has greater reliability and strength when the proximal capsule is left intact as opposed to the distal portion.

The medial eminence along with any dorsal and lateral osteophytes is resected from the first metatarsal head with a sagittal saw as this allows the capsule to advance more easily across the joint space. A lateral release may be needed in cases of severe hallux valgus, but care is taken to preserve some of this tissue as it is needed for later transposition of the "U" capsulotomy. Release of the plantar first MTP joint is only performed in the most severe and rigid cases, and care must be taken to preserve the flexor tendon as this is also needed later in the repair. Removal of the fibular sesamoid may be considered in severe cases of hallux valgus [51], but this is rarely if ever needed with an appropriate lateral release.

Up to 30–40% of the base of the proximal phalanx can be resected with a traditional Keller. However, the modified resection arthroplasty removes an oblique cut from the proximal phalanx base starting dorsal distal and ending plantar proximal. We typically remove no more than 4–5 mm as this helps to preserve the plantar intrinsic attachments to improve stability. The hallux is placed through range of motion, and if jamming still occurs, additional bone is removed. But it is important to avoid resecting too much bone as this has been shown to result in worse outcomes [12].

In order to reef the flexor tendon to prevent a floating toe or poor toe purchase, a corkscrew anchor can be placed within the medullary canal of the proximal phalanx, collinear with its longitudinal access. The most common anchor size is 5.5 mm, but the anchor must be large enough so that the threads engage the cortical bone without fracturing the phalanx. The attached nonabsorbable anchor sutures are utilized to grasp the flexor tendon at the level of the first MTPJ and then set aside to hand tie later. In lieu of using an anchor, drill tunnels may be created into the plantar ledge of the remaining proximal phalanx. However, tunneling increases the technical difficulty of the case, and the tunnels are prone to fracture especially in the patient population most suited for this procedure. For this reason, we opt for an anchor as described above as this provides a very strong repair that allows adequate reefing of the flexor tendon which ultimately provides good purchase of the hallux postoperatively.

The "U"-based medial capsulotomy is then prepared for final repair. In order to be able to wrap the capsulotomy around the first metatarsal head, a critical stitch is placed within the plantar lateral capsule next to the first metatarsal head (Fig. 16.4). If the tissue around the plantar lateral first metatarsal head is too weak, an additional small anchor may be added into the plantar lateral first metatarsal head. However, with careful dissection, this anchor is often not required. All of the sutures are placed into the "U" and opposing capsule but not yet tied down. Pop-off sutures can help expedite this process.

To complete the repair, the flexor tendon is first tied down tightly to the proximal phalanx through the use of the proximal phalanx anchor. This will allow the hallux to plantarflex. The capsular repair is then tied down, starting with the plantar lateral stitch first in order to wrap the capsule around the metatarsal head (Fig. 16.5).

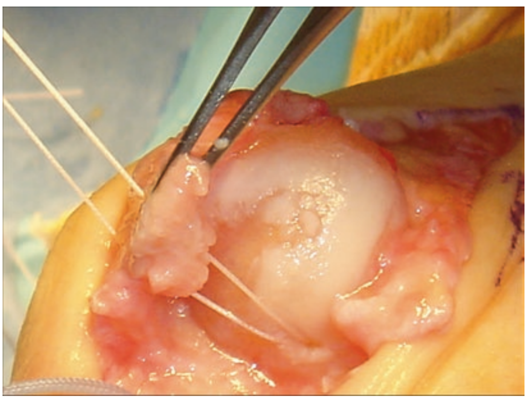

Fig. 16.4 Medial capsule being sutured across the joint to cover the metatarsal head

Implant Arthroplasty With varying types of implants available, the surgeon needs to be familiar with the specific surgical technique of the selected implant. For patients with hallux valgus who we have chosen an implant arthroplasty, we feel it is critical to concomitantly address the first metatarsal alignment. Therefore, unless the patient is significantly sedentary, the implant is usually combined with some type of re-alignment osteotomy of the first metatarsal. If the deforming forces that led to a severely degenerated joint are not addressed, those same deforming forces will cause stress on the implant and can ultimately lead to implant failure.

Of note, typically less bone resection is required with a hemiarthroplasty than with resection arthroplasty or total joint implants. Care needs to be taken to avoid damaging the insertion of the surrounding soft tissue so to not destabilize the joint. If there is damage, then these structures need to be repaired. It is also important that the appropriately sized implant be used as an implant that is too small may increase the chances of subsidence, fracture, or heterotopic bone formation (Fig. 16.6). The bone surface must be adequately prepared to allow for proper seating of the implant (Fig. 16.7). Final inspection after implant placement should show satisfactory positioning with good coverage of the cortical surfaces both intraoperatively (Fig. 16.8) and on postoperative imaging (Fig. 16.9).

