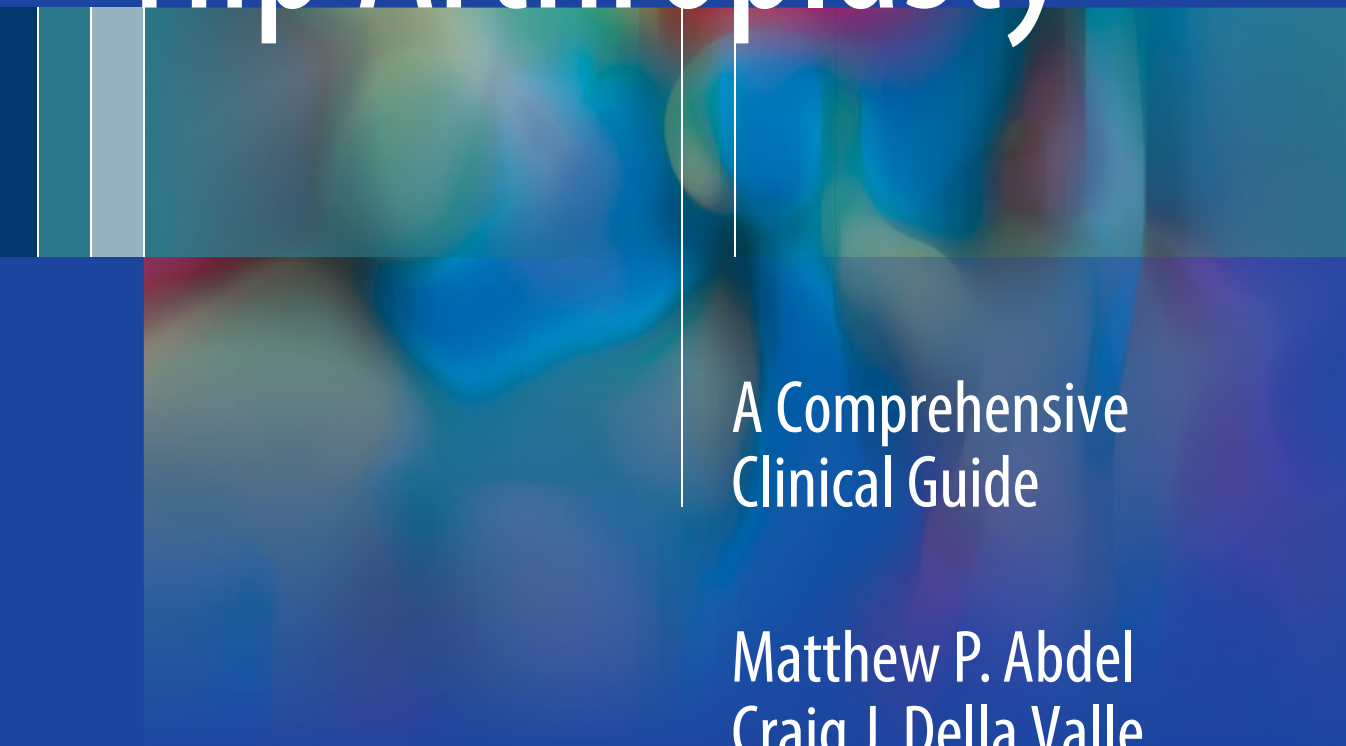
Complications after Primary Total Hip Arthroplasty



A Comprehensive Clinical Guide

Matthew P. Abdel
Craig J. Della Valle
Editors

Springer

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ISBN 978-3-319-54911-8 ISBN 978-3-319-54913-2 (eBook)
DOI 10.1007/978-3-319-54913-2

Library of Congress Control Number: 2017937365

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Primary total hip arthroplasty is a remarkable procedure that substantially improves the quality of life for patients with end-stage degenerative arthritis. However, as the volume of primary total hip arthroplasties increases, the absolute number of complications will concurrently increase as well. As such, a fundamental understanding of how to identify and accurately diagnose such complications is essential. Equally important is the expeditious management to address these complications. In this, the first edition of a novel book focusing on complications that occur during and after primary total hip arthroplasty, a case-based approach to each complication is presented by an impressive group of international experts. Each chapter includes a clinically relevant discussion of the epidemiology, risk factors, preventative measures, diagnosis, treatment, and a brief literature review related to some of the most common complications. At the completion of each chapter, the authors present their solution to the complication. We hope this book helps you in your daily practice.

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Part I

Acute Postoperative Complications

Peripheral Nerve Injury

1

Matthew C. Morrey, Robert Girling,
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Case Study

The patient is a 57-year-old with persistent left hip pain (Fig. 1.1). The patient failed conservative treatment modalities including activity modifications, various anti-inflammatory medications as well as intra-articular injections. He opted for total hip arthroplasty in spite of his BMI (41.5 kg/m^2) after lengthy discussion of the high risk nature of his surgery and the potential complications.

Postoperatively, his pain was greatly improved (Fig. 1.2). Unfortunately he had developed a foot drop after the surgery. He was intact to light touch in the distribution of the deep peroneal nerve, although somewhat decreased from the contralateral side. As his surgical approach was via a modified lateral, it was felt that this was likely due to retractor placement. He is 4 months out from his index procedure with slight improvement in his ability to dorsiflex the foot. He continues with aggressive physical therapy as well as utilization of an ankle-foot-orthotic (AFO) to assist with optimal foot positioning. He has been counseled about the nature of the injury as well as the likely prognosis. He understands that it may take a full year before it is known to what extent he will resolve his nerve palsy.

Introduction

While the incidence of peripheral nerve injury following total hip arthroplasty is rare (1–3%) [1], it can be a devastating complication with life altering consequences. It is therefore paramount to understand not only those patients at risk for peripheral nerve injury but also how to recognize nerve insult early, and intervene as appropriate.

This chapter will focus on the following:

- Definition of types of nerve injuries
- Preoperative considerations which may predispose to nerve injury
- Neurovascular anatomy of the hip joint, and peripheral nerves at particular risk
- Differential diagnosis of nerve injury following total hip arthroplasty
- Prognosis following nerve insult
- Management strategies utilized to minimize long-term complications of these injuries

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_1

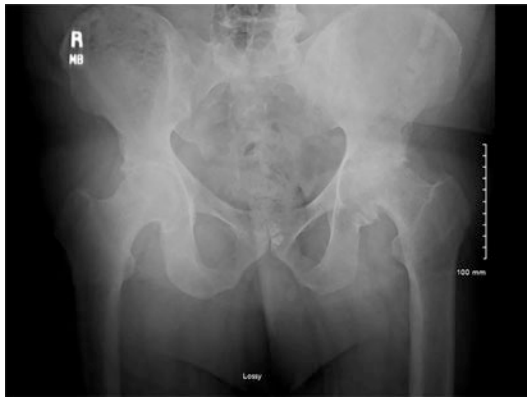

Fig. 1.1 Preoperative radiograph demonstrating profound degenerative arthritis in a 57-year-old obese male

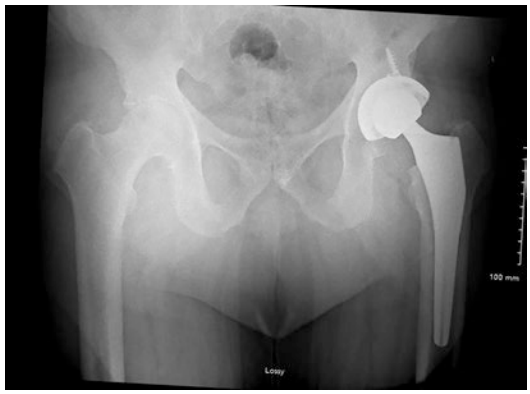

Fig. 1.2 Postoperative radiograph demonstrating left total hip arthroplasty

Types of Nerve Injuries

Nerve injuries are categorized into three types depending on the mechanism and degree to which the neural tissues are insulted.

- Neurapraxia is the result of minor injury resulting in loss of nerve conduction, but recovery is likely complete [2].
- Axonotmesis is result of more severe trauma when axons are compromised but the surrounding connective tissue remains intact, allowing for varying degrees of regeneration. Nerve recovery, via Wallerian degeneration, occurs at a rate of 1 mm per day and functional recovery is mixed [2].
- Neurotmesis is complete nerve division with no chance for functional recovery without repair [2].

The mechanism of nerve damage during THA can be independent or combined, including direct trauma, excessive traction, compression, ischemia, and or direct injection. Susceptibility to these mechanisms is influenced by the amount of epineural tissue, mobility of nerve, duration of insult, and proximity to manipulation.

Preoperative Considerations

While the incidence of nerve injury is quite rare, there are several patient risk factors that have been reported. These include, but are not limited to, developmental dysplasia of the hip (particularly with a pre-existing leg length discrepancy or a high dislocation), post-traumatic arthrosis, female gender, obesity, and a history of pre-existing sciatic nerve compromise (i.e., sciatica, existing neuropathy) [3–5].

Knowledge of these pre-existing conditions allows the surgeon to educate their patients as to the potential risks of some form of nerve insult at the time of surgery. It also should serve to heighten the awareness of the treating surgeon to the potential of intraoperative nerve injuries during surgery, which may help dictate a preferred surgical approach and specific retractor placement (or lack thereof).

Nerves at Risk: Neurovascular Anatomy of the Hip

While the neurovascular anatomy of the hip is actually quite complex, there are several nerves that are commonly at risk during total hip arthroplasty based on their anatomic location. These nerves deserve consideration during all primary and revision total hip arthroplasties. We will discuss these key nerves

and address surgical circumstances that may make them more prone to injury intraoperatively.

The sciatic nerve (supplied by the L4-S3 nerve roots) is typically located deep to the piriformis muscle within the pelvis, and travels deep to the gluteus muscles and superficially to the external rotators at the level of the hip joint, although anatomic variation of the course of this nerve has been well documented (Fig. 1.3). Injury to the sciatic nerve is the most common nerve injury reported during total hip arthroplasty [6, 7]. It is vulnerable during posterior exposure of the hip, as well as closure. The sciatic nerve requires consideration during all hip approaches, as posterior retractor placement and/or posterior retraction may lead to possible compression. Other causes of sciatic nerve palsy include postoperative hematoma causing compression [8], and lengthening of the leg (which may result in excessive nerve tension). The peroneal division of the sciatic nerve appears to be more vulnerable than the tibial division secondary to both its physical location closer to the operative field and a microarchitecture that is less tolerant of stretching injury [7]. Lengthening of more than 3 cm has been correlated with injury (specifically to the peroneal division) and lengthening of more than 3.8 cm more commonly effects both divisions [7]. Isolated injury to the peroneal division will result in a foot drop and dorsal foot numbness. A complete sciatic nerve injury (secondary to additional injury to the tibial division of the nerve) adds loss of plantar flexion as well as plantar foot numbness. Isolated tibial nerve injuries are extremely rare.

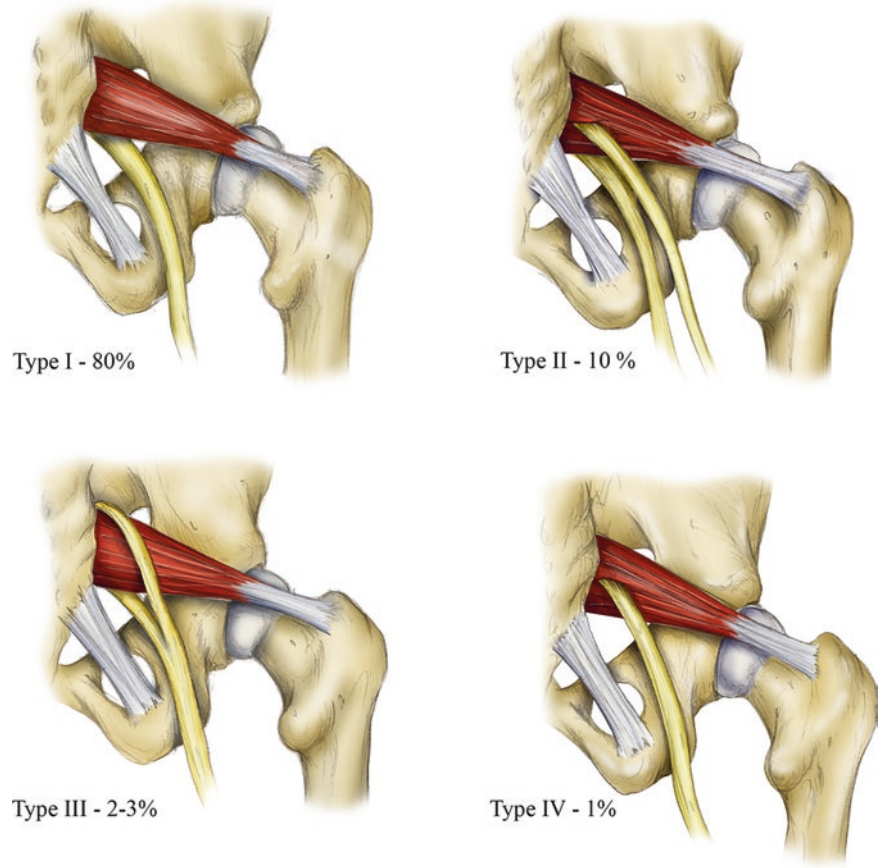

Fig. 1.3 Illustration of the most common variants of the sciatic nerve

The femoral nerve (L2-L4) passes between the iliacus and psoas muscles beneath the inguinal ligament as it courses into the thigh. It is most susceptible during anterior retractor placement during direct anterior and anterolateral approaches (Fig. 1.4). Hip hyperextension and postoperative hematoma formation are other possible causes of femoral nerve palsy after total hip arthroplasty. Impaired knee extension and anteromedial thigh to calf numbness can be seen as a result of femoral nerve compromise. Femoral nerve palsy ranks behind sciatic nerve injury as the second most common.

The superior gluteal nerve (L4-S1) travels through the greater sciatic foramen above the piriformis and innervates the gluteus medius, gluteus minimus, and tensor fasciae latae muscles. The nerve, though largely subclinical, is more commonly damaged with various lateral approaches when compared to the posterior approach. It may also be injured during anterolateral dissection between the medius and tensor muscles. Dissection greater than 5 cm proximally from the superior portion of the greater trochanter puts this nerve at risk. Trendelenburg gait and a high risk of dislocation secondary to abductor weakness are anticipated consequences with superior gluteal nerve deficiency.

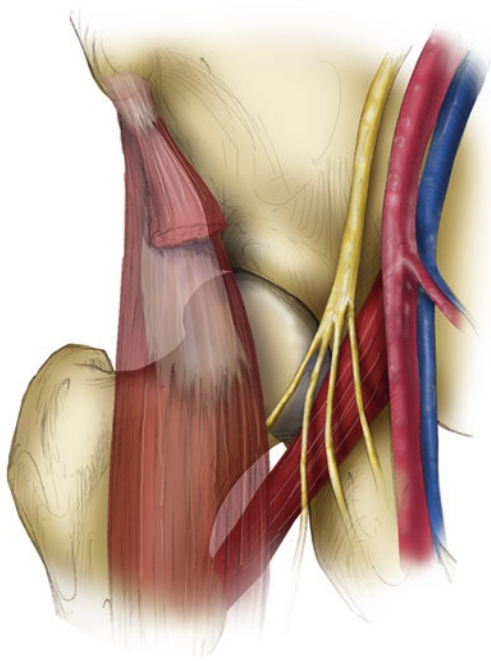

Fig. 1.4 Illustration of the course of the femoral nerve about the hip joint. Note the close proximity to the anterior acetabulum

The obturator nerve (L2-L4) descends through posterior fibers of the psoas major, passes behind the common iliac artery, along the lateral internal iliac artery and in front of the obturator vessels to the obturator foramen. The obturator nerve is most susceptible during screw placement of the acetabular component as is the external iliac artery and vein. The anterior quadrants of the acetabulum place this nerve at risk resulting in adductor weakness, groin pain, thigh pain, or even referred knee pain [9].

Differential Diagnosis of Peripheral Nerve Injury Following Total Hip Arthroplasty

Diagnosis of nerve injury following total hip arthroplasty can be quite challenging and depends on several factors, including surgical approach, degree of preoperative deformity, intraoperative factors (i.e., retractor placement), and onset of symptoms.

Careful examination of the patient is imperative to arrive at an accurate diagnosis. This can sometimes be challenging in the setting of multimodal anesthesia (peripheral nerve blocks, periarticular injections, and/or spinal anesthesia) used at the time of surgery, which may demonstrate transient neuropraxic symptoms. As such, suspected nerve insult requires close monitoring should early intervention be required.

Often, diagnosis of specific nerve injury is evident by the immediate postoperative physical examination. In patients with decreased dorsiflexion of the foot and decreased sensation in the first toe web space, insult to the deep peroneal nerve division of the sciatic nerve should be considered [10]. As previously alluded to, this may be the result of intraoperative retractor placement, lengthening of the operative extremity, or potentially formation of a compressive hematoma. If the latter is suspected, advanced imaging (often in the

form of an MRI) may be useful in identifying the source of compression, potentially allowing for earlier operative intervention in the form of hematoma decompression, hemostasis, drain placement, and revision closure [8]. Although isolated damage to the tibial division of the sciatic nerve is rare, it can occur and is manifested clinically by weakness of the knee flexors with the exception of the short head of the biceps, which gains its innervation from the peroneal division [11].

The presence of abductor weakness, particularly after lateral or anterolateral approaches to hip, can be the result of insult to the superior gluteal nerve. Picado et al. [12] reported that even in the setting of an uncomplicated total hip arthroplasty, electromyography EMG findings suggest that there may be varying degrees of insult to the superior gluteal nerve. However, the damage is transient and there does not appear to be any long-term consequences to abductor function by 24 weeks.

In patients undergoing direct anterior approach to the hip, injury to the lateral femoral cutaneous nerve should be suspected in patients who present with numbness and or paresthesias of the anterior aspect of the thigh postoperatively. Incision position, dissection plane, retractor placement, and tension during soft tissue handling or by traction tables have all been identified as a potential means of damage to this nerve.

Modalities for diagnosing nerve injury can be somewhat limited. While EMG is frequently utilized, there is still debate as to when to obtain this study. Traditionally, this study was ordered no sooner than 4–6 weeks after suspected nerve insult since examinations obtained earlier often appeared normal even in the setting of severe nerve compromise [13]. However, some argue that there is valuable information pertaining to nerve damage immediately after the suspected insult. They argue that the distal nerve stump continues to conduct after initial injury, allowing for localization of the precise location of the lesion, as there will be no conduction across the actual site of injury. This localization opportunity is lost when the distal nerve stump loses its conduction potential after about 1 week [13]. It would therefore seem that there may be some advantages to obtaining early EMGs to assist in localization of a suspected nerve injury at the time of total hip arthroplasty.

While advanced imaging has limitations in terms of localizing nerve injuries secondary to signal artifact, there are techniques utilizing MRI that have shown some promise in visualizing nerve lesions after total hip arthroplasty. Wolf et al. [14] have documented that utilization of MRN (magnetic resonance neurography) can allow for actual visualization of the fascicular distribution of the sciatic nerve such that damage to the nerve itself can be highly localized. This may of benefit when determining potential for early surgical intervention.

Prognosis Following Nerve Insult During Total Hip Arthroplasty

Prognosis for peripheral nerve injury relies on a variety of factors including the specific nerve injured, the type of neuronal insult, age and gender of the patient, as well as pre-existing factors such as sciatica, diabetes, existing neuropathy, and history of smoking [15].

Buchholz et al. [16] reported that of the 2–3% of patients who demonstrated transient neurologic symptoms, roughly 0.5% had permanent nerve damage at the time of final follow-up. As reported by Schmalzried et al. [10] patients who were suspected to have had a nerve injury intraoperatively but recovered some motor function prior to discharge from the hospital had an overall good recovery, with most patients regaining near full neurologic function by 7–12 months. Patients with dysesthesia, however, have far more unpredictable outcomes with many patients demonstrating less than satisfactory recovery and permanent nerve compromise at final follow-up.

Park et al. [17] demonstrated that in those patients who did develop motor weakness and dysfunction secondary to insult to the peroneal nerve after primary total hip arthroplasty, only 50% recovered fully with a mean time of 1 year for partial nerve palsy and one and one half years for complete nerve palsy. Obesity was found to adversely affect functional recovery.

In those patients who undergo direct anterior total hip arthroplasty and experience injury to the lateral femoral cutaneous nerve (roughly 15–20% of patients), the vast majority have near complete resolution of their symptoms at 6 months to 1 year, with no associated functional limitations [18, 19].

Management of Suspected Nerve Injury

Management of suspected nerve injury depends upon the mechanism and timing of the injury. Certain nerve injuries are not appreciable early, and thus are not recognized clinically until sometime after the insulting event. However, one should recognize potential nerve injury in the postoperative setting based on clinical exam. Foremost, all compressive dressings should be removed. If the limb has been lengthened, and there is suspected sciatic nerve involvement with resultant foot drop, the operative side should have the hip extended and the knee flexed by placing the leg off the edge of the patient's bed (Fig. 1.5). This decreases the tension on the nerve and allows it to assume a more relaxed position. If the patient develops clinical manifestations of a more progressive sciatic palsy in the postoperative period, consideration should be made to assess for the potential of hematoma formation and compression as this may require urgent surgical intervention [8].

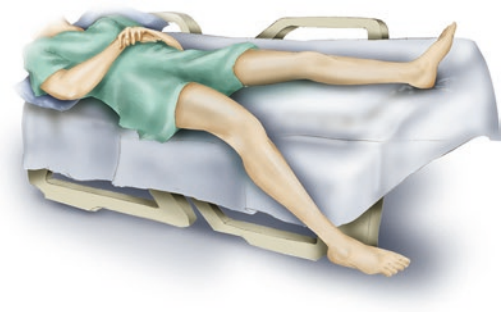

Fig. 1.5 Illustration of the patient with the leg extended and knee flexed, hanging over the side of the bed, to relieve tension off of the sciatic nerve

Late management of sciatic nerve palsy following total hip arthroplasty may involve operative intervention in the form of neurolysis. Regev et al. [20] recently reported improved motor and sensory function as well as decreased pain in patients who underwent interfascicular neurolysis of the sciatic nerve after having failed conservative management for a minimum of 6 months. They concluded that neurolysis can be of benefit and treatment should not be delayed greater than 12 months.

Soft tissue procedures can also be considered as a means of improving functional deficits secondary to palsy of the sciatic and/or common peroneal nerve. This can be done as either tendon to bone transfer or tendon to tendon transfer [21]. While several variations of this procedure have been described, the majority do appear to restore some level of active dorsiflexion of the foot, and prevention of flexion deformity in the toes and as such could be considered as means of restoring function [22].

Suspected injury to the superior gluteal nerve, as reported by Picado et al. [12], is most often managed by observation with near full resolution expected within 24 weeks following injury. If the nerve is more severely damaged (i.e., transected), than severe abductor dysfunction and an increased risk of chronic instability is likely. These patients present with a chronic Trendelenburg gait secondary to abductor insufficiency. Various surgical interventions have been proposed to address this issue. Lavigne et al. [23] reported that hip stability can be improved with the utilization of an Achilles allograft as augmentation for deficient abductors. In their series, six of ten patients had no recurrent instability at 3-year follow-up. More recently, Van Warmerdam et al. [24] described utilization of an Achilles sling to improve stability. In their series, seven of eight patients had no recurrent instability at 5-year follow-up.

Diagnosis and management of femoral nerve injury after total hip arthroplasty can be difficult. However, a similar strategy should be considered as is utilized with sciatic nerve injury. Close postoperative observation and assessment is crucial for establishing a diagnosis of insult to these nerves. While conservative modalities remain the corner-

stone of treatment [25], early surgical decompression should not be overlooked when warranted, especially in cases of suspected compression from postoperative hematoma formation. If treated conservatively, it is recommended that EMG should be obtained at 6 weeks and 3 months postoperatively. If still abnormal at 3 months, MRI should be considered [25]. The potential for femoral nerve recovery after total hip arthroplasty is related to the severity and location of the injury. Management of these is best undertaken by an interdisciplinary approach between the treating orthopedic surgeon, neurologists, and physical therapists. Improvements can continue for at least 1 year after the injury, but the status is unlikely to change after 2 years [26, 27].

Management of obturator neuropathy depends primarily on the etiology. Surgical decompression can be beneficial if it is determined that the nerve is compromised via fascial entrapment versus direct compression from hematoma formation. Prognosis for recovery is determined by the nature and chronicity of the nerve insult [28].

Management of suspected injury to the lateral femoral cutaneous nerve is almost universally conservative with the vast majority resolving within 6–12 months. However, in those patients with persistent symptoms after 1 year, a multimodal approach to their pain may of benefit, often under the guidance of a pain management specialist.

Conclusion

While rare, nerve insult at the time of total hip arthroplasty can be a devastating and life-changing event. It is therefore the responsibility of the surgeon to not only have a thorough understanding of the anatomy of the hip joint, but also to have a heightened awareness of those structures placed at risk depending on surgical approach, potential anatomic variations, and multiple host factors.

If a nerve injury is suspected, appropriate clinical examination and documentation is crucial as it can dictate further management strategy (conservative or operative).

It is imperative that the risk of potential nerve injury be discussed with the patient prior to surgery for purposes of full disclosure.

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Vascular Injuries

2

Philipp von Roth and Carsten Perka

Case

An 85-year-old female was scheduled for a left THA. After supine positioning for a Watson-Jones approach, a 10-cm incision was performed over the left trochanter and the joint was exposed. After the femoral neck osteotomy, a retractor was placed in the anterior superior quadrant (Fig. 2.1). Upon placement of the retractor, an intense amount of bleeding was encountered and it was determined that the iliac artery was injured with overly aggressive placement of anterosuperior retractor. Upon identification of the source of bleeding, the anesthesiologist was alerted and the wound was packed. As the bleeding was under control, there was no immediate need for blood transfusion. In parallel, the vascular surgeon on call was informed and asked for further assistance.

Introduction

Vascular injuries are a rare but devastating complication after total hip arthroplasty (THA) [3, 4]. A recent meta-analysis by Alshameeri et al. [5] reports a total of 61 articles describing 138 vascular injuries in 124 patients in the last 22 years. However, to avoid a potentially life- or limb-threatening complication, arthroplasty surgeons should be intricately familiar with the anatomy, epidemiology and risk factors, causes of injury, and potential treatment options [3].

Epidemiology and Risk Factors

The incidence of vascular injuries during primary THA is considerably low. Abularrage et al. [6] found an incidence of 0.04% in a series of more than 13,000 primary THA [5]. Other authors have reported an incidence of 0.09–0.3% [7–9]. The orthopedic surgeon might encounter about one vessel injury every 14 years of practice [5]. Risk factors can be divided into patient, procedure, and implant-specific.

Patient-specific factors include a clinically relevant vascular disease, previous bypass operations, or revascularization procedures [7, 10–12]. A severely calcified atherosclerotic femoral artery poses a risk of spontaneous occlusion during the manipulation of the leg during total hip arthroplasty [7]. Vascular injuries are more common in female individuals [5]. Due to their anatomical proximity of the aorta to the hip joint, procedures of the left hip are at a higher risk for vascular injuries [10–12]. Patients who have undergone an aorto-bifemoral bypass are at high

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_2

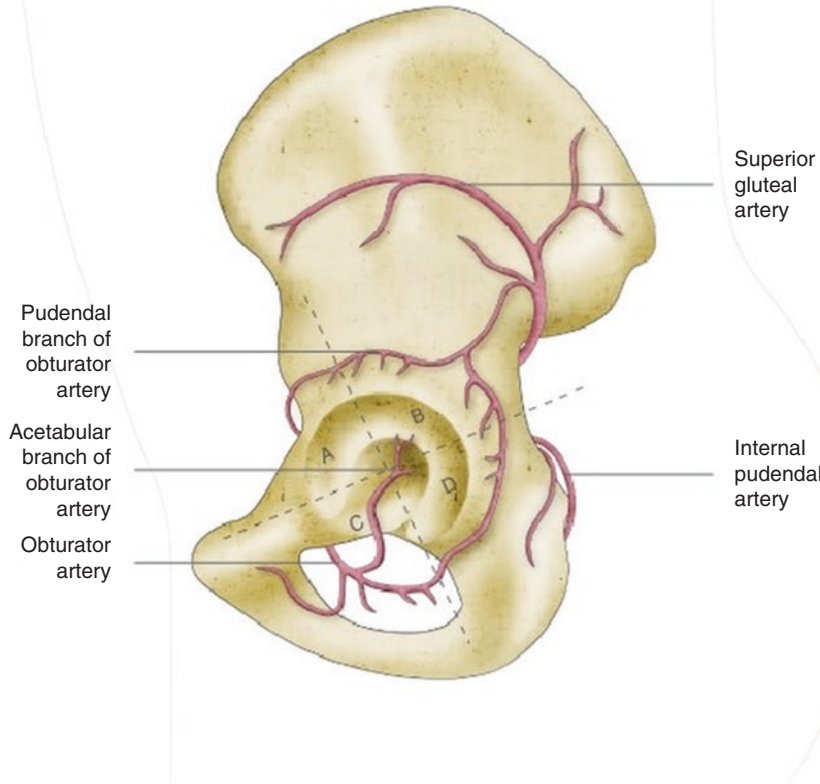

Fig. 2.1 Lateral view of the acetabulum showing the arteries at risk for injuries during total hip arthroplasty. The dotted lines define the safe zones for screw placement according to Wasielewski (anterior superior, *A*; posterior superior, *B*; anterior inferior, *C*; posterior inferior, *D*) [1]. This figure was modified from [2], copyright Elsevier

risk for vascular injury [13, 14]. If such a bypass is present, Cameron et al. [13] recommend performing a trochanteric osteotomy to avoid end-range positioning of the lower extremity. In concerning cases, patients should be evaluated by a vascular surgeon preoperatively.

Procedure-specific vascular injuries can occur either through indirect or direct trauma [15]. The most prevalent forms of injury are penetration or laceration [5]. Indirect trauma can be caused by stretching or compression during exposure, as well as dislocation and reduction of the joint. Cement extrusion and excessive use of electrocautery have been associated with thermal injuries of the vascular walls [16].

Direct trauma secondary to a retractor, scalpel, drill, or acetabular reamer can also occur [17]. Darmanis et al. [17] reported an increased risk of vascular injuries with the use of threaded acetabular components. In addition, cement, cables or wires, and aberrant placement of screws can harm vessels [18]. A quadrant system drawn in a lateral view on the acetabulum (Fig. 2.1) helps the surgeon to identify areas at risk for vessel injury during the drilling of the screw canal and screw insertion [1]. The safest zone is the posterosuperior quadrant (Fig. 2.1, zone B). In this quadrant, screws with a typical length of 35 mm may be used. Next, the posteroinferior quadrant (Fig. 2.1, zone D) allows screws typically no more than 25 mm. The anterosuperior and inferior quadrants are at high risk for screw placement. If necessary, only monocortical screws should be used.

Anatomy and Situations at Risk

The vascular structures at risk for injuries during primary THA include the common iliac, external iliac, superior and inferior gluteal, profunda femoris, femoral and obturator vessels (Figs. 2.1, 2.2 and 2.3) [12, 19]. Of these, the external iliac and common femoral arteries are involved most often [3]. The external iliac vessels follow the medial border of the psoas muscle. Harm to this vascular complex can occur during every step of the procedure if a retractor is placed too far medially over the anterior column of the acetabulum (Fig. 2.2). The psoas muscle is the only anatomical structure that separates the vascular complex from the capsule of the hip joint. That is why a retractor in this area should be placed with care and as laterally as possible to the surgical site. As the belly of the psoas muscle is more present proximally, the retractor should also be placed as proximally as possible. In addition, the iliac vessel can be injured when perforating the medial acetabular wall [11, 20]. In the case of a dysplastic acetabulum,some authors advocate placing the acetabular component as medial as possible to obtain sufficient bone coverage [21]. However, this puts the iliac vessels at risk for injury. If the preoperative planning results in a medial position of the acetabular component in order to get a good bone coverage and a perforation of the medial could be possible, the authors recommend performing a preoperative angiogram to show the anatomical relation between the bone and the vessels.

After it has crossed the ilioinguinal ligament, the external iliac vessel gives off the common femoral artery that runs anterior and medial to the hip joint (Fig. 2.3). Damage of these structures through retractors, the excessive removal of anterior osteophytes as well as secondary to forced dislocation or reduction has been described [11, 16]. Some approaches like the anterolateral and direct anterior approach have a higher risk of femoral artery injury [1]. The lateral and medial branch of the circumflex

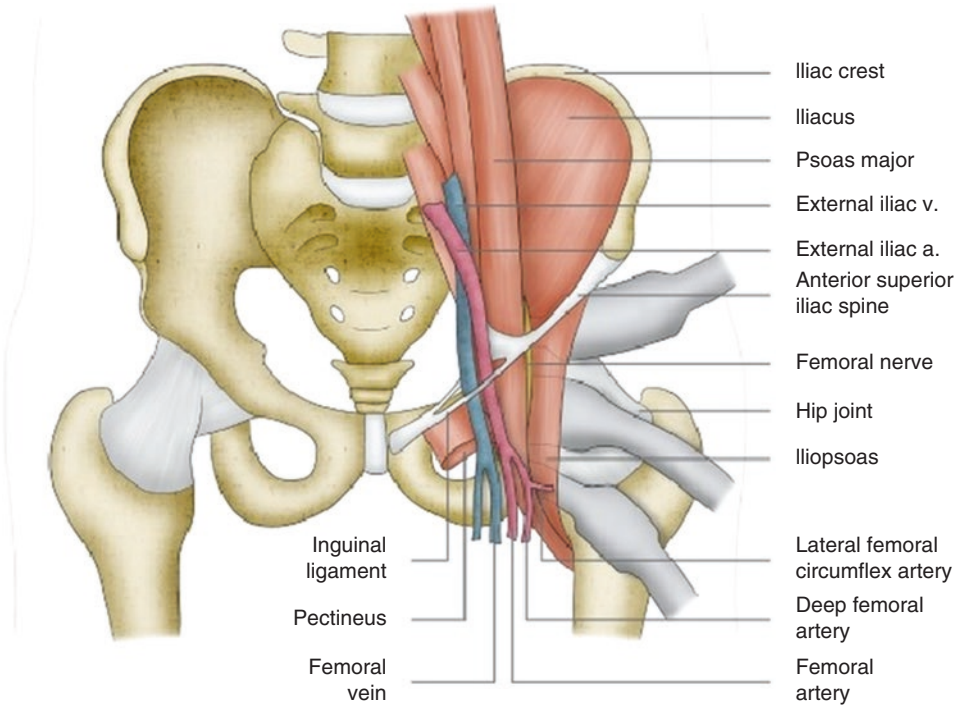

Fig. 2.2 Anterior view on the hip joint demonstrating proximity of the external iliac and femoral vessels to intraoperatively placed retractors. The psoas muscle is the only structure that separates the joint capsule from the vascular structures. This figure was modified from [2], copyright Elsevier

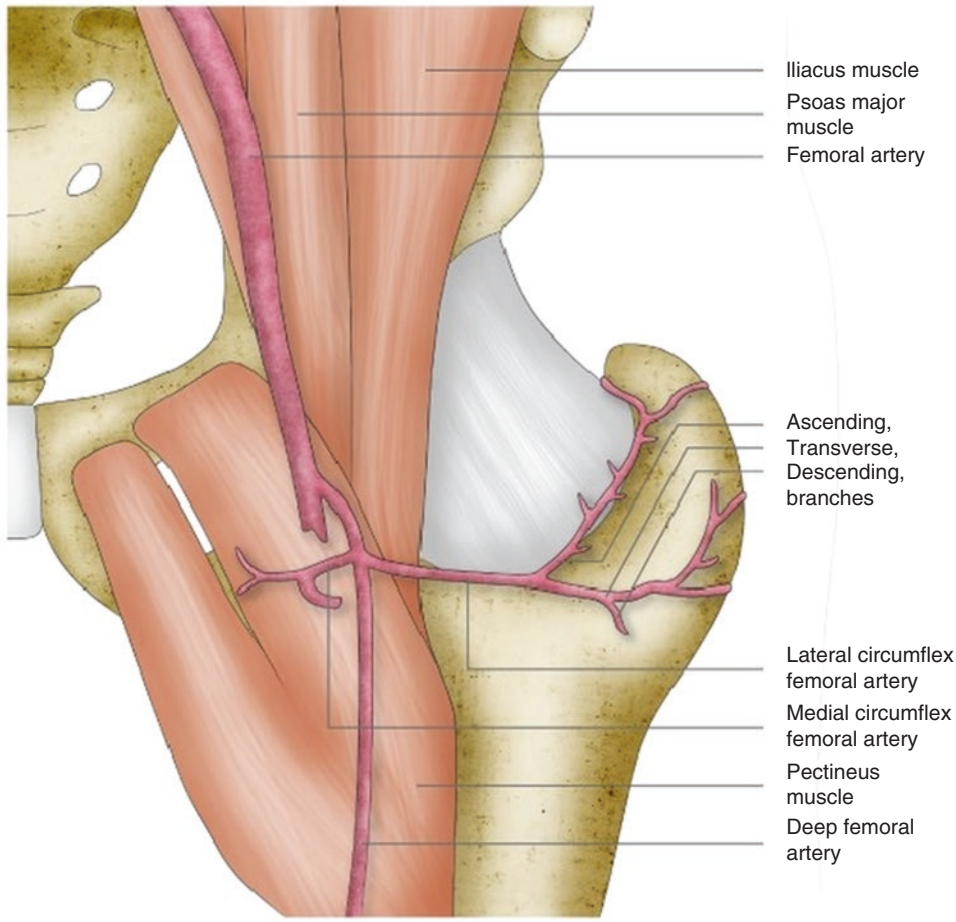

Fig. 2.3 Anterior view on the hip joint showing the arteries at risk for injuries during the femoral head cut and placement of retractors. This figure was modified from [2], copyright Elsevier

femoral artery derive from the profunda branch of the femoral artery and are at high risk for injury when retractors are placed too far medially over the anteroinferior quadrant, as well as during resection of the femoral head (Fig. 2.3).

The superior gluteal vessel, a branch of the internal iliac artery, can be harmed while placing a retractor too far posteriorly or when placing screws into the sciatic notch (Fig. 2.1). Wide acetabular and iliac exposure as is occasionally required in a complex primary THA (e.g. oncologic or post-traumatic) may also place this vessel at risk. The inferior gluteal vessel is also a branch from the internal iliac artery and is most often injured when placing screws into the posteroinferior quadrant.

Symptoms and Diagnosis

The most common presenting feature is bleeding and a sudden loss of blood pressure [5]. If an injury to a major blood vessel is suspected and cannot be visualized (e.g., loss of blood pressure after screw placement), an intra-abdominal and/or retroperitoneal ultrasound or angiogram should be completed immediately. About 50% of vascular injuries are identified by occult or frank hemorrhage, including shock during surgery or within the first 24 h thereafter [5]. However, the other 50% do not manifest until 4 days after the index arthroplasty [8], mostly in patients with an epidural anesthetic. According to Calligaro

et al. [8] epidural anesthesia can mask ischemic rest pain. A vessel injury can also present as visibly uncontrolled bleeding, thrombosis, compartment syndrome, or false aneurysm formation. False aneurysm formation is often identified at a late stage as the symptoms can vary and are unspecific. Shoenfeld et al. [11] report an average time to the diagnosis of a false aneurysm of 29 month after index surgery. They are not usually diagnosed unless the patient complains of unusual swelling and paresthesia due to compression of neurovascular structures [8]. If suspected, the dressing should be immediately removed; an angiogram or CT angiogram should be completed, along with urgent vascular consultation.

Treatment

If a vascular injury occurs, endovascular stenting, open exploration including laparotomy, and ligation have been reported as being the most common interventions [5].

Preoperative

If any risk factors are present, a careful evaluation of the vascular situation is mandatory. In the case of doubt, a vascular surgeon should be consulted to decide whether or not additional noninvasive studies or invasive procedures (such as angioplasty, stenting, or bypass) are necessary prior to the index arthroplasty.

Intraoperative

If an anterosuperior retractor is necessary to obtain a better overview, it should be placed while the hip joint is flexed to relax the femoral neurovascular bundle. Before reaming the acetabulum, the bone quality should be meticulously checked to prevent an accidental penetration of the medial wall. To avoid a vessel injury during the drilling of the screw canal and the placement of screws, the surgeon should be aware of the quadrant system (Fig. 2.1) [1]. A careful drilling of the canal with a meticulous observance of the loss of resistance at the contralateral cortex and an exact measurement of screw length is mandatory. If there are doubts, the correct length should be verified via intraoperative radiograph prior to drilling and placing the screw.

The surgeon and anesthesiologist should be in consistent communication if intraoperative bleeding is appreciated, or if a change in hemodynamics (i.e., unexplainable hypotension and tachycardia) concerning hypovolemic shock is appreciated. If necessary, the anesthesia team should be prepared for massive transfusion of packed red blood cells and factors, as well as potentially tranexamic acid [22].