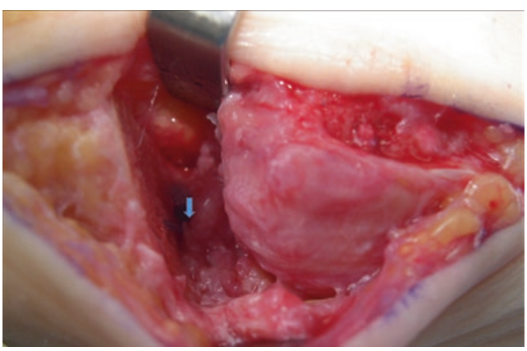

Fig. 16.5 Secured capsule interposition with resection of proximal phalanx base and tagged FHL tendon sutured into the proximal phalanx base *(blue arrow)*

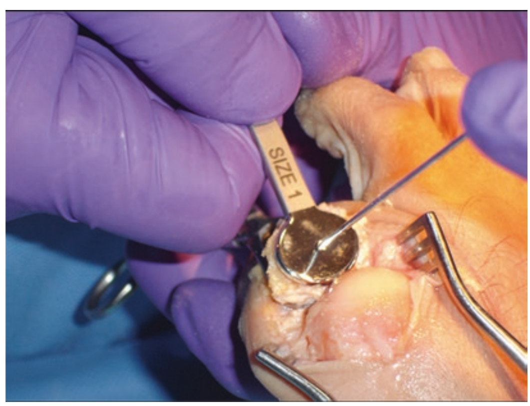

Fig. 16.6 Sizing the implant on the base of the proximal phalanx

Fig. 16.7 Preparing the base of the proximal phalanx

Fig. 16.8 Placing of proximal phalanx base hemi-implant with good coverage of all cortices

Fixation Options and/or Materials for Implant Arthroplasty

Since the first designs for implant arthroplasty were introduced in the mid-twentieth century, there have been significant advances in engineering design, biomaterial composition, and surgical techniques. The evolution has resulted in the creation of many different implants that range in design complexity. Each revision in design is to better replicate the natural biomechanical properties of the joint and increase patient satisfaction while minimizing complications and failures. The major types of implant materials used are silicone, ceramic, and metal or metal alloys. Metal implants are preferred as they have been shown to have a 10% greater level of patient satisfaction than other implant compositions

Fig. 16.9 Postoperative AP X-ray showing good positioning of implant

[35]. A thorough review of the history and discussion of each of the materials used in implant arthroplasty can be found in the third edition of McGlamry's Comprehensive Textbook [52].

Implant fixation designs and techniques have evolved as flaws in previous designs became apparent. Early techniques included synthetic implants with smooth stems that were made to fit on either the base of the proximal phalanx, the head of the metatarsal, or both. Implant stems have then changed design in an effort to minimize loosening and subsidence. The newer implant surfaces have evolved to become a better resurfacing prosthesis with minimal bone resection. Less bone resection helps to preserve stability, but also makes revisions or failed cases much easier to convert to an arthrodesis if needed.

The evolution of implant design, material composition, and fixation options has been a process that has taken years of learning from good outcomes as well as failures to get to where they are today. This has resulted in multiple generations of implants that vary according to material composition and design and are listed in Table 16.3 [35].

Table 16.3 Generations of implants based on stem characteristics

Generation	Material	Design
1	Silicone	Hemi; total
2	Improved silastic	Hemi; total (grommets)
3	Metallic	Hemi; total (press fit)
4	Metallic	Hemi; total (threaded stem)

Postoperative Considerations

Postoperative protocol for arthroplasty with and without implantation is fairly similar. A bulky dressing is applied immediately after surgery, and the patient may be weight bearing as tolerated in a rigid postoperative shoe. When the incisions are adequately healed, usually around 2 weeks, the sutures are removed, and the patient is encouraged to begin range of motion (ROM) exercises in both plantar flexion and dorsiflexion. Range of motion is important to initiate as soon as the wound can tolerate to prevent stiffness from scar tissue formation. Once the patient is able, they are transitioned into regular sneakers and referred to physical therapy if needed for continued ROM exercises and normal gait training. PT may be continued up to 3–4 months in order to prevent stiffening of the joint. If satisfactory ROM is not achieved by 6 weeks postoperatively, then the surgeon may consider aggressive manipulation under anesthesia to break up tough scar tissue.

In the authors' opinion, it is important to discuss with the patient, pre- and postoperatively, that return to normal ROM is not to be expected after implant arthroplasty and that the most motion seen with the implant in place will be on the operative table. The toe will stiffen with time as scar tissue develops, and aggressive, early PT will minimize this stiffness. However, the goal is not to attain full ROM, but to regain enough pain-free motion to allow for return to desired bending activities and basic shoe gear options.