In the event of intraoperative bleeding, the source should be identified. An initial attempt of compression is reasonable if a single source of bleeding cannot be identified. When injured, the superior gluteal artery retracts promptly. As such, it is recommended to aggressively explore the vessel in order to stop the bleeding. If any doubt remains, or if the source of bleeding cannot be identified and adequately stopped, an interventional radiologist and/or vascular surgeon must be consulted immediately. If an injury of the femoral or external iliac vessel occurs while the patient is placed in the lateral decubitus position, it is recommended to transfer the patient into the dorsal decubitus position. For arterial injuries, percutaneous endovascular interventions are only possible in 30% of cases [5]. If the vascular surgeon is not able to stop the bleeding through the incision of the index arthroplasty, the wound should be packed and the patient should be prepared for a laparotomy. Upon identification and treatment of the vessel injury, the patient can be re-positioned and the THA should be completed.

Postoperative

In cases where postoperative bleeding is suspected, a decision must be made to treat the patient either with endovascular or open assistance. This decision is usually made in conjunction with an interventional radiologist and a vascular surgeon. It is mandatory not to exceed a warm ischemic time of more than 6 h [14]. Fasciotomy may be necessary if the warm ischemia time is more than this time frame. Parvizi et al. [23] reported on fasciotomies due to a compartment syndrome in three of five patients with vascular injury after THA. In addition, attention has to be paid to thromboembolic complications. In their series, Shoenfeld et al. [11] found thromboembolic events following vessel injury in 46% (31 of 68) of the cases.

Prognosis

Vascular injuries are associated with significant complications such as persistent ischemia or neurologic deficits, amputation, and death [5]. The overall mortality rate was reported to be 7.8% [5]. The ultimate goal is to identify such injuries early, followed by immediate treatment.

Case Solution

A vascular surgeon performed an immediate vascular repair, and the THA was completed without additional intraoperative complications. When the patient was transferred to the hospital floor, both legs were warm and well perfused. Four hours later the patient complained about increasing pain and numbness in the operative limb. She was subsequently diagnosed with two emboli in the left external iliac artery and popliteal artery, with a superimposed compartment syndrome. An immediate endovascular intervention and fasciotomy was performed, with revascularization of the iliac artery (Figs. 2.4 and 2.5) but not popliteal artery (Fig. 2.6). The patient ended up having a below knee amputation.

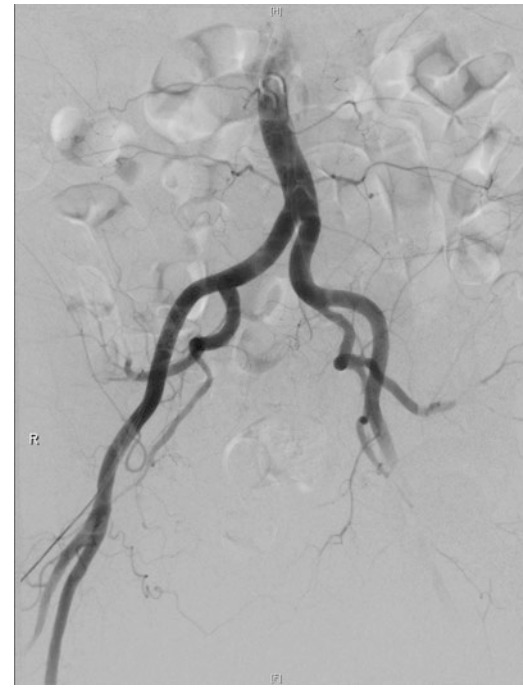

Fig. 2.4 Anterior radiograph *before* endovascular intervention of the left occluded external iliac artery

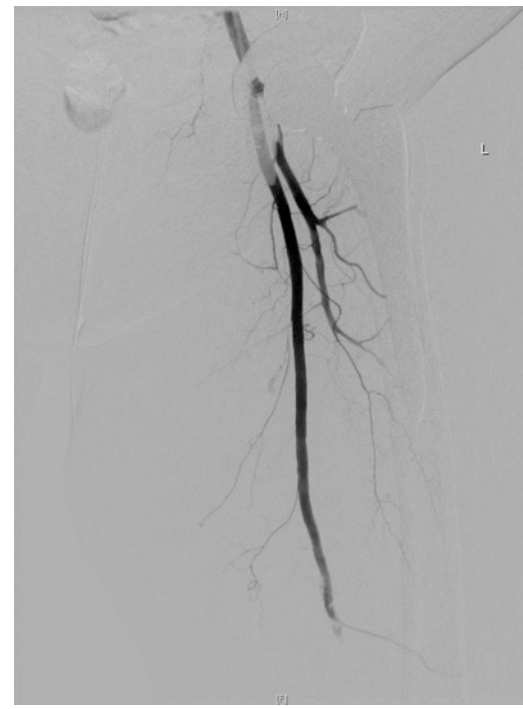

Fig. 2.5 Anterior radiograph *after* endovascular intervention. The left external iliac artery shows sufficient blood flow

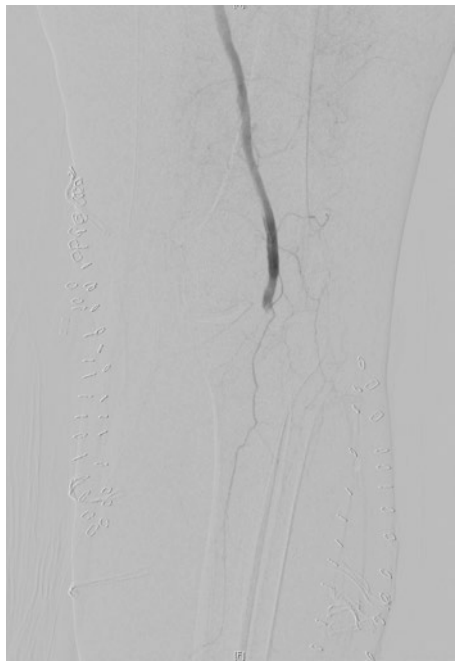

Fig. 2.6 Anterior radiograph of the left popliteal artery. There is no blood flow detectable after endovascular intervention distally to the popliteal fossa. The staples of the fasciotomy can be identified in the medial and lateral aspect of the lower leg. The patient finally underwent below knee amputation

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Intraoperative Periprosthetic Femoral Fracture (IPF)

3

Sulaiman Alazzawi and Fares S. Haddad

Case Presentation

An 82-year-old female was undergoing an elective left primary total hip arthroplasty for end-stage osteoarthritis via a posterior approach. The acetabulum was reamed gradually and an uncemented acetabular component 50-mm Reflection acetabular component; Smith and Nephew; Memphis, TN) was inserted without issue. Two posterosuperior screws were inserted. A 32 mm 20° elevated highly cross-linked polyethylene acetabular liner was used. The femoral canal was prepared with broaches for an uncemented component. A cementless femoral component was then prepared and utilized. The joint was stable at the end of the operation and the closure was performed in layers.

Routine postoperative X-rays showed suspicion of an undisplaced proximal femoral fracture (Figs. 3.1 and 3.2). CT scan of the left proximal femur was performed and confirmed the fracture which compromised the fixation of the proximally fitting primary stem (Fig. 3.3).

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Epidemiology

Intraoperative periprosthetic femoral fractures (IPFs) occur at a higher rate in revision THAs compared to the primary setting. The reported incidence of IPF during primary THA is 0.23% for cemented stems but this rate increases up to 3% with uncemented THA (results from the Mayo Clinic, 2016) [1]. The rate during revision THA has been reported to be 6% during cemented revision THAs and 19% during uncemented revision THAs [2].

Risk Factors [3–6]

1. Patient-related factors
   - Female sex
   - Increased age, particularly above 70
   - Fracture of the neck of the femur
   - Presence of large bone defects from previous surgery or ongoing osteolysis
   - Osteoporosis (primary or secondary to steroids or other drugs)
   - Vitamin D deficiency
   - Osteopenia (secondary to rheumatoid arthritis, osteomalacia, Paget's disease, *osteopetrosis, osteogenesis imperfects, or Thalassaemia*)
   - Previous hip surgery (stress risers within the cortex such as screw holes or the ends of the plates (Fig. 3.1))

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_3

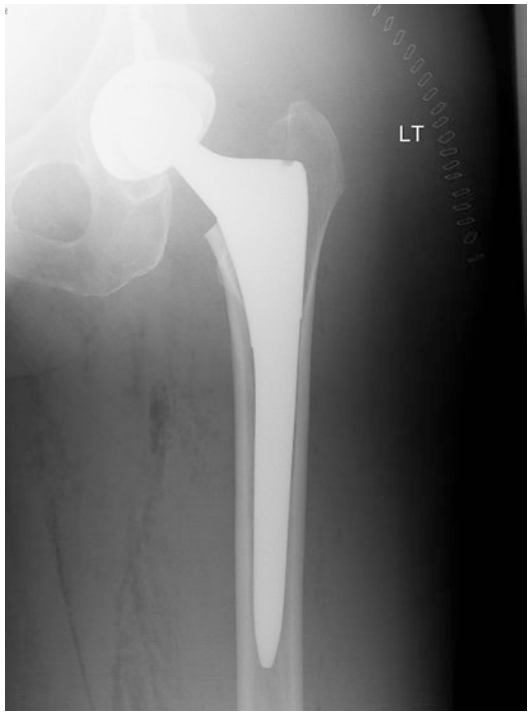

Fig. 3.1 Anteroposterior (AP) image of the *left hip* following primary total hip arthroplasty. The image showed suspicion of an undisplaced proximal femur fracture

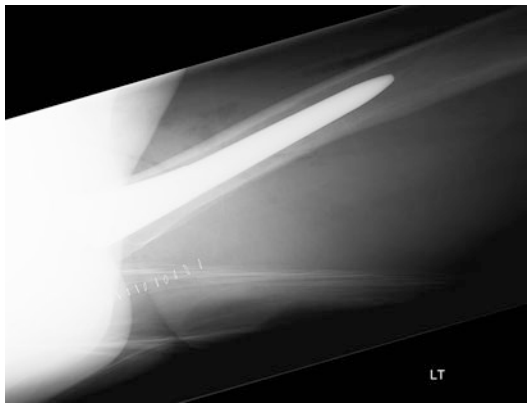

Fig. 3.2 Lateral postoperative X-ray image of the *left hip* following primary total hip arthroplasty. The image showed suspicion of an undisplaced proximal femur fracture

- Difficult anatomy (narrow femoral canals, developmental dysplasia of the hip [DDH], juvenile rheumatoid arthritis [JRA], pre-existing areas of femoral bone loss)

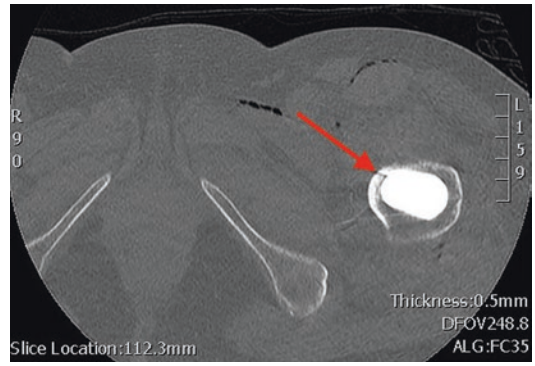

Fig. 3.3 An axial image from CT scan of left proximal femur showing an undisplaced periprosthetic fracture

2. Surgical technique factors
   - Use of uncemented components
   - Revision surgery
     - IPF can occur either during the extraction of well-fixed implants or while inserting the new components. In many revision cases, there will be wear debris and resultant osteolysis, and hence damaged bone stock. This makes it susceptible for fractures, especially when uncemented stems are utilized. In addition, some revision stems with increasing length may not match the natural bow of the femur.
   - Minimally invasive techniques

Prevention of IPF

The key to preventing IPF is thorough preoperative surgical planning, assessing risk factors, and anticipating potential difficulty [4]. This can be achieved through taking a detailed history, an adequate clinical examination, and obtaining the necessary investigations. Preoperative radiographs should include an anteroposterior (AP) pelvis and a lateral view of the operative hip. Occasionally, additional imaging such as Judet views and/or a CT scan may be required to assess bone loss or deformity [7]. It is also essential to template the sizes of the components [7].

During primary THAs, the surgeon must ensure an adequate and a safe surgical exposure,

including appropriate soft tissue releases. In the revision setting, the surgeon should be prepared for multiple options. The aim is to minimize the amount of bone loss while removing the components. If the femoral component is well fixed, then an extended trochanteric osteotomy (ETO) should be considered [7]. Some surgeon may elect to place a prophylactic cerclage cable or wire at the distal extent of an ETO to prevent propagation of a potential future fracture [7].

During canal preparation, attention should be paid to the alignment of the bone and the direction of inserting the reamers, broaches, and final femoral component. Eccentric reaming should be avoided and areas of bone loss should be protected. Intraoperative imaging may be useful to ensure central placement of the instruments in the intra-medullary canal [7].

Diagnosis and Classification

The key to managing intraoperative periprosthetic femur fractures is early recognition. The use of suction, normal saline washes, and drying enable the surgeon to have a clear view of the bone. The surgeon needs to pay attention to the alignment of the femur and the direction of instruments (such as broaches or reamers) during the preparation or insertion of the stem. A sudden change in resistance is highly suggestive of a femoral fracture. In addition, using an implant with a size that is incosisting with preoperative templating should raise the suspicion of an intraoperative periprosthetic femur fracture. Finally, if the real implant advances beyond where the broach or trial seated, suspicion for an intraoperative fracture should be high and an X-ray obtained.

When a suspicion of IPF is raised during surgery, intraoperative radiographs should be obtained to confirm the diagnosis [7]. However, the absence of clear fracture on the intraoperative images may not be enough to exclude it, especially in cases of nondisplaced fractures, or if the patient is obese or if the intraoperative images obtained or otherwise of poor quality. Therefore, it is always important to correlate the clinical suspicion with radiographic findings. One may consider postoperative images in form radiographs and/or CT scan for further evaluation (Fig. 3.2).

Classification

Intraoperative periprosthetic femoral fractures can be classified according to the Vancouver classification. It is based on three elements: location, pattern, and stability of the fracture. There are three main types (A, B, and C). If the fracture involves the proximal metaphysis without extension into the diaphysis of the femur then it is type A. If it involves the diaphyseal bone around the tip of the femoral stem then it is type B. Type C fractures include those distal to the stem tip extending into the distal metaphysis [7]. Each category (A, B, and C) can then be subdivided into (3) subcategories including (1) cortical perforations, (2) nondisplaced linear cracks, and (3) displaced unstable fractures.

Most recently, this system was modified to the Unified Classification System (UCS) described by Duncan and Haddad in 2014 (Table 3.1) [8, 9]. It has six main types (A, B, C, D, E, and F). Type B can further be subclassified into three grades similar to the Vancouver type B fractures: 1) the implant is well fixed; 2) a fracture with a loose implant and good bone stock and 3) a fracture with a loose implant and poor bone stock) [8]. This system has the mnemonic described in the table, which helps understand and recall the classification Table 3.1 [8, 9].

By applying the UCS into the femur, the six types are:

Type A (apophyseal): which includes the greater or lesser trochanter

Table 3.1 Mnemonic which helps understand and recall the Unified Classification System (UCS) described by Duncan and Haddad in 2014

Type	Description
A	**A**pophyseal
B	**B**ed of the implant or close to it
C	**C**lear of the implant bed
D	**D**ividing one bone which supports two joint replacements
E	**E**ach of two bones supporting one joint replacement
F	**F**acing or articulating with an implant

Type B (bed of the implant): around or close to the femoral stem. It is subclassified into:
B1: Stem well fixed
B2: Stem loose with adequate bone stock
B3: Stem loose with poor bone stock
Type C (well clear of the implant): The femur distant from the implant
Type D (dividing the femur between two implants): Between a hip and knee arthroplasty
Type E (each of two bones supporting a joint replacement): Both the femur and acetabulum
Type F: Does not apply to the femur [8]

Treatment

1. When the fracture is recognized intraoperatively.

   The first step to treating an IPF is to recognize the complication and pattern of the fracture. The treatment aims include (1) achieving a stable construct, (2) preventing fracture propagation, and (3) maintaining good component position and alignment [7].

   Based on the modified Vancouver classification system for intraoperative fractures, general treatment strategies include:

   - A1 (cortical perforation of the proximal metaphysis): These are most common during revision THA and rarely require additional interventions than bypassing the perforation.
   - A2 (undisplaced fracture of the proximal metaphysis): Most of these fractures are treated with cerclage cables of wires if the stem is stable. Otherwise, a revision diaphyseal engaging stem should be utilized (i.e., treat similar to an A3 fracture) [7]. Nondisplaced great trochanter fractures may be treated with protected weight-bearing and a hip abduction brace.
   - A3 (displaced fracture of the proximal metaphysis): These fractures usually involve the medial metaphyseal region, and therefore proximal fixation is compromised. Treatment should include conversion to a diaphyseal fitting revision type stem [7]. The options are either to use an extensively porous-coated cobalt-chrome stem [10, 11] or a titanium modular fluted tapered stem [12]. If the surgeon decides to use a cemented stem, great attention must be taken to ensure all the cancellous bone is already not removed, forcing cementation into a polished canal. In addition, cement should not be allowed in the fracture site. Displaced great trochanter fractures require ORIF.
   - B1 (diaphyseal cortical perforation): Long stems that bypass the perforation by at least twice the diameter of the femur [7, 13].
   - B2 (undisplaced diaphyseal fracture): Most of these fractures are usually recognized only on the postoperative images. Hence, they usually treated with protected weight bearing. However, in the presence of an unstable fracture pattern like short oblique or transverse near the tip of the stem, it is advisable to treat like B3 fractures [7]. If these are recognized intraoperatively, the placement of cerclage wires or cables is typically adequate for treatment.
   - B3 (displaced or unstable diaphyseal fracture): there are two possible strategies that can be used here, first to reduce the fracture and fix it prior to the insertion of a long stem. Second is to impact a long modular stem into the intact distal diaphysis to achieve axial and torsional stability. The modular portions of the implant then can be assembled to reproduce optimal proximal implant length and anteversion. The proximal fracture fragments can be reduced around the proximal femur and fixed with cerclage cables, wires, and/or sutures [14].

     It is also beneficial to use cortical allograft struts when the patient has poor bone quality or the surgeon is unable to bypass the fracture with the stem. This can be achieved with single or double strut grafts [7].
   - C1 (perforation that is distal to the stem tip): C type fractures are those which extend beyond the longest revision stem. In C1 fracture the treatment usually includes bone graft to protect the area of perforation [7]. Grafting the defect helps avoid leaving a stress riser for potential late periprosthetic fracture.

- C2 (undisplaced fracture distal to the stem tip): the use of cerclage wires is standard with the addition of cortical strut allografts if felt to be necessary [7].
- C3 (displaced or unstable fracture distal to the stem tip): these fractures should be treated with open reduction and internal fixation (periprosthetic locking plate, screws with or without cerclage wires) [7].

2. Treatment when fracture is recognized postoperatively.

As previously discussed, many of these fractures are first recognized on the immediate postoperative X-ray. They are classified and generally treated as described earlier in the Vancouver classification for postoperative periprosthetic fracture. If the fracture is missed on the postoperative radiographs, then the patient may present with displacement of the components and early joint failure, and an early revision is usually required [4].

Literature Review

In general, intraoperative periprosthetic fracture is uncommon phenomena especially during primary THA [15]. Hence, there are only limited reports for the outcomes of these patients [15–18]. A summary of the percentage and outcome of intraoperative fractures is provided in Table 3.2. IPFs are more common with the use of uncemented stems and in revision settings. There is also an increased risk of revision during the first six postoperative months [16–18].

Case Solution

Following discussion with the patient, a decision was made to proceed with a revision left total hip replacement. The preoperative plan was to use a diaphyseal engaging stem that bypasses the fracture and provides good distal fixation.

Table 3.2 Outcomes of patients who sustained intraoperative fractures during primary total hip arthroplasty

Intraoperative fractures of the femur during primary total hip arthroplasty						
Paper	Total number	Uncemented implant	Cemented implant	No. of fracture	Comment	Outcome
Cameron et al. [16]	3316 (primary and revision)	1316	2000	116	• 31: cemented primary	• Two nonunion
					• 47: uncemented primary	• Two stem subsidences
					• 38: revision	
Meek et al. [17]	211 (all revision)	211	–	64	Only 39/64 have minimum of 2 year follow-up	• 32 had bone ingrowth
						• One stable fibrous ingrowth
Thillemann et al. [18]	39,478 (primary and revision)	–	–	519	• 282 patients (0.7%) were treated nonoperatively	• Cumulative failure rate was 0.9% for patients without intraoperative fracture and 3.4% for patients with intraoperative femoral fracture
					• 237 patients (0.6%) were treated with osteosynthesis	• Intraoperative fractures increase the relative risk of revision during the first six postoperative months

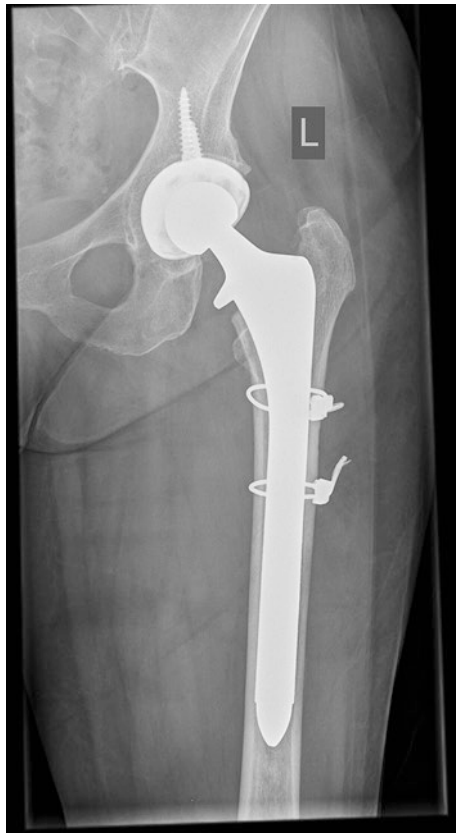

Fig. 3.4 Anteroposterior (AP) postoperative X-ray image of the *left hip* following revision of the femoral stem into a diaphyseal engaging stem that bypassed the fracture and provided good distal fixation

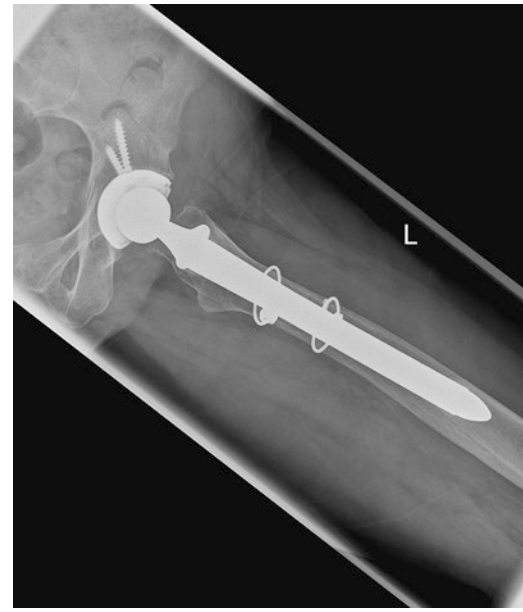

Fig. 3.5 Lateral postoperative X-ray image of the *left hip* following revision of the femoral stem into a diaphyseal engaging stem that bypassed the fracture and provided good distal fixation

The operation was performed through the recent surgical wound with a slight extension of the incision distally to allow a better exposure for proximal femoral shaft. Through a posterior approach, the joint was exposed and dislocated, the femoral head was removed, and a careful dissection was performed to lift the vastus lateralis off the femur. A very faint undisplaced fracture was identified exiting at the proximal femur. At that stage, the uncemented femoral stem was extracted. Two cables were passed to reduce and hold the fracture. Following this, the femur was prepared for an Echelon stem (Smith and Nephew) using sequential reamers and a size 17 reamer achieved good distal fixation. Therefore, an uncemented Echelon femoral stem size 17 was used and achieved good distal fixation. A trial reduction was performed and noted to achieve a stable reduction and adequate restoration of leg length and offset.

Postoperatively, the patient was allowed to mobilize full weight bearing as tolerated. Postoperative check X-ray images were satisfactory (Figs. 3.4 and 3.5) and patient continued to make good recovery. At 3 months follow-up, the patient was completely asymptomatic and has no concerns or problem.

Summary

In summary, periprosthetic fractures are best avoided through careful planning, appropriate implant choice, and judicious surgery. When they occur, they should be recognized intraoperatively and stabilized in order to avoid postoperative surprises and costly revision surgery. Patients at high risk should be warned about this potential complication when consenting for the operation.

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Wound Complications

4

Tae-Young Kim and Javad Parvizi

Case Presentation

A 65-year-old woman underwent a total hip arthroplasty for her left hip osteoarthritis. She had suffered from the persistent drainage in the operative wound 4 days after surgery (Fig. 4.1).

Introduction

Despite the implementation of numerous measures, wound-related complications after total joint arthroplasty (TJA) continue to be a concerning problem. Wound-related complications are associated with increased morbidity, and can elevate the cost of episode of care substantially. Carroll et al. [1] reported that superficial wound complications occurred at a rate of 9% in total hip arthroplasty (THA) and of these 30% required readmission to hospital for management. Wound complications after THA can occur in the form of persistent drainage, hematoma formation, blistering, wound dehiscence, and skin necrosis. Among the latter, wound drainage is not an infrequent complication that is usually self-limiting and stops within a few days after surgery. Drainage continuing beyond 48 h after hip arthroplasty, especially at high volume, is considered as persistent wound drainage that usually requires intervention. The incidence of serosanguineous drainage after primary THA, which persists beyond 48 h, is 1.3–3% [2, 3].

Significance of Wound Complications

Wound complications require prompt attention as they either arise as a result of deep periprosthetic infection (PJI) or pose a serious risk to cause such event if left untreated. Superficial wound complications, such as surgical site infection (SSI) and prolonged wound drainage, have been consistently implicated in the development of periprosthetic joint infection and may increase the risk of subsequent deep infection by up to 35-fold [4, 5]. Most infections present within the first year following surgery and may be associated with contamination at the time of surgery or in the early postoperative period [6]. Each day of persistent wound drainage increases the risk of infection by 42% in THA [7]. In addition, superficial wound complications, without deep infection, are associated with patient morbidity and cost to the healthcare system, including prolonged hospital stay, readmission, ongoing treatments, and reduced patient satisfaction [4, 5, 8, 9].

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_4

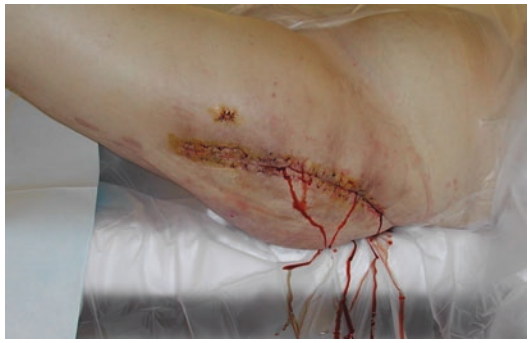

Fig. 4.1 The persistent drainage was seen in the operative wound 4 days after total hip arthroplasty

Risk Factors for Wound Complications

Identification and modification of risk factors that lead to wound complications can reduce the incidence of subsequent serious problems such as deep PJI. As previously mentioned, prolonged wound drainage is associated with a higher rate of infection following THA [4, 7]. Risk factors for persistent wound drainage include malnutrition [2], obesity [6, 7, 10, 11], use of aggressive prophylactic anticoagulation such as low-molecular-weight heparin or an elevated INR as a result of administration of Coumadin [7], and use of a surgical drain [7]. There are also reports of some skin preparation agents predisposing patients to the development of skin blisters and other wound-related problems. One such agent that has been implicated is 0.5% chlorhexidine in 70% alcohol [1].

Types of Wound Complications

Skin Blistering

- Blisters can be attributed to the movement between the skin and the wound dressing over time. The dressing type and the technique of dressing application, as well as the degree of swelling of the skin or allergic response to the adhesive material in the dressing, can influence the incidence of blistering [12, 13].
- The Delphi Panel [14] suggested that an ideal wound dressing that could minimize blister formation should conform well to the wound, be easy to apply and remove, and allow for soft-tissue swelling.
- Exudate from blisters is sterile but rapidly becomes contaminated with bacteria from the skin flora after rupture until re-epithelialization. Blistering results in breakdown of the epithelia barrier in the skin and can potentially lead to infections.
- The best method for treatment of skin blistering is to burst and drain the blister fluid. The roof should, however, be left intact to act as a barrier during the process of epithelialization. There is no evidence to support the use of antibiotics in patients with skin blisters after THA.

Prolonged Wound Drainage

- The definition of persistent wound drainage varies. The International Consensus Meeting (ICM) on Periprosthetic Joint Infection defined it as drainage covering an area greater than 2 × 2 cm of gauze persisting beyond 72 h after total joint arthroplasty (TJA) (Fig. 4.1). The ICM recommends that persistent wound drainage after TJA should be managed aggressively. The first line of treatment involves application of compressive dressing, negative-pressure wound dressing (VAC), and observation. If the wound drainage persists beyond 5–7 days, especially if copious, surgical intervention is recommended [15].
- Administration of antibiotics for persistent wound drainage is discouraged as this may mask an underlying infection.
- Swab culture of a draining wound should not be performed as it does not provide any information except isolation of organisms resident on the skin [16].

Skin Necrosis

- Skin necrosis following THA may be less critical than total knee arthroplasty because of the relative good coverage of soft tissues around the hip. Necrosis of skin around the hip does however require thorough debridement and revision closure of the wound if adequate soft tissue

exists. Less than 3 cm of superficial necrosis can also be treated with local care or delayed closure. However, skin necrosis more than 3 cm often requires treatment with soft-tissue coverage and split-thickness skin grafts (STSGs) or fasciocutaneous flaps. Full-thickness skin necrosis exposing the prosthesis leads to colonization of the prosthesis, and necessitates resection arthroplasty and later reconstruction that should include soft-tissue flaps.

Hematoma

- Hematoma formation around a surgical incision impairs soft-tissue healing by increasing the wound tension and reducing tissue perfusion. The latter may then lead to soft-tissue ischemia/necrosis. Hematomas can also act as a favorable culture medium for pathogens, prevent antibiotic access, and lead to infection [4, 17].
- There are multiple reasons for the development of a hematoma after THA. Mortazavi et al. [18] reported that the high blood loss, administration of fresh frozen plasma (FFP) or vitamin K, and administration of perioperative therapeutic anticoagulation for a preexisting condition and hormonal therapy were independent risk factors for hematoma formation.
- Hematoma formation is associated with a subsequent PJI [19].
- Administration of less aggressive, yet effective, form of venous thromboembolism (VTE) prophylaxis, such as aspirin, minimizes hematoma formation and reduces the incidence of subsequent PJI [20].

Cellulitis

- Cellulitis refers to a superficial infection that occurs in the skin presenting as a patch of red, warm, tender skin over the surgical site. Cellulitis is not usually a serious problem and typically resolves with appropriate treatment.
- However, the presence of erythema, swelling, and tenderness around the surgical site can also be a manifestation of a deep PJI that requires further investigation, namely aspiration of the joint to confirm or refute the diagnosis of deep PJI [21].
- Most cases of cellulitis are treated with elevation, antibiotics, warm compression, and marking out the involved area for close observation.
- Rodriguez et al. [22] reported 16 cases of erythematous eruption on the skin within the flaps of the surgical incision after primary THA over an 8-year period. All the patients had a similar onset and appearance of the skin eruption, which began at the posterior skin flap and spread radially. All were treated with antibiotics with complete resolution of the eruption within 1–6 days. There were no cases of PJI or other sequelae.
- The cause of cellulitis is unclear. Mainetti et al. [23] have reported cellulitis after internal fixation using a dynamic hip screw. They suggest that the compromise of the venous and lymphatic circulation around the skin flaps may have been responsible.

Wound Dehiscence

- Dehiscence involves breakdown and opening of the surgical incision. A wound may break down and open up for several reasons, including infection, poor healing, or tension and pressure from within the incision due to collection of blood or fluid. Superficial dehiscence is usually not serious, but does merit close observation. The wound usually fills from within by granulation tissue, over a period of weeks. Sometimes superficial dehiscence may require packing, or application of negative-pressure dressing until it heals.

Differential Diagnosis of Superficial vs. Deep-Wound Complications

- Differentiation between superficial infection and deep PJI may be difficult. Local inflammation around the sutures in a wound that heals within 3 weeks is likely to be a superficial infection. On the other hand, an erythema-

tous, indurated wound with persistent and copious drainage is more suggestive of a deep infection.
– As distinction between superficial and deep infection is difficult, it is recommended that aspiration of the joint be carried out in patients presenting with wound-related problems. Areas of cellulitis should be avoided when completing an aspiration.

Wound Management

– Wound management is often a neglected area in joint arthroplasty because of the common belief that complications such as blistering, drainage, and SSI are rare.
– In recent years, and with economic emphasis on minimizing readmission and reoperation, there has been increasing interest in implementing strategies that can minimize wound-related complications.
– Wound healing is affected by various factors related to the host, surgery, and postoperative wound care. Wound management will be discussed by dividing it into local and general managements.

General Managements

Malnutrition

Preoperative malnutrition has been associated with delayed wound healing, longer length of hospital stay, and higher incidence of subsequent infection [24]. The definition of malnutrition varies but is determined by measuring the serum level of transferrin, total lymphocytes, total albumin, and prealbumin. Gherini et al. [25] reported that only preoperative serum transferrin level was strongly associated with delayed wound healing.

Anticoagulant

Well-designed studies evaluating the effects of anticoagulation on wound complication and hematoma formation in patients who have undergone reoperation for wound-related problems are lacking. Parvizi et al. [26] reported that a mean INR of greater than 1.5 was found to be more prevalent in patients who developed postoperative wound complications and subsequent PJI. Another retrospective observational study found that patients who received low-molecular-weight heparin for VTE prophylaxis had a longer time until the postoperative wound was dry than those treated with aspirin and mechanical foot compression or those who received Coumadin (warfarin) for the persistent wound drainage [7].

Anemia

Preoperative anemia prior to TJA has been associated with a prolonged length of hospital stay, greater 90-day readmission rates, and need for higher allogeneic blood transfusion [27, 28]. Therefore, all possible means must be undertaken to improve hemoglobin levels prior to TJA. Both preoperative anemia and need for allogeneic blood transfusions have been associated with higher rates of PJI [27]. Hence, blood conservation protocols were devised to decrease the need for postoperative transfusions in anemic patients. Patients should have an evaluation to determine the cause of the anemia such as colon cancer or other causes of a GI bleed can be identified and addressed preoperatively.

Tranexamic acid (TXA) is a synthetic derivative of the amino acid lysine with antifibrinolytic properties. A meta-analysis performed by Sukeik et al. [21] showed that the administration of TXA in THA significantly diminished blood loss and need for allogeneic blood transfusion. However, it did not show any increased risk of thromboembolic events, infection, or other complications.

A systematic approach to optimizing hemoglobin levels preoperatively that implements oral and possibly intravenous iron, folic acid supplements, and erythropoietin while minimizing blood loss intraoperatively by the use of tranexamic acid, cell salvage, and induced hypotension has been shown to diminish the need for allogeneic transfusion [28].

Diabetes Mellitus

Diabetes mellitus has been implicated in causing higher rate of early wound complication after TJA [29] and PJI [30] with the capacity to dou-

ble the risk of wound complications in patients with uncontrolled diabetes [31]. The exact definition of uncontrolled diabetes is not clear. The pending surgical site infection (SSI) prevention recommendations by the Center for Disease Control have chosen fasting glucose levels >200 mg/dL as being indicative of uncontrolled diabetes that requires optimization prior to elective arthroplasty. The threshold for hemoglobin A1c that is indicative of uncontrolled diabetes remains unknown and its value in predicting risk for subsequent infection after TJA is also unknown [32]. Jamsen et al. [31] reported that in patients without a diagnosis of diabetes at the time of the surgery, there was a trend toward a higher infection rate in association with a preoperative glucose level of >6.9 mmol/L (124 mg/dL) compared with <6.9 mmol/L. A recent study [24] showed that patients with a mean postoperative blood glucose of >200 mg/dL or a preoperative hemoglobin A1C level of >6.7% are at increased risk for wound complications following elective primary total joint arthroplasty.

Smoking

Approximately 20% of the adults in the United States smoke [33]. Smoking is a modifiable patient factor that has been previously shown to increase postoperative complications. Nicotine-mediated vasoconstriction is considered to be the primary etiology of these effects [34–36]. Nicotine results in decreased blood flow, local tissue hypoxia, decreased collagen production, and increased platelet aggregation ultimately affecting wound healing as well as fracture healing [37–40].

Duchman et al. [41] reported that current smokers have an increased risk of wound complications and both current and former smokers have an increased total complication risk following total hip or total knee arthroplasty.

Several studies have noted that smoking cessation may reverse the risk for all-time complications as long as it is implemented far in advance (4 weeks) of elective arthroplasty [42–46]. Moller et al. [46] performed a randomized clinical trial that demonstrated that smoking cessation program implemented 6–8 weeks before surgery reduced the incidence of postoperative complications, in particular wound-related problems.

Local Managements

Wound Closure

The goals of wound closure are to maximize blood flow while minimizing bacterial contamination and dead space around the incision.

We believe that the use of monofilament suture for wound closure in patients undergoing THA is likely to reduce issues related to wound healing by minimizing tissue ischemia and by providing a better watertight closure and potential for ingress of bacteria into the deeper tissues [15].

A prior meta-analysis has shown that the risk of developing a wound infection was four times greater when staples were used for wound closure compared to suture closure [9, 47]. However, there was no significant difference between the development of inflammation, wound discharge, wound dehiscence, skin necrosis, and allergic reaction when suture versus staples were used.

Dressing

- Wound dressing is probably one of the most important aspects of local wound care. An ideal wound dressing is one that is:
  Permeable: Keeping the wound environment appropriately moist while preventing skin maceration, and blister formation [48].
  Barrier: That prevents ingress of microbes into the deeper tissues. In addition it is a barrier for entry of water into the incision, thus allowing the patients to shower [49].
  Occlusive: Resulting in creation of a sealed hypoxic environment that accelerates angiogenesis, mitotic cell division, and leukocyte activity, all being critical for wound healing. Each dressing change disrupts the fibroblast activity around the wound for a period of 3–4 h for this activity to resume.
- ***Dressing change:*** Frequent dressing changes expose the wound to exogenous bacteria and increase the risk for SSI, especially when performed in contaminated environment such as the hospitals, rehabilitation facilities, and

skilled nursing facilities with abundant pathogens. Reducing dressing changes not only minimizes the cost and pain associated with the dressing changes, but it also reduces the risk of blistering and skin injury [12].

- The introduction of recent occlusive dressing allows for minimizing dressing changes. The first dressing change can occur at 7 days during which the critical part of wound healing has taken place.
- More regular dressing changes may be needed in patients with drainage when the dressing is saturated.
- A few studies have shown that wound management following TJA with the use of an occlusive dressing with alginated hydrofiber and silver leads to a reduction in the incidence of all-time complications including PJI [13, 48, 50–52]. However, the role of silver in reducing wound infection and PJI still remains unclear [53–55].

Surgical Drains

The rationale for the use of surgical drain is to reduce hematoma formation and postoperative edema, thereby decreasing the possibility of infection [56]. There are numerous randomized, prospective studies that have failed to prove the intended benefits of surgical drains [57–59]. The studies have not shown a difference in the incidence of wound-related problems, hematoma formation, need for postoperative blood transfusion, range of motion, and duration of the hospitalization when surgical drains were used. In addition, separate Cochrane meta-analyses have shown that the use of surgical drain leads to a lower incidence of bruising around surgical incision but no other benefits [56]. Some authors have advocated that not using surgical drains would have more benefits for patients undergoing THA, by allowing tamponade and reduction of blood loss [60]. Several meta-analyses also showed that the routine use of closed-suction drainage for elective THA may be of more harm than benefit [56, 60].

Management of Wound Complications (Fig. 4.2)

Nonoperative Management

Wound drainage has been shown to stop in most patients between 2 and 4 days postoperatively [2]. Persistent wound drainage for greater than 72 h after TJA should be managed by wound care [15].

Treatments for persistent wound drainage initially consist of local wound care (sterile dressing and wound cleansing to decrease the bacterial contamination) and compressive wrapping.