Complications

The traditional Keller arthroplasty destabilizes the joint through the loss of intrinsic muscular attachment to the proximal phalanx base and laxity that occurs within the flexor tendon. This can result in a shortened toe with loss of push-off strength and an apropulsive gait. An excessively shortened hallux may result in patient dissatisfaction with cosmesis of the toe, dorsal irritation from shoe gear, and frontal plane rotation deformities. Other complications associated with the Keller arthroplasty include a cock-up toe deformity with loss of hallux purchase and transfer metatarsalgia [41, 53]. By transferring weight to the lateral foot, the lesser metatarsals become more susceptible to stress fractures. The use of a modified interpositional resection and implant arthroplasty has significantly helped to decrease these risks by preserving the soft tissue attachments that stabilize the toe and allow for push-off strength.

Implant arthroplasties have their own set of complications that include implant subsidence, aseptic loosening, pathologic wear, implant displacement, heterotopic ossification, fracture of the surrounding bone, infected hardware, avascular necrosis, and host rejection. Complications should be addressed if there is the presence of infection or continued postoperative pain secondary to loosening, subsidence, or fragmentation [54].

Implant subsidence and loosening are often caused by using an undersized implant. In this case, the implant is not well supported by the underlying medullary bone and can crush into the canal. Some subsidence is a common radiographic finding, but its presence on radiographs does not always correlate with patient satisfaction and require removal [29, 55].

Heterotopic ossification (HO) can also be seen when an implant is undersized, leaving exposed cortical bone around the rim that may proliferate. It is a common radiographic finding and does not always correlate to patient satisfaction outcomes [55]. HO can impinge on the implant, causing limitation in motion as well as pain. Heterotopic ossification can typically be prevented by using the appropriate sized implant that allows for circumferential coverage of all cortical bone.

Continued pain at the first MTP joint in the postoperative period can be seen in arthroplasty with and without implant placement. Radiographic and clinical evaluation should be used together to help to identify the source of the patient's pain. Options for treating continued pain after an implant arthroplasty include removal of the implant and conversion to a resection arthroplasty or arthrodesis. Revision of an implant arthroplasty with another implant may be difficult as there is a lack of revision components that account for bone loss [54].

Transfer metatarsalgia can be the result of an abnormally shortened first ray from excessive bone resection leading to overload of the lateral aspect of the foot. Conservative treatment can include the use of an orthotic, and surgical treatment would be dependent upon each patient's specific circumstances. Surgical treatment may require addressing the lesser digits and metatarsals or may require consideration of a distraction arthrodesis with structural bone graft to restore length to the first metatarsal.

Infection of the implant can occur at any point in the postoperative period and should be correlated to radiographic findings. Findings of subsidence or loosening should raise suspicion of possible infection. To rule out infection, a joint aspiration can be performed as well as obtaining an ESR and CRP [54]. Infection of an implant in the acute postoperative phase (<30 days) may be appropriately treated with an aggressive washout and IV antibiotics. However, deep infections that are not outside of the acute postoperative window will require explanation of the implant with revision in a two-stage approach according to the most recent IDSA guidelines [56].

Joint stiffness can be a common complaint and can be avoided by encouraging the patient to beginning ROM exercises as soon as the wound permits. Referral to physical therapy is also appropriate for more aggressive therapy. In our experience, allowing the patient to walk in a regular sneaker as soon as possible decreases the chances of developing a stiff joint. In late presentations of stiffness, treatment may include returning to the operative room for aggressive ROM under anesthesia.