Negative-pressure wound therapy (NPWT) in general surgical patients has been shown to normalize tissue stresses [61], reduce seroma [62], and aid healing of surgical wounds in high-risk patients (Fig. 4.3) [63]. The use of NPWT is 75–100 mmHg continuous for 48 h. Pachowsky et al. [64] reported in a prospective study of THA that NPWT decreased development of postoperative seroma and improved wound healing. The effect appears to be greatest in the patients at high risk for postoperative drainage, including obese patients, large incisions, and revision surgeries.

Operative Management

Surgical intervention should be considered for patients when wound drainage persists beyond 5 days despite appropriate nonoperative management [2, 3, 29, 65]. Surgical treatment consists of irrigation and debridement (I&D) of the superficial soft tissue, with wound exploration and I&D of the deep periarticular tissue if there is communication with the periprosthetic hematoma [2].

Antibiotic treatment should be withheld until cultures have been obtained. However, the administration of preoperative antibiotics to patients with a positive preoperative joint aspiration does not appear to interfere with isolation of the infecting organism from intraoperative culture samples more than when antibiotics were withheld [66–68].

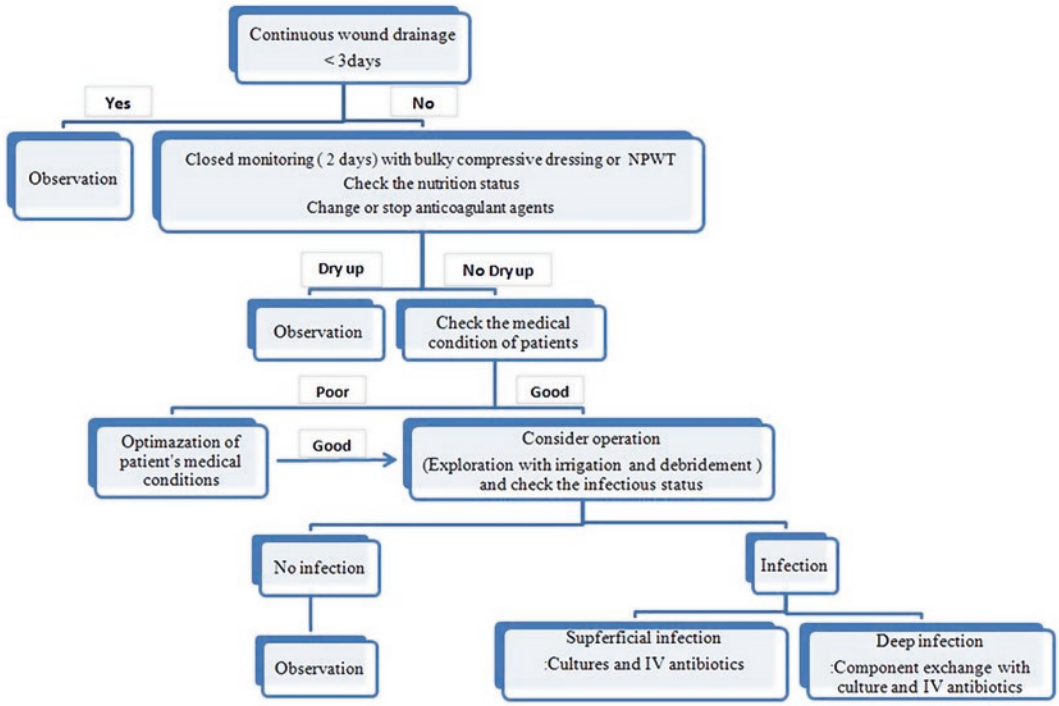

Fig. 4.2 Prolonged wound drainage for greater than 72 h should be managed by wound care such as compressive wrapping and negative-pressure wound therapy (NPWT). Patients' conditions such as malnutrition, stop or change of anticoagulation, anemia, smoking, and diabetes mellitus are important to manage the wound complication. When wound drainage persists beyond 5 days despite appropriate nonoperative treatments, surgical treatment such as incision and debridement and exchange of modular components should be considered

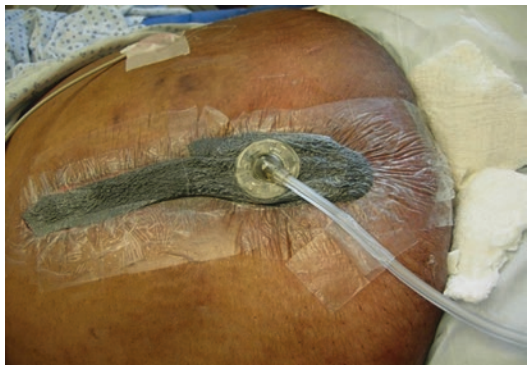

Fig. 4.3 The wound was irrigated and compressive dressing with negative-pressure wound therapy (NPWT) was applied on the wound

Exchange of modular components (femoral head and acetabular liner for THA) should be performed if communication with the deep tissue is encountered.

Intraoperative cultures (minimum of three) should be taken when performing an I&D for a persistently draining wound. Positive cultures should be expected in 25% of cases [2, 3]. Treatment with intravenous antibiotics and consultation with an infectious disease specialist is in order if cultures are positive. The presence of purulent fluid at the time of I&D portends a poor outcome [2, 29].

Conclusion

Total hip arthroplasty gives promising results and better life quality to the patients, but sometimes leads to a disaster outcome owing to the wound complications that may cause the deep infection. Perioperative managements to prevent the wound complications are the first priority. Wound complications would be prevented by careful periop-

erative examination and managements of the conditions such as malnutrition, stop or change of anticoagulation, anemia, smoking, and diabetes mellitus. Wound closure with monofilaments without drain would be a reasonable procedure during the operation.

Prolonged wound drainage should be started with the careful observation with regular dressing change but persistent drainage for greater than 72 h should be managed by wound care such as compressive wrapping and NPWT as well as be aware of the differentiation between superficial and deep-wound complications. When wound drainage persists beyond 5 days despite appropriate nonoperative treatments, surgical treatment such as I&D and exchange of modular components should be considered.

Case Summary

The patient was on anticoagulant therapy due to her cardiac history prior to the THA. Given the persistent drainge, the patient returned to the operating room for an irrigation and debridement. At the time of the procedure, a hematoma above the tensor fascia lata was noted and debrided. The wound was irrigated and a compressive dressing with NPWT was applied on the wound (Fig. 4.3). The wound was closely monitored with dressing changes. At most recent follow-up, the wound was clean, dry, and intact.

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Acute Postoperative Periprosthetic Joint Infection

5

Sherif M. Sherif and Hany S. Bedair

Case Presentation

A 66-year-old male who had undergone left total hip arthroplasty (THA) for end-stage osteoarthritis (Fig. 5.1) presented with complaints of fever to 102 °F, fatigue, wound redness, and persistent drainage approximately 2 weeks following his left THA. We followed the drainage for a week, he continued to drain and did not have any change in his symptoms, his C-reactive protein (CRP) was 4.1 (normal <0.8 mg/dL), and erythrocyte sedimentation rate (ESR) was 40 (normal 1–15 mm/hr). Due to his persistent drainage and the presentation of his surgical incision, we decided to perform left hip joint aspiration. Aspiration of the joint revealed fluid nucleated cells of 71,500 uL, with 93% segmented cells. Gram stain was positive and cultures grow *Staphylococcus aureus*. Therefore, he was diagnosed with acute periprosthetic infection of the left THA.

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Epidemiology

This chapter focuses on periprosthetic total hip infection in the early postoperative period, defined as within 6 weeks from surgery. Yi et al. [1] reviewed 6033 consecutive primary THAs and identified 73 patients (1.2%) who underwent reoperation for any reason within the first 6 weeks postoperatively. Thirty-six (0.59%) of these patients were infected according to modified Musculoskeletal Infection Society criteria. Studying PJI in the early postoperative period did not have the same share as did chronic PJI in the literature.

Total hip arthroplasty (THA) is considered one of the most successful operations in modern medicine and has positively impacted the life of many patients, providing mobility and relief from pain for a wide range of hip conditions. One of the biggest threats to the success of this procedure is periprosthetic joint infection (PJI), which can convert a highly beneficial procedure into one of frustration and disability for the patient. Over 50 years ago, PJI rates were reported to be as high as 7% [2]. Improvements in surgical technique, operating room environment, body exhaust systems, as well as perioperative care (including skin preparation, antibiotic prophylaxis, and wound management) have led to substantial reductions in

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_5

Fig. 5.1 Intraoperative image of the primary *left hip* replacement

the risk of PJI. Currently, the risk is approximately 1–2%; however this rate has not changed substantially in decades [3] and represents thousands of cases each year. The cost of treatment for such cases is much higher than treatment for other complications of THA, up to $50,000 more per case, thus imposing a huge strain on the already struggling healthcare system [4].

Internationally, there are similar reports of PJI complicating total hip arthroplasty from the UK, France, Germany, and Australia [5]. In the UK, 12–15% of hip revisions are secondary to PJI [5]. An in-depth study from France measured the direct costs due to revisions of infected THAs, and calculated these at just over 32,000 Euros per patient, representing 3.6 times the cost of the primary procedure and 2.6 times the cost of revisions for other indications [6]. A small study from Australia assessed the longer term impact of infection on several quality-of-life measures in patients undergoing hip and knee replacement and found substantial detriments to mobility, independent living, and psychological health in patients whose surgery was complicated by infection [7]. In the United States, PJI complicates 1.63% of primary THAs within the first 2 years in the Medicare population. The Mayo Clinic reported a 1.7% infection rate in primary THAs over a 28-year period (1969–1996) [8].

Understanding the incidence of causative organisms is key to prophylactic antibiotic choice. Parvizi et al. [9] reviewed 9245 primary joint replacements. The most commonly isolated organisms in the order of frequency were methicillin-resistant *Staphylococcus aureus* (MRSA) (19%), methicillin-sensitive *Staphylococcus aureus* (19%), methicillin-resistant *Staphylococcus epidermidis* (11%), and methicillin-sensitive *Staphylococcus epidermidis* (8%). Fifty-three percent of the *Staphylococcal* organisms were resistant to methicillin. Gram-negative organisms were isolated in 11%, with *Escherichia coli* and *Klebsiella pneumoniae* being the most common. Polymicrobial infection occurred in four patients (5%) [9].

Risk Factors

Although modern surgical techniques and antibiotic prophylaxis have significantly lowered the incidence of PJI, it has not been eliminated. Therefore, identifying and modifying the preoperative risk factors can help mitigate the incidence of PJI. These risk factors can be divided into host-related factors and hospital-related factors.

Host factors are related to both general health and local conditions of the tissues. General health concerns are variable, but they all share one common effect, which is decreasing or modifying the host immunity. Obesity increases infection risk by 3–4.2-fold, with every 1 kg/m^2 increase in body mass index. In another study, obesity and morbid obesity increased PJI by 2.6- and 9.1-fold, respectively. Diabetes mellitus has been identified as an independent risk factor for PJI, with an 11% increased infection rate associated with perioperative poor glycemic control [10]. This study suggests that tight perioperative glycemic control can reduce PJI after THA. Metabolic syndrome includes the presence of increased waist circumference, hypertension, diabetes mellitus, and dyslipidemia. Forty percent of the population over 60 years of age in the United States has metabolic syndrome with the incidence likely higher among

the joint replacement population [11]. Metabolic syndrome is associated with increased systemic levels of acute-phase response cytokines and cortisol, suggesting a miss-regulated immune response with an inability to mount an effective attack against infectious organisms. It is interesting that the risk of postoperative complications in patients with metabolic syndrome was greater than the sum of each individual component, suggesting synergistic effect of its concomitant elements [12]. Malnutrition is also associated with an increased risk of both chronic and acute PJI [13] and is known to affect innate immunity and normal immune response by altering both humeral and cell-mediated immunity. Malnutrition can be screened for via serum albumin, prealbumin, transferrin, and/or total lymphocyte counts. Paradoxical malnutrition is common among obese and normal-weight patients. If identified preoperatively, malnutrition must be corrected, even if that means delaying the surgery.

Advanced age is another independent, uncorrectable risk factor that decreases patient immunity, exposing them to more risk of PJI [14]. Atrial fibrillation and myocardial infarctions have also been shown to be independent risk factors for PJI in a review of large series, possibly related to aggressive heparin anticoagulation and/or infirm nature of these patients [9, 15]. Autoimmune diseases like rheumatoid arthritis are associated with a 2.6-fold increase in infection rates compared to patients with osteoarthritis [16]. Psoriasis is another autoimmune disease associated with increased infection risk. Organ failure, like chronic renal failure, patients on dialysis, and those with liver, heart, or kidney transplant, are at increased risk for infection. Patients with malignancy and those with human immunodeficiency virus, particularly patients with CD4 counts below 240 cells/mm^3, are also at increased risk [17–19]. Patient colonization with MRSA is a growing concern in modern arthroplasty with the prevalence of MRSA in the community found to be 0.6–6% in current hospital screening programs [20]. The presence of urinary tract infection (UTI) after surgery is also associated with increased risk for infection [9]. However, performing preoperative urine screening has been proven to be unnecessary [21, 22]. Smoking has been shown to increase the risk for wound complications and PJI, with a randomized controlled trial from Denmark demonstrating that cessation or at least 50% reduction in smoking decreased wound complications from 30 to 5% ($p < 0.001$) in patients undergoing total joint replacement [23]. Smoking cessation should be considered for all patients.

Postoperative host factors that increase the risk for PJI include hematoma formation and profuse wound drainage with an odds ratio of 11.8 and 1.32, respectively. The risk of deep infection subsequent to superficial infection is 10%, with the same organism being isolated from both sites in most instances [24].

Revision surgery carries a threefold increase in the risk for infection [25, 26]. Peel et al. [27] have shown that previous PJI increases the risk of infection at the same site by 36-fold, while the incidence of developing PJI in a subsequent joint replacement was 15% [28]. Even after successfully treating a PJI, the relative risk of developing an infection in a subsequent total joint was 21, significantly higher than patients with no such history [29].

Hospital-related risk factors have been studied as a function of the annual volume of THAs. In a review of 5000 Medicare patients, a 69% reduction in the rate of deep infection and dislocation was correlated with hospitals in which more than 100 THAs were performed annually. Factors associated with decreased complication rates included private hospitals, academic institutions, dedicated orthopedic nursing teams, and laminar airflow in the operating room. The most significant determinant is increased surgeon caseload, which in turn affects the duration of surgery, tissue handling, blood loss, need for blood transfusion postoperatively, operating room traffic, and attention to sterility [30, 31].

Prevention

Prevention of PJI in the early postoperative period (first 4–6 weeks postoperatively) revolves around identifying and if possible eliminating and/or modifying most of the above-mentioned risk factors. The single most important factor in

reducing postoperative wound infections is antibiotic prophylaxis. Optimizing antibiotic coverage can protect the local tissue from bacterial colonization at the time of surgery and requires both optimal timing and type of antibiotic used. An effective bactericidal concentration of antibiotic should be present in tissues and serum at the time that surgery begins. The highest serum and bone tissue levels appear to be achieved 35–40 min after intravenous antibiotic injection [32]. For prolonged operations (more than 2.5 h), and/or increased blood loss (more than 1000 cm^3), a second dose of IV antibiotic appears to reduce the risk of infection [33]. The duration of postoperative antibiotics has been debated, but multicenter studies have shown no difference between 24 h, 3 days, and 7 days [34, 35]. A shorter course of antibiotic would be more cost effective, and reduce side effects and possible development of resistance to frequently used agents. Since it is very difficult to provide coverage for all organisms causing infections, it is recommended to use an agent with excellent protection against the most common gram-positive organisms (i.e., *Staphylococci and Streptococci*). The antibiotic of choice also must have a low side effect profile, be well tolerated by patients, be less likely to have resistance development, and possess an appropriate half-life. As such, first-generation cephalosporins (e.g., cefazolin) is optimal and remains the antibiotic of choice for most patients. In a randomized controlled study, cefazolin use before and after surgery reduced the incidence of PJI from 3.3 to 0.9% compared to placebo [36]. For patients with penicillin allergy, vancomycin or clindamycin can be used as a substitute. Vancomycin combined with an antibiotic covering gram-negative organisms (e.g., gentamicin) can be utilized in patients who are colonized with MRSA. Nasal decolonization with mupirocin has been shown to decrease rates of PJI by 50% among patients who test MRSA positive during the preoperative screening [37].

From an operative standpoint, frequent irrigation of the wound with pulsatile lavage can be helpful [38]. Additional factors to consider include the use of dilute betadine lavage (which has been shown to decrease the risk of infection [39], frequent glove change, and suction tip change). Operative environment control through vertical laminar airflow, body exhaust suites, and reinforced Gore-Tex gowns decrease dissemination of shed bacteria by the surgical team. Limiting operative room personnel and decreasing room traffic also mitigate the risk of infection [40–42].

Diagnosis

Acute PJI diagnosis can be challenging with symptoms being easily confused with normal inflammatory response to surgery.

Clinical Evaluation

Evaluation of the patient with a possible PJI should include a thorough history and physical examination. Items that should be obtained in the history include the types of prostheses, date of implantation, past surgeries on the joint, history of wound healing problems following prosthesis implantation, remote infections, current clinical symptoms, drug allergies and intolerances, comorbid conditions, prior and current microbiology results from aspirations and surgeries, and antimicrobial therapy for the PJI including local antimicrobial therapy. While being febrile is traditionally associated with infection, it is important to distinguish fever resulting from infection from a normal postoperative course [43, 44]. A recent study of 100 patients undergoing THA and 100 patients undergoing TKA showed that the normal postoperative febrile response peaked on the first postoperative day and normalized by the fifth day. In 19% of patients, the maximum body temperature was between 39 and 39.8 °C [45]. Febrile episodes can be a sign of other complications with significant morbidity and mortality, such as atelectasis, hematoma, urinary tract infection, fat emboli, or deep vein thrombosis [43].

Another concerning finding is a draining wound. The incidence of superficial wound infections progressing to deep PJI is difficult to assess. Gaine et al. [24] reviewed 530 patients with either THAs or TKAs and found an over 15% rate of wound complications. Six patients had deep PJI

that required operative debridement, while two patients required removal of their prostheses. The rate of postoperative PJI ranges from 1.3 to 50% in patients with persistent wound drainage. Postoperative drainage correlates to body mass index and type of anticoagulation used. Each day of prolonged drainage is associated with up to 42% increased risk of wound infection in total hip patients [46] Ultimately, PJIs have been shown to highly correlate to superficial surgical site infections but they are a poor predictor of ongoing problems or periprosthetic infection at 1 year post-surgery [47]. As such it is very difficult to make a diagnosis of infection during the early postoperative period. Wound complications in themselves do not confirm the presence of deep infection, and additional studies are often required to define a diagnosis.

While a draining wound can be very tempting to culture, this temptation should be avoided. Tetreault et al. [44] investigated 55 patients draining wounds after total joint arthroplasty with wound swabs and found that only 47% of the wound swabs correlated with deep cultures. The superficial cultures were typically polymicrobial and would have resulted in an antibiotic regimen change in 41.8% of cases. More importantly, superficial cultures yielded microbial growth in 80% of cases deemed negative for deep infection. The authors thus recommended against wound or sinus swabs for diagnosis due to possible overtreatment [48, 49].

Radiographic Evaluation

Plain radiographs have limited usefulness in the early postoperative period as it is premature to develop or detect bony radiographic changes such as lacy periostitis, osteopenia, endosteal resorption, loosening of the prosthesis, and rapid progression of osteolysis, finding that can be useful in the setting of chronic PJI. However, they are essential to rule out other etiologies that may be contributing to the patient's symptoms.

Magnetic resonance imaging (MRI) is not widely used. White et al. [50] have described technical modifications to traditional MRIs with the use of a metal artifact reduction sequence (MARS). This allows for better visualization of the bone-prosthesis interface and adjacent soft tissues, although it is not intended for PJI diagnosis [51].

A technetium-Tc99m (99MTc) isotope bone scan can be performed in the assessment of a failed THA. Although it has a high sensitivity, the low specificity for infection limits its use [52]. Indium-111-labeled white cell scans have a much higher sensitivity in infection, which has been found to be 77%, with specificity of 86%, a positive predictive value of 54%, and a negative predictive value of 95% [13]. However, this test is expensive and time consuming and its utility in the acute postoperative period is unknown [53]. Other isotopes have been investigated but none has demonstrated clinically useful sensitivity or specificity. The use of radioactive immunoglobulin G has also been described but has not become common, as its sensitivity and specificity were similar to those of standard laboratory investigations [54, 55].

Laboratory Evaluation

After a complete history, physical examination, and review of radiographs, the next step should be to measure serological inflammatory markers, specifically C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR). These markers are strongly recommended for every painful or failed THA, regardless of cause of failure, as multiple modes of failure can coexist.

Both ESR and CRP are normally elevated during the early postoperative period [56, 57]. Interpreting the results of these markers during the early postoperative period is based on their behavior curve. Following uncomplicated surgery, the ESR has been shown to peak approximately 5 days postoperatively, and remain elevated for several months; the CRP has been shown to peak approximately 2 days postoperatively, and should return to normal within 21 days [57]. More importantly, CRP response is not correlated with type of anesthesia, estimated blood loss, operative time, transfusions, medications, age, or gender. As such, any late reversal of

downtrend should raise suspicion of, and be concerning for, infection. The CRP level, therefore, is more helpful in the evaluation of acute postoperative infection, especially if it continues to increase after the third postoperative day. The optimal cutoff CRP level for acute postoperative infection has been studied in acute postoperative THA infections confirmed with culture or intraoperative purulence by Yi et al. [1], with the optimal diagnostic cutoff for infection as measured by CRP found to be 93 mg/L (AUC of 93%). Given these findings, in the patient with any suspicion of infection, we obtain a serum CRP and if near or over 100 mg/L, an aspiration of the hip is obtained [1, 58].

Joint Aspiration

When the history, physical examination, and inflammatory markers yield a high suspicion of acute PJI, aspiration of the joint fluid is indicated. Arthrocentesis should be done under ultrasound or fluoroscopy to confirm position. In addition, the patient should be off antibiotics for at least 2 weeks to avoid false-negative culture results. Synovial fluid is sent for WBC count, differential, and culture. Yi et al. reviewed 6033 consecutive primary THAs and identified 73 patients (1.2%) who underwent reoperation for any reason within the first 6 weeks postoperatively. Thirty-six of these patients were infected according to modified Musculoskeletal Infection Society criteria. The best test for the diagnosis of PJI in the early postoperative period after THA was the synovial fluid WBC count (AUC = 98%; optimal cutoff value 12,800 cells/μL), and synovial fluid differential (AUC = 91%; optimal cutoff value 89% PMN) [59]. It is important to note that these thresholds are quite different than the recommended value of 3000 WBC/μL used for the diagnosis of chronic PJI. Synovial fluid cell count can be adjusted for synovial red blood cell (RBC), serum RBC, and serum WBC counts according to a formula proposed by Ghanem et al. [60]. Phagocytosed metal debris within monocytes may be read as neutrophils by automated hematology instruments resulting in falsely elevated cell counts. In these settings, a manual count should be obtained [61, 62].

Newer tests for PJI of the synovial fluids have emerged such as leukocyte esterase test and alpha-defensin peptide. The utility of these tests in the acute postoperative period is not known [63, 64].

Organism identification is paramount for antimicrobial treatment plan. Routine cultures should be maintained for 14 days. Extending the incubation period to 2 weeks will significantly increase culture yield particularly in patients who may be infected with low-virulence organisms [65, 66]. In a study from Mayo Clinic of 897 PJI cases (from 1990 to 1999), 60 cases (7%) were culture-negative periprosthetic joint infections (CN-PJI). Prior antimicrobial use has been shown by prior investigators to reduce the sensitivity of periprosthetic tissue cultures [67].

Frozen section and histology have been used as part of the intraoperative evaluation with the criterion value of the histologic diagnosis of infection reported to be either five or ten neutrophils per high-power field. The sensitivity for the cutoff of five neutrophils has been 100%, with a specificity of 96%. Using a cutoff criterion of ten neutrophils per high-power field did not change the sensitivity, but the specificity increased to 99% [68]. The utility of these tests in the acute postoperative phase, however, has not been studied.

Treatment

In the vast majority of cases, surgical management is deemed necessary for the treatment of acute PJI.

Irrigation and Debridement (I&D) with Modular Exchange and Component Retention

Although results are not favorable, irrigation and debridement with modular exchange and component retention continues to be the most common treatment for acute PJI. There is increasing evidence of substantial morbidity and cost of I&D as a treatment for acute prosthetic joint. Many centers

have reported poor results [69], with most studies demonstrated success rates only between 40 and 50% [70]. Successful outcomes have been reported in 71% of acute PJIs [71, 72]. The time between the onset of symptoms and initiation of treatment has been investigated, where when treatment was initiated within 48 h of symptoms, the success rate was 56%. Treatment started after 2 days yielded success rate of only 13% [73].

During I&D for acute PJI, all necrotic tissue is meticulously removed, all modular parts should be removed to allow access to as much as possible of the interface, and irrigation with 9 L of sterile normal saline is recommended. The implants should be tested for loosening, and if found to be loose, retention of the prosthesis should be abandoned. Patient should receive an extended course of organism-specific intravenous antibiotics in consultation with an infectious disease specialist [71].

Direct or "Single-Stage" Exchange

Direct exchange with cemented implants in the appropriate patient appears to be a reasonably successful treatment, but it has been more popular in Europe than in North America. Most of the literature relating to one-stage exchange has been with the use of cemented components and the subsequent use of antibiotic cement in the setting of late infections. Little has been written on the use of cementless components [74]. In a recent retrospective review of 27 patients who were treated with a one-stage exchange using cementless components following a primary THA at one of the three centers, Hansen et al. demonstrated just over a 70% success rate for one-stage exchange for the treatment of acute postoperative PJI at a minimum of 2 years postoperatively [75]. The hip provides a unique opportunity for acute direct exchange in the early postoperative period if uncemented components are utilized, but are yet to be well fixed.

Based on this rationale, a recent decision analysis by Bedair et al. attempted to pool all the relevant data regarding treatment of early infections after THA, and mathematically derive the treatment regimen that optimizes clinical outcome based on cumulative gains in quality of life. Their model demonstrated that a one-stage exchange may be optimal for treatment of an acute postoperative infection assuming that the failure rate of attempted debridement and component retention is greater than 49% while the success of a one-stage exchange is 71% or greater. Thus once the decision has been made to reoperate for infection, it appears from this analysis that a one-stage exchange may be most efficacious with little increase in the time or technical skill of the treating surgeon [76].

Two-Stage Exchange Arthroplasty

Two-stage exchange arthroplasty is considered the standard of care for chronic PJI and for cases of acute PJI with antibiotic-resistant organisms. The benefits in the acute stage include the fact that uncemented implants usually do not have bony ingrowth or ongrowth, allowing for easier removal with less bone loss. The procedure includes removal of the prostheses, retained bone cement (if utilized), and thorough debridement of necrotic soft tissue and bone to remove any biofilm material. Insertion of an articulating antibiotic cement spacer is more functional than a non-articulating antibiotic spacer [77]. The antibiotic spacer improves patient's quality of life, pain, and leg-length discrepancy during the interim treatment period [78]. Reports showed higher chances of success when using antibiotic cement spacer versus nonantibiotic cement spacer [79]. Use of combinations of antibiotics seems to be synergistic and improves elution. Vancomycin is commonly combined with an aminoglycoside [80]. The use of oral rifampin between stages, in which an antibiotic-loaded cement spacer was used, was believed to assist with the interruption of the biofilm [81].

Most authors recommend the mixture of at least 4 g of the indicated antibiotic per one 40 g batch of cement without any systemic side effects; however, the type of cement utilized will affect elution and this should be considered when determining how much antibiotic to be added to the cement spacer [81]. Specifically higher viscosity cements elute antibiotics more efficiently,

and hence less antibiotics can be utilized, or conversely the use of higher doses of antibiotics could translate into high serum levels and the associated risks of antibiotic toxicity.

The time between resection and reimplantation remains controversial. In one study, 22% of patients who underwent reimplantation more than 22 weeks after the first stage became reinfected compared with 14% of those treated within 6 weeks. A study of 50 consecutive two-stage revisions reported a 92% success rate with the second stage performed at 3 weeks; the authors advocated delaying reimplantation if there are signs of persistent infection, wound healing complications, or inadequate bone stock [82].

Following the treatment with IV antibiotics for minimum of 6 weeks, systemic inflammatory markers are followed up for a downward trend from the initial time of infection diagnosis which should continue after the antibiotic therapy is discontinued. The normalization of these values is not necessary [83]. During the reimplantation, hip joint aspiration is performed and sent for histological and microbiological evaluation. Any signs for persistence of infection warrants abortion of reimplantation and repeat I&D with spacer exchange.

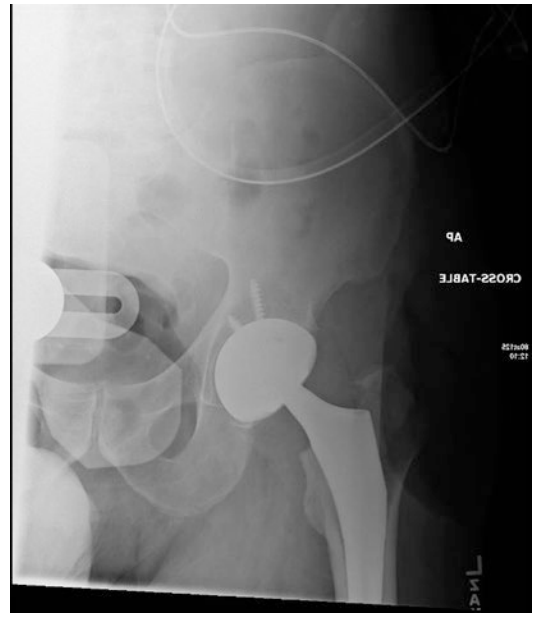

Fig. 5.2 Intraoperative image at the single-stage exchange; all components were replaced by same model and size implants

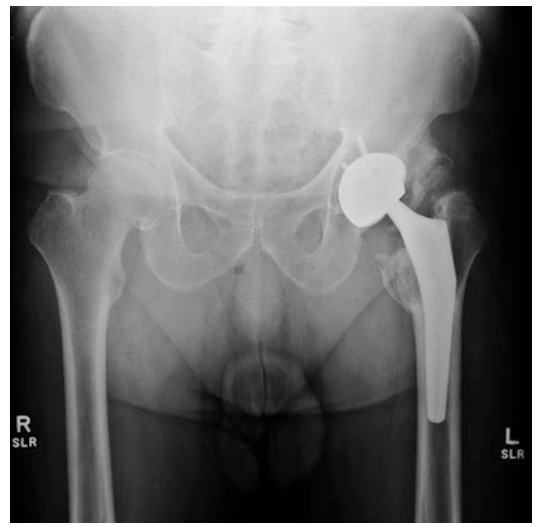

Fig. 5.3 Two years from the single-stage exchange revision for periprosthetic infection; note the heterotopic bone formation around the *left hip*

Case Solution

Based on the synovial fluid WBC count and differential, PJI was diagnosed, and after discussing the various treatment options with the patient, a one-stage exchange was decided; patient was taken to the OR; same approach was utilized; superficial layer above the fascia lata was copiously irrigated with 3 L; approach was then carried out; all implants were removed, taking great care to preserve all the bony structures; deep cultures were obtained; femoral canal, acetabulum, and surrounding soft tissue were irrigated with 6 L of antibiotic-loaded saline; a new set of the same make, model, and size were implanted and secured in place; and wound was then closed in standard fashion (Fig. 5.2). Both her preoperative and intraoperative cultures grew *Staphylococcus aureus*. With the input of the infectious disease specialists, she was put on a 6-week intravenous course of a vancomycin and oxacillin, and then transitioned to a 1-year oral course of a first-generation cephalosporin. At the most recent follow-up, 2 years following surgery (Fig. 5.3), she remained free of infection with an ESR and CRP of 3 and <5, respectively.

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Venothrombotic Embolus (VTE)

6

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Case Presentation

The patient is a 75-year-old male who has painful osteoarthritis of the right hip and requires a total hip arthroplasty. Five years ago the patient had a left total hip arthroplasty and developed a pulmonary embolism 4 days after surgery. The pulmonary embolism was successfully treated with anticoagulation for 3 months and the patient has been asymptomatic since that time. The plan is to now proceed with a right total hip arthroplasty. What type of anticoagulation would this patient require postoperatively?

Epidemiology

Venous thromboembolic (VTE) disease, consisting of pulmonary embolism (PE) and/or deep venous thrombosis (DVT), is the third leading cause of cardiovascular mortality and affects approximately 600,000 Americans each year [1–3]. Total hip arthroplasty (THA) is in the highest risk category for postoperative VTE complications and there is general agreement that patients undergoing this procedure require VTE prophylaxis [4–7]. Overall, routine prophylaxis has decreased the risk of symptomatic VTE after THA to less than 1% [8, 9]; however, despite significant advances in prophylaxis and identification of risk factors, VTE remains a relatively common reason for emergency readmission and death after THA [10–14].

Increased rates of post-discharge VTE complications are partly due to decreasing inpatient lengths of stay after THA. Currently, the proportion of VTE events that occur after discharge is greater than 50% [8]. The mean time to diagnosis of VTE complications after THA ranges between 17 and 22 days and the risk of developing this complication can extend up to 6 weeks postoperatively [15–17].

Risk Factors Associated with Complication

The pathogenic process of VTE formation begins in the perioperative period and stems from Virchow's triad of venous stasis, endothelial injury, and hypercoagulability. This triad serves as a basis for determining the preoperative, intraoperative, and postoperative risk factors associated with thromboembolic disease after THA.

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_6

Preoperative Risk Factors

All patients undergoing THA should be assessed preoperatively for increased risk of postsurgical VTE complications. The most common approaches to preoperative risk stratification are based on a thorough evaluation of the patient's medical history and occasionally the use of a formal risk assessment tool [18]. The utility of these risk assessment tools is unclear and up to 50% of patients who develop VTE after THA had no identifiable clinical or hemostatic risk factor preoperatively (Table 6.1) [19].

Many studies have attempted to identify specific clinical risk factors that increase the likelihood of postoperative VTE after THA. However, reproducibility of these risk factors has been limited, largely due to variations in the diagnosis and definition (symptomatic versus nonsymptomatic) of VTE. The most commonly agreed upon clinical risk factors include increasing body mass index, and history of a prior VTE episode [19–27]. Age greater than 70 or 75, cancer, cardiovascular disease, diabetes, hypertension, hormone replacement therapy, peripheral vascular disease, varicose veins, and a history of blood clotting disorders are potential clinical risk factors for VTE complications [8, 18, 19, 25–29].

In patients with a history of blood clotting disorders, there may be a genetic component and a thorough family history must be obtained. Several studies have found higher rates of VTE after THA in patients with high homocysteine levels, Factor-V Leiden mutation, antiphospholipid antibody syndrome, protein-C or S deficiency, antithrombin III deficiency, and prothrombin promoter G20210A mutation [19, 26, 30, 31].

Table 6.1 Preoperative risk factors for venothrombotic complications after total hip arthroplasty

Clinical risk factors	Hematologic abnormalities
Prior venous thromboembolic disease	Antithrombin III deficiency
Advanced age	Disorders of plasminogen
Obesity	Protein C or protein S deficiency
Trauma (pelvis, hip, femur, tibia fracture)	Myeloproliferative disorder
Prolonged immobility	Heparin-induced thrombocytopenia
Coronary artery disease	Factor-V Leiden mutation
Congestive heart failure	Antiphospholipid syndrome and Lupus anticoagulant
Myocardial infarction or stroke	
Hypertension	
Malignancy	
ASA score ≥3	
Oral contraceptives or hormone replacement	
Varicose veins	

Anderson FA Jr., Spencer FA. Risk factors for venous thromboembolism. Circulation. 2003;107:I9–16. Beksac B, Gonzalez Della Valle A, Salvati EA. Thromboembolic disease after total hip arthroplasty: who is at risk? Clin Orthop Relat Res. 2006; 453:211–24

Intraoperative Risk Factors

Intraoperative events during THA significantly impact the components of Virchow's triad and contribute to the risk of postoperative VTE complications. Venous capacitance and outflow may be reduced during THA, resulting in subsequent venous stasis; leg positioning for exposure may further exacerbate stasis [32]. Endothelial injury may occur during manipulation of the extremity during dislocation of the hip or insertion of the prosthesis and the endothelium may suffer thermal injury from bone cement's exothermic reaction [33, 34]. Lastly, hypercoagulability is markedly increased due to the release of several prothrombotic factors during soft tissue dissection and subsequent preparation and insertion of the femoral component [35].

Several studies have attempted to identify modifiable intraoperative risk factors for postoperative VTE complications, and particular emphasis has been placed on the type and duration of anesthesia utilized. Regional versus general anesthesia may result in lower risk of postoperative VTE because the sympathetic blockade secondary to regional anesthesia may result in vasodilation, increased blood flow, and, theoretically, less venous stasis. However, the actual benefit of regional anesthesia has not been definitively determined with regard to VTE complications

and recent systematic reviews suggest there is no benefit [26, 36–39]. Duration of the anesthesia may also have an impact on the incidence of postoperative VTE [40, 41].

Postoperative Risk Factors

Early mobilization and shortened hospital stays associated with THA today may prove to be critical factors in decreasing VTE risk after surgery [13, 42].

Prevention

Clinical practice guidelines established by professional organizations have been present for over 25 years, providing VTE prophylaxis recommendations after THA. The Surgical Care Improvement Project (SCIP) and Joint Commission on Accreditation of Healthcare Organization (JCAHO) mandate that some form of VTE prophylaxis be implemented postoperatively for THA patients, but do not recommend a specific prophylaxis regimen. The most commonly referenced guidelines are those published by the American College of Chest Physicians (ACCP) and the American Academy of Orthopaedic Surgeons (AAOS) [18].

The ACCP first established VTE prophylaxis guidelines in 1986 and frequently updates them, with the most recent being in 2012 [43]. For some time, the orthopedic community had significant concerns regarding these guidelines because there was an increased emphasis on efficacy of a prophylaxis regimen and limited focus on safety [44]. The most recent guidelines published in 2012 demonstrated that the ACCP had clearly listened to the concerns of the orthopedic community. The ACCP recommended a variety of chemoprophylaxis regimens including aspirin and portable mechanical compression devices, which were designated as acceptable when compared to no prophylaxis at all. The ACCP guidelines did not differentiate between total hip and knee arthroplasty regarding selection of an appropriate prophylaxis regimen.

In response to the guidelines established by the ACCP, the AAOS published their first VTE prevention guidelines in 2007 and, most recently, a second version in 2011 [26]. In this guideline, the AAOS panel did not recommend a specific prophylaxis agent or duration.

Currently, the orthopedic surgeon has a multitude of pharmacologic and/or nonpharmacologic VTE prophylaxis options available after THA. The selection of a prophylaxis regimen is a balance between efficacy and safety. The ideal regimen is highly patient-dependent and must consider each patient's individual risk of VTE formation, postoperative bleeding, or other complications from VTE prophylaxis. The risks, benefits, and best available evidence (Table 6.2) of the most commonly used VTE prophylaxis modalities will be further discussed in the following sections.

Pharmacologic Prophylaxis

A complete understanding of the physiologic coagulation cascade is essential to understand how each of the following six classes of VTE chemoprophylaxis agents executes its antithrombotic effect: vitamin K antagonists, low molecular weight heparins (LMWH), factor Xa inhibitors, antiplatelet agents, pentasaccharides, and direct thrombin inhibitors (Fig. 6.1).

Vitamin K Antagonists

Warfarin continues to remain one of the most commonly utilized agents to prevent VTE events postoperatively largely due to its long track record [53]. It acts by preventing the carboxylation of glutamic acid on clotting factors II, VII, IX, X and cofactors C and S. It is orally dosed and titrated to a target goal for the international normalized ratio (INR). The ACCP recommends a range of 2–3 while the AAOS recommends a goal INR of two or less [26, 43]. A number of randomized trials have compared warfarin to LMWH and have demonstrated higher overall VTE rates in patients treated with warfarin. However, symptomatic VTE rates between the two groups are similar and postoperative bleed-

Table 6.2 Summary of results from clinical trials comparing lovenox with new anticoagulant agents after total hip arthroplasty

Study	Dosage	Total deep venous thrombosis[a]	Total pulmonary embolism	Major bleeding complications
Colwell et al. [45]				
Enoxaparin	30 mg BID	3.2%	1.0%	1.2[b]%
Warfarin	INR 2–3	3.1%	0.8%	0.5[b]%
Record I [46]				
Enoxaparin	40 mg daily	3.4%[b]	<0.1%	<0.1%
Rivaroxaban	10 mg daily	0.8%[b]	0.3%	0.3%
Record II [47]				
Enoxaparin	40 mg daily	8.2%[b]	0.5%	<0.1%
Rivaroxaban	10 mg daily	1.6%[b]	0.1%	<0.1%
Advance III [48]				
Enoxaparin	40 mg daily	3.6%[b]	0.2%	0.7%
Apixaban	2.5 mg BID	1.1%[b]	0.1%	0.8%
Re-novate [49]				
Enoxaparin	40 mg daily	6.3%	0.3%	1.6%
Dabigatran	220 mg daily	4.6%	0.4%	2.0%
Dabigatran	150 mg daily	7.2%	<0.1%	1.3%
Re-novate II [50]				
Enoxaparin	40 mg daily	8.6%	0.2%	0.9%
Dabigatran	220 mg daily	7.6%	<0.1%	1.4%
Ephesus [51]				
Enoxaparin	40 mg daily	9.0%[b]	0.2%	2.6%
Fondaparinux	2.5 mg daily	4.0%[b]	0.2%	4.1%
Pentathlon [52]				
Enoxaparin	30 mg BID	8.2%[b]	0.1%	1.0%
Fondaparinux	2.5 mg daily	5.6%[b]	0.4%	1.8%

[a]Symptomatic and asymptomatic DVTs
[b]Indicates a statistically significant difference
Modified with permission from Lieberman JR, Pensak MJ. Prevention of venous thromboembolic disease after total hip and knee arthroplasty. J Bone Joint Surg. 2013;95(19):1801–11

ing complications are generally lower in the warfarin group [45, 54, 55]. The major advantages of warfarin are that it is an oral agent and the level of anticoagulation can be titrated, but its use is limited by the need for frequent INR monitoring and interactions with other medications and food products.