Detailed Review of the Evidence-Based Outcomes

In 2010, Cook et al. [35] performed a meta-analysis including 47 studies with a mean follow-up of 61.4 months. A total of 3,049 various arthroplasty procedures were performed on patients with a mean age of 54 years. One-third of the included studies were prospective. The meta-analysis found patient satisfaction averaged 85.7%. However, given the heterogeneity of the included groups, a sub-analysis was performed of the highest-quality prospective studies only, which resulted in significantly reducing heterogeneity. By means of this new sub-analysis, patient satisfaction was found to increase to 94.5%. An additional analysis of variance was used to account for the differences between the implant material and designs. When analyzing implant material and design, silicone hemi-implants resulted in significantly lower satisfaction outcomes compared to other materials and designs. Overall, greater patient satisfaction has been reported after arthrodesis than arthroplasty; however, better functional results were achieved by arthroplasty when newer-generation implants are used. The results of this meta-analysis found that first MTP joint implant arthroplasty compares favorably with other joint (hip, knee) replacement outcomes in the literature. In 2013, Erdil et al. [57] compared first MTP joint arthrodesis, total joint arthroplasty, and hemiarthroplasty for 38 patients with a mean follow-up of 27.9 months. Significant improvements in the AOFAS-HMI (hallux metatarsophalangeal interphalangeal) score and visual analog scale (VAS) score were seen in all three groups. However, the AOFAS-HMI score was lower for the arthrodesis group compared to either total joint arthroplasty or hemiarthroplasty because of the loss of motion at the MTP joint. The VAS scores improved in all groups but more significantly in the arthrodesis group. In his results 1 year earlier, Erdil et al. [58] had also reported outcomes of patients who underwent metatarsal head resurfacing for hallux rigidus. Those results demonstrated satisfactory postoperative outcomes, including improved AOFAS score and increased dorsiflexion. Although this was not a comparison study, the author concluded that the metatarsal head resurfacing arthroplasty may be a reliable alternative for the treatment of advanced hallux rigidus which is not responsive to conservative treatment. Gibson et al. [29] performed a prospective, randomized controlled trial comparing arthrodesis versus total joint arthroplasty for patients with symptomatic hallux rigidus with a mean age of 55 years (34–77 years). Seventy-seven feet in 63 patients with hallux rigidus were randomized to either arthrodesis or arthroplasty using an uncemented prosthesis. While VAS scores at 24 months were significantly reduced in both groups, the arthrodesis group experienced greater pain relief than the arthroplasty group. In addition, functional results favored the arthrodesis group. However, study protocol deviation and loss to follow-up raise questions concerning the validity of the study's findings. In 2007, Raikin et al. [30] did a comparison of 21 hemiarthroplasties and 27 arthrodesis procedures with mean follow-up of 79.4 months. AOFAS, VAS, and satisfaction scores were better in the arthrodesis group. They reported a 24% failure rate in the arthroplasty group at the 2-year follow-up. Four of the five arthroplasties went on to failure and were converted to arthrodesis, while only one was revised. The authors concluded that arthrodesis was more predictable than hemiarthroplasty for alleviating symptoms and restoring function. Study flaws such as the comparability of the groups also make it difficult to draw definitive conclusions.

Concerning biologic interpositional arthroplasties, Aynardi et al. [59] looked at the survivorship of 133 arthroplasties at a mean follow-up of 62 months. Failure rates were reported at 4%, but good to excellent patient-reported satisfaction scores were recorded in 90% of the patients. These reports relied on telephone questionnaires, and no formal postoperative evaluation was performed by the surgeon, which introduces potential recall bias by the patient. Hahn et al. [60] reported on results of 22 patients who underwent interpositional arthroplasty for severe hallux rigidus. Their technique included preservation of the flexor hallucis brevis (FHB) and interposing the medial capsule. Postoperative AOFAS score was 77.8, and the range of motion and function were also found to increase. The authors concluded that interpositional arthroplasty is comparable to arthrodesis while preserving motion. Circi et al. [61] looked at the results of a hemiarthroplasty on the metatarsal head at a mean of 22 months on a small group of 12 patients. An improvement in the outcome scores was recorded with the AOFAS score, pain score, function scores, and range of motion scores compared to the postoperative phase. Twenty-five percent required revision surgery secondary to pain.

Some papers have found better success with implants in grade III disease with worse results in grade IV. Konkel et al. [62] published a retrospective review of 23 feet with hemiarthroplasty for grade III and IV hallux rigidus with a mean follow-up of 72 months. Overall, they reported 88% good to excellent results and 88% patient satisfaction. Interestingly, they also observed that patients with more severe grade IV arthritis tend to develop progressive sesamoid arthritis and recurrent dorsal osteophyte faster than grade III. This suggests that hemiarthroplasty should not be used in the most severe cases as it may result in lower patient satisfaction scores.

A newer type of hemiarthroplasty has recently been showing favorable result studies with some short-term and mid-term follow-up. Daniels et al. [63] performed a 5-year follow-up study on 27 of 29 patients that had polyvinyl alcohol hydrogel hemiarthroplasty spacers implanted on the metatarsal head. Their prior follow-up study at 2 years demonstrated results similar to arthrodesis. At 5 years, the VAS, Short Form-36 (SF-36), the Foot and Ankle Ability Measure (FAAM), and activities of daily living (ADL) subscale were assessed. All outcomes continued to show significant improvements in all outcome measures and a survivorship of 96%. While this survivorship is encouraging longer follow-up, studies with a larger group of patients are lacking.

Due to the lack of high-quality studies and the heterogeneity of the implants being reported in the literature, it is very difficult to draw a conclusion on the long-term outcomes including survivorship and patient satisfaction. Overall, however, the evolution of the first MTP joint arthroplasty has allowed it to be considered a viable option in the correct patient where maintenance of joint motion is preferred.

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