Low Molecular Weight Heparins

LMWH functions by binding to antithrombin III (AT III), which accelerates the subsequent inactivation of thrombin and factor Xa. LMWH is administered through a subcutaneous injection and requires no monitoring. Currently, LMWH is the most commonly used prophylactic agent for VTE after THA worldwide [53]. Its efficacy has been well documented in numerous randomized trials, including those comparing it to warfarin as previously discussed. Several other studies have compared the efficacy of LMWH to newer antithrombotic agents that will be discussed later in this chapter. The dosing of LMWH is either 40 mg once daily (European regimen) or 30 mg twice daily (North American regimen). The limitations of LWMH stem from concerns about post-discharge patient compliance regarding subcutaneous injections, its relatively high cost compared to warfarin or aspirin, and surgeon concern about increased postoperative bleeding risk.

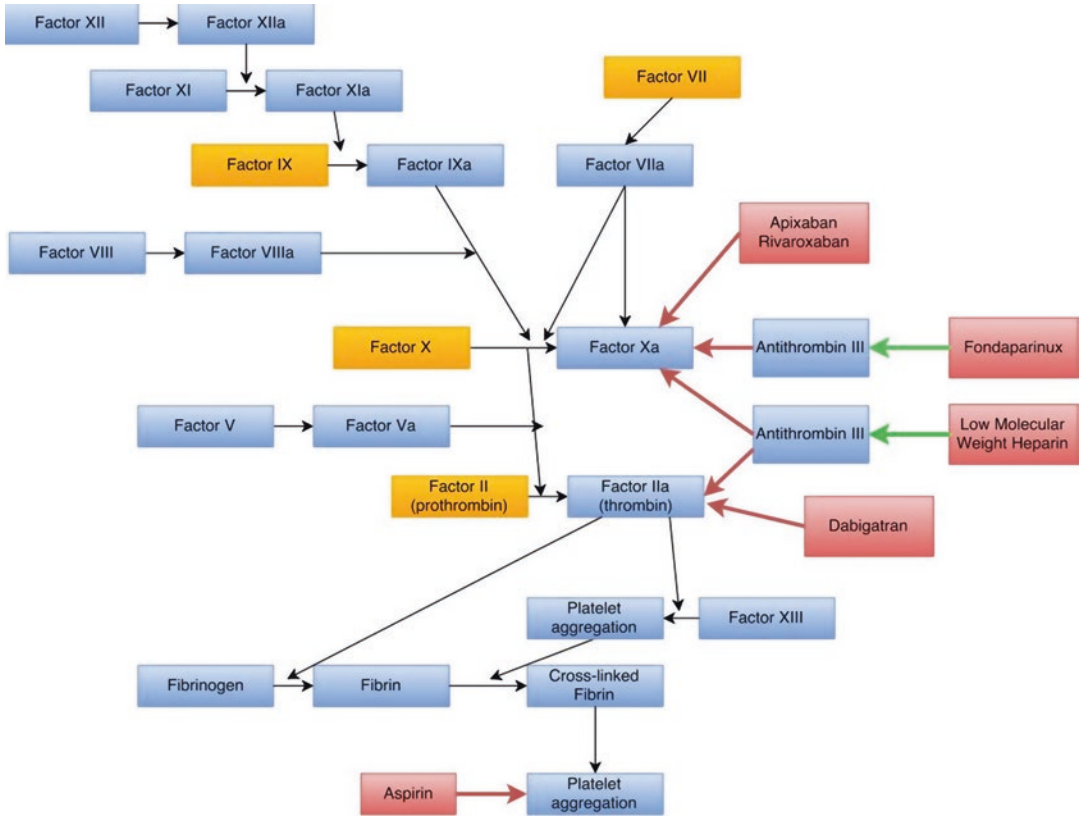

Fig. 6.1 Coagulation cascade and the sites of action of commonly used anticoagulants. *Red arrow* = inactivation; *Green arrow* = activation; *Orange boxes* = Vitamin K-dependent factors sensitive to Warfarin (Modified with permission from Leung KH, Chiu KY, Fan CH, Ng FY, Chan PK. Review article: venous thromboembolism after total joint replacement. J Orthop Surg. 2013;21(3):351–60)

Direct Factor Xa Inhibitors

Factor Xa inhibitors directly and reversibly inhibit factor Xa, which catalyzes the conversion of prothrombin to thrombin. In the United States there are currently two factor Xa inhibitors available for VTE prophylaxis after THA: apixaban and rivaroxaban. Edoxaban is a third agent currently approved in Japan for VTE thromboprophylaxis following major orthopedic surgery, but its use in the United States following THA is pending phase III trial results. The ACCP recommends the use of Apixaban/Rivaroxaban (grade IB) in patients undergoing major orthopedic surgery.

Apixaban is orally administered at 2.5 mg twice daily and rivaroxaban is orally administered at a dose of 10 mg daily. In randomized trials, both agents have demonstrated greater efficacy in preventing VTE after THA in comparison to LMWH, without increased risk of postoperative bleeding [46–48]. The major concern with the use of these Factor Xa inhibitors is the risk of postoperative bleeding and some orthopedic surgeons elect to administer the drug off label, 18–24 h after surgery, to help minimize this risk.

Antiplatelet Agents

Aspirin functions by irreversibly inactivating cyclooxygenase's formation of thromboxane A2 in platelets, thus inhibiting platelet function. Interest in aspirin for VTE prophylaxis after THA has grown over the past decade as evident by recent changes in the ACCP guidelines [34, 44]. In the 8th edition of the ACCP guidelines, a grade IA recommendation was made against the use of aspirin as a thromboprophylaxis agent [56]; however,

in the most recent 9th edition, a grade IB recommendation was made for the use of aspirin as a prophylactic VTE agent following major orthopedic surgery when compared to no prophylaxis at all [43]. The SCIP guidelines accordingly changed and now include aspirin as an acceptable agent for VTE prophylaxis following THA.

These recent changes in national guidelines were largely driven by results of the Pulmonary Embolism Prevention (PEP) trial which demonstrated a significant difference between aspirin and placebo, without an increase in bleeding complications, with respect to VTE complications in all patients with a hip fracture and those patients with a hip fracture managed with arthroplasty [57]. Unfortunately, the study was underpowered to evaluate the efficacy of aspirin in patients undergoing elective THA. Whether or not aspirin is as effective in reducing VTE complications after THA in comparison to other agents remains controversial as nonrandomized studies have demonstrated differing results from the PEP trial [7]. In a report by Jameson et al. [58] from the National Joint Registry for England and Wales for THA, overall efficacy was the same for LMWH and aspirin and bleeding rates were also the same. The selection of a prophylaxis agent is a balance between efficacy and safety. Aspirin is likely not as powerful an anticoagulant as other available chemoprophylaxis agents, but the major benefits of aspirin include its oral dosing, high rate of patient compliance, and perceived lower risk of bleeding [57, 59–61]. The optimal dose for aspirin in VTE prophylaxis has not been identified, but the most commonly prescribed dose is 325 mg twice daily for 6 weeks.

Pentasaccharides

Fondaparinux is a synthetically manufactured polysaccharide that inactivates factor Xa by causing a conformational change in AT III, which increases the binding of AT III to factor Xa. It is administered subcutaneously and its overall efficacy is similar to that of LMWH [51, 52]. It is typically injected at 2.5 mg once daily in patients greater than 50 kg without a history of renal insufficiency. A possible advantage of fondaparinux over LWMH is its potentially lower rate of heparin-induced thrombocytopenia (HIT) and its use in patients already diagnosed with HIT [62]. However, concerns regarding postoperative bleeding complications have limited the use of fondaparinux [63].

Direct Thrombin Inhibitors

Dabigatran etexilate is orally administered and directly binds to the active catalytic site on thrombin, reversibly inhibiting it. Dabigatran was previously approved only for prevention of stroke or atrial fibrillation, but in 2014 the Food and Drug Administration (FDA) approved its use for secondary prevention of DVTs and PEs. The ACCP recommends its use (grade IB) in patients undergoing major orthopedic surgery. Dabigatran is typically administered once daily at doses of either 150 mg or 220 mg and both doses have demonstrated similar efficacy to LWMH in preventing VTE complications after THA without increasing postoperative bleeding complications [49, 64].

Nonpharmacologic Prophylaxis

Mechanical Prophylaxis

Recently, increased interest in pneumatic compression devices for VTE prophylaxis following THA has developed due to the development of mobile compression devices that can be used after hospital discharge [44]. The use of pneumatic compression devices is predicated on the physiological concept that compression of the lower extremity venous system decreases venous stasis, increases local blood flow, and increases local, but not systemic, fibrinolysis [50, 65]. The efficacy of these devices in preventing VTE after THA has been assessed since the 1980s, but conclusions have been limited by the quality of these studies. Initial studies demonstrated pneumatic compression devices to be inferior to warfarin in preventing VTE formation after THA [66–68]. More recent studies comparing LWMH to the use of a foot pump or mobile compression device suggest similar efficacy between the two modalities but these studies were underpowered [69, 70].

The aforementioned results led to the ACCP recommending (grade IC) mobile pneumatic compression devices as a stand-alone measure for VTE prophylaxis after THA only if worn for at least 18 h per day [43, 71]. The obvious advantage of these mechanical compression devices is the absence of postoperative bleeding risk, but mechanical prophylaxis is typically discontinued at the time of discharge and given recent decreases in inpatient stay after THA, this could lead to inadequate prophylaxis. The development of portable mechanical compression devices has helped mitigate this issue and recently published studies demonstrate promising results [71]. However, the cost of these devices and continued concerns regarding post-discharge compliance have limited their use.

Decreased venous stasis and increased regional blood flow can also be achieved through postoperative ambulation. Some studies have demonstrated a significant decrease in postoperative VTE complications in patients who ambulated early in the postoperative period [13]. The AAOS makes a consensus recommendation for early mobilization after THA given its potential efficacy, minimal cost, and low risk [26].

Inferior Vena Cava (IVC) Filters

Patients undergoing THA who have increased risk for both PE and major bleeding, contraindications to chemoprophylaxis, or recurrent PE despite therapeutic chemoprophylaxis may be considered for IVC filter placement [72]. When placed, these filters have the ability to block the passage of emboli from the lower extremity venous system to the pulmonary circulation. However, there have been no randomized studies assessing the primary prevention efficacy of IVC filters in preventing PEs. Therefore, the ACCP does not recommend (grade 2C) the use of an IVC filter as primary prophylaxis as opposed to no thromboprophylaxis at all in patients with high risk for both PE and bleeding [43]. The AAOS makes an inconclusive statement about the use of IVC filters in this same patient population [26]. The concern is that IVC filters may not reduce symptomatic PE rates and that chronic disease may develop if filters are left in place [73, 74].

Duration of Prophylaxis

The exact duration of VTE prophylaxis following THA has not been definitively established but there is general agreement that prophylaxis should start on the day of surgery and continue for at least 10–14 days [16]. However, extended duration of VTE prophylaxis, up to 35 days, has demonstrated significant decreases in VTE complications as well [75–79]. Currently, the ACCP provides a grade IB recommendation for 10–14 days of prophylaxis and a grade 2B recommendation for extended prophylaxis up to 35 days, while the AAOS does not provide a specific duration recommendation [26, 43]. The ideal duration for postoperative VTE prophylaxis remains highly patient-dependent and most surgeons base their duration on perioperative risk factors for VTE complications after THA [18, 34].

Summary of VTE Prevention

The selection of an ideal postoperative VTE prophylaxis regimen after THA is of paramount importance in the perioperative management of arthroplasty patients. As the total number of THAs performed annually continues to grow, particularly in patients with greater clinical risk factors for VTE, an effective and safe prophylactic regimen that minimizes VTE complications without significantly increasing postoperative bleeding complications must be selected in a patient-dependent manner. Further research is needed to develop more effective risk stratification strategies, allowing for appropriate anticoagulation strength and duration, while minimizing chemoprophylaxis complications. An ideal prophylaxis regimen seeks to prevent symptomatic VTE events while limiting bleeding and other wound complications.

Diagnosis

The clinical diagnosis of DVT and PE can be extremely challenging as signs and symptoms are neither specific nor sensitive for each entity, and thus clinical suspicion must always remain high

for VTE complications after THA [4, 80]. Thigh and calf swelling (85%), localized limb pain (78%), positive Homan's sign (56%), erythema (24%), and fever (5%) have been associated with the presence of DVT [81–83]. Unfortunately, the specificity of these clinical signs is low and less than a third of patients with a proven DVT will present with a combination of these physical exam findings [4].

The clinical diagnosis of PE also remains challenging due to the absence of specific exam findings and often vague or atypical patient symptoms. Classically, PE presents with dyspnea (60%) and pleuritic chest pain (80%); however, the combination of these findings is present in only 40% of patients with proven PE [14, 84]. Additional clinical signs of PE may include fever (50%), tachycardia (43%), neck vein distention (30%), hypoxia (18%), and hypotension (10%) [84, 85]. Massive PE can present as syncope or sudden death. Due to the lack of specificity in clinical exam findings for diagnosing PE, several lab tests and clinical prediction models have been developed. The D-dimer level may be a useful predictive tool, particularly in patients where there is a low clinical suspicion for PE; however, D-dimer levels are typically already elevated in postoperative patients, making this an unreliable test acutely after THA [86]. The Wells score, a popular clinical predictive model, was developed in nonsurgical patients and has never been validated in an orthopedic population [87].

Given the nonspecific clinical exam findings associated with both DVT and PE, their diagnosis is dependent on both high clinical suspicion and confirmatory testing with advanced imaging. Venography has classically been deemed the "gold standard" for the diagnosis of lower extremity DVT, but is associated with high cost, patient discomfort, and requires the use of contrast material [14]. Ultrasound has largely replaced venography and is able to detect symptomatic proximal DVTs with near 100% sensitivity in a noninvasive manner [88]. However, ultrasound remains user-dependent and reported sensitivities of the modality may not be generalizable to all institutions. Currently both the AAOS and ACCP guidelines strongly recommend against routine postoperative screening with ultrasound [26, 43].

The diagnosis of PE is also dependent on advanced imaging modalities. In all patients with suspicion for PE, the treating physician should consider obtaining an electrocardiogram (EKG), chest radiograph, and/or arterial blood gas. Although these initial studies are not adequate to diagnose PE, they may serve to identify other cardiopulmonary pathologic processes that present similarly to PE and thus appropriately guide treatment [14]. Pulmonary angiography has long served as the benchmark for the diagnosis of PE, but it is invasive and expensive. Therefore alternative modalities including ventilation-perfusion (VQ) scanning and computed tomography pulmonary angiogram (CTPA) were developed [59]. CTPA allows for direct visualization of the clot while also identifying other potential pathologic processes in a time-efficient manner; however, it is expensive and has a radiation exposure equivalent to 100–400 chest radiographs [59]. VQ scanning requires less radiation and provides a cheaper diagnostic alternative, but interobserver agreement may be as low as 70% in intermediate and low-probability scans [89]. When comparing the two imaging modalities, CTPA has a higher positive predictive value than VQ scans; both have similar accuracy when ruling out PE [90].

CTPA has evolved into the primary imaging modality to detect PEs and its high sensitivity led to an increase in the diagnosis of PE; however, there has not been an associated increase in mortality [91]. The increase in diagnosis is likely due to detection of additional small segmental and subsegmental emboli which may be secondary to fat and marrow debris [91]. There is concern that these small emboli are not clinically relevant and that patients may receive unnecessary anticoagulation.

Clinical suspicion for VTE complications after THA must be individualized on the basis of perioperative risk factors, and pretest suspicion should guide appropriate ordering of diagnostic studies to confirm or exclude the diagnosis of DVT or PE.

Treatment

The goal of treating lower extremity DVTs after THA is to prevent propagation of thrombus, prevent formation of PEs, restore venous patency, and decrease the risk of post-thrombotic syndrome (PTS). PTS can be a painful and a disabling condition consisting of leg swelling, dermatitis/cellulitis, and ulceration which can occur in 4–29% of patients after acutely diagnosed DVT [92, 93].

The causal relationship between lower extremity DVT and development of PE remains controversial and not clearly understood. Some physicians consider DVT and PE to be distinct clinical entities while research has demonstrated both strong and weak correlations for developing a PE in the setting of a diagnosed lower extremity DVT [94–98]. Currently, the AAOS guidelines state that there is a lack of evidence establishing a clear association between DVT and PE in patients undergoing THA, while the ACCP guidelines maintain that there is a consistent association [26, 43]. The unclear relationship between lower extremity DVTs and formation of PE has made the treatment of calf clots controversial.

The treatment of PE is focused on decreasing and preventing morbidity and mortality. The acute and chronic complications of untreated PEs include increased pulmonary vascular resistance, increased airway resistance, chronic thromboembolic pulmonary hypertension, and mortality [94, 99]. Although historically there was an established link between untreated PE and mortality, as more sensitive imaging modalities have developed, the diagnosis of PE more than doubled without a corresponding increase in mortality rate [91, 100, 101]. This lends credence to the thought that PE is a spectrum of disease ranging from large central clots to small subsegmental clots [94]. Currently the clinical significance of these smaller, asymptomatic occlusions remains unclear and it is possible that PEs are being overtreated in the THA population [59, 91].

In a patient with a diagnosed PE or DVT after THA, treatment regimens are highly individualized and must consider the location of the DVT, amount of PE pulmonary involvement, and risk factors for development of recurrent VTE complications. In the setting of diagnosed VTE complications after THA, many institutions follow antithrombotic recommendations made by the ACCP. Currently, the ACCP makes a strong (Grade 1B) recommendation for 3 months of anticoagulation for a first time proximal DVT or PE in a patient after THA [102]. In patients with an isolated distal DVT after THA, the ACCP makes a weak (Grade 2C) recommendation for 3 months of anticoagulation [102]. In patients with elevated risk factors for recurrence or in patients with previous PE or DVT who redevelop VTE complications, consideration should be given toward extended or life-long anticoagulation. There are several pharmacologic agents available to achieve therapeutic anticoagulation and ACCP guidelines currently recommend initial anticoagulation with LMWH, fondaparinux, or rivaroxaban, and long-term anticoagulation with warfarin [102]. Although there are several other agents (i.e., dabigatran, rivaroxaban, apixaban) also being used for long-term anticoagulation. If a patient requires long-term anticoagulation, the senior author defers to the patient's primary care physician for selection of the appropriate agent.

With parenteral anticoagulation, the ACCP recommends continuing warfarin for at least 5 days and until the INR is 2–3 for at least 24 h. In the setting of VTE, LMWH is dosed at 1 mg/kg twice daily or 1.5 mg/kg daily. Fondaparinux dosing varies based on weight: 5 mg daily for patients <50 kg, 7.5 mg daily for patients 50–100 kg, and 10 mg daily for patients >100 kg. Rivaroxaban is dosed initially at 15 mg twice daily for 21 days followed by a long-term dose of 20 mg daily**.** The senior author tries to avoid giving patients in the early postoperative period a bolus dose of intravenous heparin because of concerns regarding bleeding.

The initiation of therapeutic anticoagulation should occur as soon as possible. The surgeon must make this decision by factoring in the risks of withholding anticoagulation and the risks of anticoagulation itself, particularly bleeding leading to wound complications and increased infection rates [59]. Consideration should also be given toward intra-arterial thrombolysis or surgical

embolectomy, in patients with PE and hemodynamic instability. Intra-arterial thrombolysis allows for mechanical fragmentation of thrombus and is often combined with pharmacologic thrombolysis. Surgical embolectomy may best be suited for patients with massive PE who require removal of a right atrium thrombus or closure of a patent foramen ovale. Finally, in patients who develop VTE complications while already on therapeutic anticoagulation or those with contraindications to therapeutic anticoagulation, placement of an IVC filter should be considered.

The treatment of VTE complications after THA remains a controversial subject. Untreated VTE complications may increase mortality rates after THA, but unnecessary anticoagulation may contribute to increased mortality rates and morbidity from postoperative bleeding. Further research is needed specifically assessing the relationship between DVT and PE and the clinical significance of small, asymptomatic PEs.

Case Solution

The patient has a prior history of PE after THA so he is considered high risk for development of a PE with this procedure. There is no evidence-based data to guide the orthopedic surgeon with respect to management of this problem, but the senior author has a protocol that he uses, which starts prior to surgery. First, these patients are sent for medical evaluation of their overall cardiopulmonary status, which often includes a cardiac stress test. Second, the patients receive an ultrasound duplex scan. A duplex scan is ordered because in some cases these patients may have had a simultaneous lower extremity blood clot with the PE. This can lead to an abnormality in the venous system. If the patient develops postoperative lower extremity swelling, there is a low threshold to obtain a duplex scan and it is important to recognize if the abnormality in the venous system was present before the surgical procedure. The patient diagnosed with the clot on an aggressive anticoagulant agent who had a prior PE could end up on anticoagulation therapy for life, which is associated with morbidity and mortality.

With regard to anticoagulation, the senior author usually prefers to place these patients with prior pulmonary embolism on warfarin for 6 weeks with a LMWH bridge. The use of LMWH bridge therapy is decided upon after discussion with the patient's primary care physician or cardiologist. The patients receive 10 mg of warfarin the night of surgery. They are given a first dose of LMWH 30 mg beginning 24 h after the surgery. Mechanical compression is also used. LWMH 30 mg twice daily is given until the INR is at a level of 2.0 for 2 days. The target INR for the warfarin is 2.0. The dosing of warfarin on the second day is determined by the INR result after the initial dose. Given the patient is on two anticoagulant agents, there are concerns about bleeding, so the warfarin dose is gradually increased.

If the patient has a prior DVT, but not a pulmonary embolism, then the senior author does not use bridging with LMWH; however, warfarin is continued for 6 weeks and the target INR is still 2.0 in these cases.

Early ambulation is probably very important in these patients. These patients should ambulate the day of surgery if possible. In addition, these patients are prescribed compressions stockings to limit venous stasis.

Summary

Orthopedic surgeons are highly interested in VTE prophylaxis because it can lead to death of the patient. The goal of prophylaxis is to prevent symptomatic DVT and PE. Risk stratification is the key to prevent over-anticoagulating some patients with subsequent bleeding, while leaving some patients at increased risk for VTE because of insufficient anticoagulation. Appropriately powered multicenter randomized trials with well-defined parameters for symptomatic PE and DVT are needed to assess the efficacy of various agents. In addition, studies are needed to determine the critical coagulation factors that increase the risk of thrombus formation in certain patients after THA.

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Part II

Chronic Complications

Evaluation of the Painful Total Hip Arthroplasty

7

Jeffrey Ryan Petrie and Denis Nam

Case Example

A 45-year-old female underwent a right primary total hip arthroplasty 3 years ago for a diagnosis of osteoarthritis. She notes that she never had complete resolution of pain following her surgery, with persistent symptoms that have markedly worsened over the last month. Her pain is localized to the groin and anterior thigh. She denies start-up pain in the thigh, fevers, or chills. She has an antalgic gait that favors her right side. She also complains of a leg-length discrepancy with the right, operative side being longer than the left. This discrepancy was measured to be 2 cm both clinically and radiographically from her presenting anteroposterior radiograph. Her prior posterolateral incision is well healed, and she has slight pain with hip internal rotation to 20° and extension/external rotation of the lower extremity. She also noted significant pain when moving from the seated to standing position in the groin area. The patient's radiographs demonstrated a well-fixed total hip arthroplasty with cementless acetabular and femoral fixation (Fig. 7.1).

Introduction

Total hip arthroplasty (THA) is one of the most successful procedures in orthopedics, demonstrating excellent survivorship and low complication rates in the treatment of degenerative hip disease [1]. Pain relief remains the primary goal of THA, yet many patients continue to experience persistent pain postoperatively, even in the setting of well-fixed and acceptably aligned components. Prior reports have noted up to 40% of patients to report some pain following their THA, and thus persistent pain following THA remains a concern [2–10]. In a prospective investigation of 196 patients less than 60 years of age undergoing THA, Nam et al. found 40% of patients report pain in at least one location around the hip, with 29% reporting groin pain, 25% reporting anterior thigh pain, and 20% reporting lateral thigh pain when assessed using a pain-drawing questionnaire [11]. Trochanteric pain was noted to be very high, with 37% of THA patients reporting pain in that location.

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_7

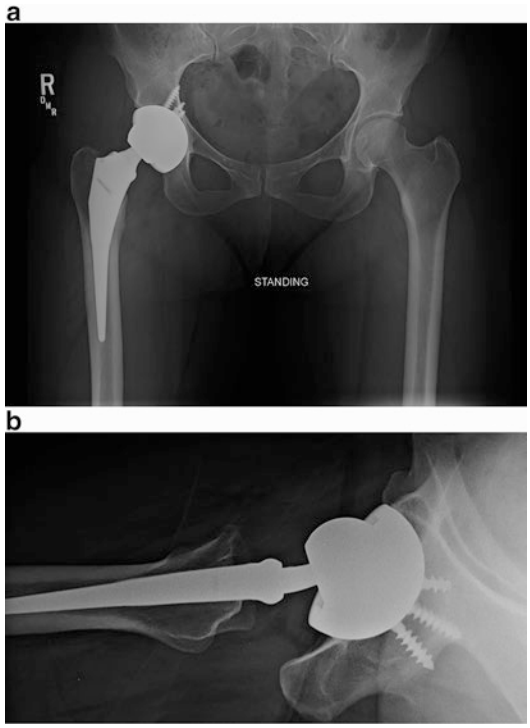

Fig. 7.1 Anteroposterior pelvis (**a**) and cross-table lateral hip (**b**) radiographs demonstrating a cementless total hip arthroplasty without signs of radiographic loosening. The acetabular component is in approximately 60° of abduction and 30° of anteversion

As groin pain is often a presenting symptom in patients seeking THA, its presence postoperatively remains a major concern for patients. Potential causes of groin pain following THA include impingement of the femoral neck against the acetabulum or soft tissues, irritation of the iliopsoas tendon across the rim of the acetabular component, or potential anterior instability with irritation of the capsule and anterior musculature [3, 12]. Furthermore, numerous factors have been associated with the occurrence of thigh pain after the use of cementless femoral stem fixation in THA including a patient's bone quality, prosthesis design, stem size, age, gender, and activity level [13–15].

Given the high prevalence of pain following THA, patient education remains critical. Surgeons must counsel their patients prior to THA that even in the setting of well-fixed and acceptably aligned components, there remains the risk that some symptoms may persist. Mancuso et al., in a telephone interview of 405 patients undergoing THA, noted that only 43% of patients reported all of their preoperative expectations to have been fulfilled following THA [8]. In addition, prior reports have noted failure to fulfill patient preoperative expectations as the primary predictive factor of patient dissatisfaction following total joint arthroplasty [16, 17].

However, while patients may present with a painful THA without a clear etiology, it is critical that the physician is aware of the wide array of identifiable causes of pain following THA that require investigation. Potential etiologies include infection, component loosening, fracture, soft-tissue impingement, bursitis, tendonitis, bearing surface wear, and synovitis as well as adverse local tissue reactions secondary to corrosion at modular junctions [12, 18]. Ulrich et al. reviewed 225 revision THAs performed over a 6-year time period at two centers, and noted 51.9% to be revised for aseptic loosening, 16.9% for instability, and 5.5% for infection. The most common causes for revision within 5 years were instability and infection [19]. Haynes et al., in an institutional review of 870 revision THA procedures, noted the most common indications for revision surgery to be aseptic loosening (31.3%), osteolysis (21.8%), and instability (21.4%) [20]. The introduction of highly cross-linked polyethylene in total hip arthroplasty has demonstrated excellent wear properties; thus revision specifically for periprosthetic osteolysis will hopefully decrease and implant longevity will improve [21, 22]. However, osteolysis still remains a predominant cause of long-term failure, especially in THAs implanted prior to the introduction of highly cross-linked polyethylene and in malpositioned components predisposed to eccentric loading. Thus, there are an extensive number of potential etiologies of pain following primary THA, and it is critical that physicians maintain a systematic approach towards the painful THA to avoid a missed diagnosis. The purpose of this chapter is to review the evaluation and approach to the painful THA, including the physical examination, radiographic analysis, and indications for secondary imaging and laboratory studies that may guide the physician towards a diagnosis.

Patient History and Differential Diagnosis

A thoughtful, precise history is tremendously valuable in the evaluation of the patient with a painful THA. Being thorough can narrow the differential diagnosis and focus the diagnostic workup considerably. It is helpful to categorize pain arising from THA into intrinsic origins and extrinsic origins (Table 7.1), and attention should be directed towards the location of pain, time of onset, severity, character of the pain, precipitating factors, and relieving elements.

In a patient presenting with a painful THA, it is often beneficial to obtain the patient's prior clinical and operative records, along with implant stickers identifying the specific prosthesis utilized. This can provide valuable insight into potential intraoperative or perioperative complications that may have occurred and provide clues towards etiologies of the patient's pain. In addition, implant records allow the surgeon to keep in mind specific failure mechanisms that are associated with certain devices, and they are also useful during preoperative planning of a revision procedure.

The temporal onset in particular can provide a wealth of clues. If the patient has had pain since the index procedure without a pain-free interval, then failed fixation of implants, acute infection, intraoperative or postoperative fracture, or misdiagnosis of the patient's original disability (lumbar spine disease) are all potential causes [23–25]. Likewise, delayed pain years after the well-functioning index arthroplasty is performed is suggestive of aseptic loosening; while osteolysis, chronic infection, and periprosthetic stress fracture are also included in the differential. While a history of multiple dislocations regardless of the time of presentation presents a clear diagnosis as a potential etiology of pain, more subtle findings such as hip instability and increased demand on secondary stabilizers of the hip joint may require further investigation.

Table 7.1 Differential diagnosis of the painful THA

Intrinsic origins	Extrinsic origins
Infection	Lumbar spine disease
Loosening	• Stenosis
• Cemented prosthesis	• Spondylolisthesis
• Uncemented prosthesis	• Herniated disc
Periprosthetic fracture	Peripheral vascular disease
Stress fracture	Neuropathic causes
Implant fracture	• Sciatic, femoral
Dislocation	Hernia—femoral, inguinal, obturator
Osteolysis	Metabolic disease
Adverse local tissue reaction	• Paget's disease
Heterotopic ossification	Metastatic disease
End-of-stem pain (modulus mismatch)	Retroperitoneal abscess
Bursitis or tendonitis	Retroperitoneal tumor

The location can also provide the physician with insight into the etiology of pain. Groin or buttock pain often indicates acetabular component (loosening, uncoverage of component, osteolysis), capsular, or iliopsoas dysfunction (tendinitis or impingement). Acetabular component uncoverage of >5 mm on a cross-table lateral radiograph has been associated with an increased likelihood of groin pain following THA [8]. Furthermore, in a patient with eccentric polyethylene wear, corrosion at a modular interface, or metal-on-metal bearing surface wear, intra-articular debris may stimulate an inflammatory response leading to synovitis and groin pain [26]. Less likely origins of groin pain also include hernias, metastatic cancer, neuropathy, vascular pathology, retroperitoneal abscess, and certain metabolic conditions (Paget's disease) [27–30].

In contrast, anterior thigh pain is often related to the femoral component, and can represent loosening or an elastic modulus mismatch between an uncemented stem and bone in the case of end-of-stem pain [5, 31–34]. With the use of cementless femoral fixation, it is hypothesized that a more physiologic stress transfer with loading of the proximal, metaphyseal femur should diminish the incidence of thigh pain, while isolated loading of the diaphyseal region may increase its incidence. However, multiple factors may predispose a patient to postoperative thigh pain including the femoral stem design used, stem composition (titanium vs. cobalt-chrome), and native femoral anatomy [15, 33, 35]. Cooper et al., in a retrospective review of 320 consecutive THAs performed using a proximally coated,

tapered wedge femoral stem, found a greater canal fill at the distal-third of the femoral stem to be a risk factor for failed stem osseointegration and pain [15].

One specific symptom often described is "start-up" pain, or pain at the initiation of activity (often walking) that subsides with increased movement. This symptom is often indicative of femoral stem loosening or failure of ingrowth [36]. This is in contrast to "end-of-stem pain" as described by Engh and Bobyn, in which micromotion at the tip of the femoral stem (often in an implant well fixed proximally) or load transmission through the tip of the stem to the native femur may cause discomfort [34]. Of note, in a well-fixed cemented femoral prosthesis, thigh pain is rare as bone cement distributes the load over the full length of the stem and prevents apical oscillations seen with end-of-stem pain [37]. Thus, thigh pain in a patient with a cemented femoral prosthesis is often indicative of component loosening [38].

Pain localized over the greater trochanter is very common following THA and often represents bursitis. However, it can also be attributed to abductor deficiency or fracture of the greater trochanter from trauma and/or osteolysis [11, 39]. Thus, a thorough clinical examination is essential to distinguish bursitis from abductor deficiency or potential periprosthetic fracture.

Pain that becomes more severe with activity, such as walking or standing, and is significantly improved with rest, suggests loosening, fracture, or vascular/neurogenic claudication. Alternatively, rest pain that is constant or night pain should raise one's suspicion for deep infection or tumor. The surgeon should also inquire about postoperative wound drainage, fever, or being prescribed a course of oral antibiotics if an infectious cause for THA pain is being sought. As noted earlier, significant pain that occurs with the first few steps the patient takes and then improves ("start-up pain") can occur with a loose or fibrous adherence of a cementless femoral component, but may also be present due to inadequate acetabular component fixation.

Precipitating and relieving factors should also be identified during the patient interview. Pain occurring after a fall or other traumatic event could be the result of fracture or component subluxation/dislocation. The patient that has a painful THA after a urologic, gynecologic, or gastrointestinal surgery, systemic illness, or dental procedure should be worked up for infectious etiology. Additionally, radiating hip pain or numbness that has improved with physical therapy, oral steroids, or epidural injections could be attributed to lumbar disc disease, a frequently missed diagnosis in these patients [23, 25, 40].

Physical Examination

A comprehensive examination of the patient presenting with a painful THA includes evaluation of the hips, knees, and spine. Neurogenic and vascular causes of pain should be ruled out. A detailed neurovascular examination including deep tendon reflexes, sensory assessment, and peripheral pulses can often distinguish lumbar spine and vasculogenic pain from true hip pain. The patient's gait should be scrutinized for a Trendelenburg gait, antalgia, limb-length inequality, and muscular deficiencies. A Trendelenburg gait often suggests abductor weakness whereas an antalgic gait can be secondary to numerous hip or spinal conditions. True limb lengths can be determined with wooden blocks and are differentiated from apparent limb lengths caused by abduction or adduction contractures, scoliosis of the lumbar spine, or fixed pelvic obliquity. Plaas et al. reported on limb-length discrepancy in THA in regard to function and pain [41]. They found that limping was more common in patients with a shorter postoperative leg while pain was more common in patients with a longer operative leg when compared to patients with equal leg lengths (within 3 mm) [41].

The skin of the back and lower limbs is assessed for signs of infection (warmth, drainage, fluctuance), open wounds, tender bursae (especially over the greater trochanters), or hernias. Additionally, hip and knee arc of motion can provide valuable information, especially when symptoms can be reproduced, for narrowing the differential. Pain with passive motion can be the

result of infection, fracture, synovitis, or gross component loosening. On the other hand, pain with active or extreme motion may indicate loosening, instability, or impingement. Pain from iliopsoas tendonitis can be elicited with resisted hip flexion or passive extension, while pain with ipsilateral or contralateral passive straight leg raise is often noted in lumbar spine disease. If based on the physical examination multiple potential etiologies of pain are identified, local anesthetic injections may prove both diagnostic and therapeutic. Ultrasound-guided injections into the iliopsoas sheath are often useful in identifying iliopsoas tendonitis, while trochanteric bursa or lumbosacral injections may also help to localize a patient's symptoms. Pain due to hip instability or subluxation may be elicited with provocative maneuvers such as hip flexion, adduction, and internal rotation (posterior instability), or extension and external rotation (anterior instability), although significant caution should be used to avoid frank dislocation in the outpatient clinical setting.

Lastly, prior to performing the physical examination in a patient with a prior total hip arthroplasty, the authors suggest that standard anteroposterior pelvis and lateral hip radiographs are obtained and reviewed. In the setting of gross implant loosening, instability, or fracture, the physical examination should be limited to avoid worsening of a patient's condition (Fig. 7.2).

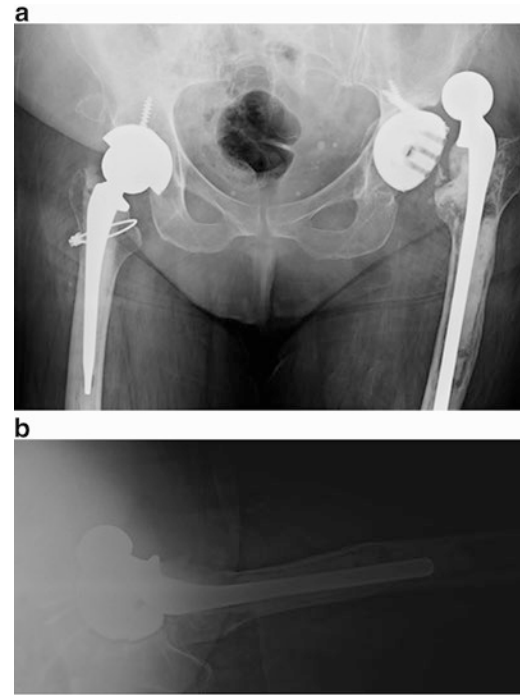

Fig. 7.2 Anteroposterior pelvis (**a**) and cross-table lateral hip (**b**) radiographs revealing a anteriorly dislocated total hip arthroplasty. The acetabular component is grossly loose and there is suspected loosening of a long-stem, cemented femoral prosthesis

Radiographic Evaluation

All patients presenting with a painful primary total hip arthroplasty should receive radiographic imaging as part of their initial evaluation. Plain radiographs, including an anteroposterior pelvis and cross-table lateral radiograph of the entire prosthesis, can prove tremendously useful in narrowing the differential diagnosis. Radiographs may clearly demonstrate subluxation or dislocation of the prosthesis, or even a periprosthetic fracture as the etiology of a patient's pain (Fig. 7.3). It is important to first understand the "normal" radiographic appearance of a THA, as this will help the surgeon recognize abnormalities that may guide them to their diagnosis.

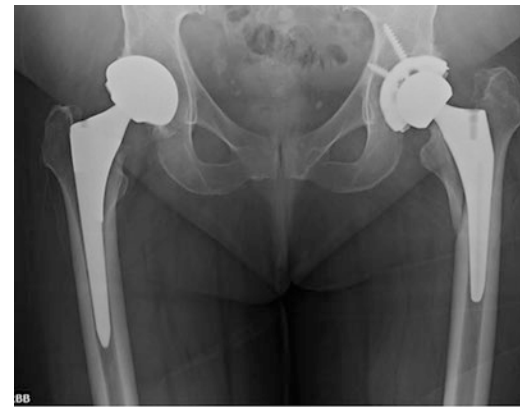

Fig. 7.3 Anteroposterior pelvis radiograph of a patient presenting with left hip pain 6 weeks following their primary THA. Radiographs demonstrate a left medial calcar fracture and femoral stem subsidence

In a primary THA, the acetabular and femoral components may be cemented or noncemented, although most commonly cementless fixation is currently utilized in the United States.

The acetabular component should be assessed for component alignment (often with a target of approximately 40° of abduction and 20° of anteversion based on surgeon preference) and appear well seated without radiolucencies at the bone-implant interface. The femoral head should sit concentrically within the acetabular component, as superior migration of the femoral head indicates polyethylene wear. When a cementless femoral component is used, the well-fixed component demonstrates bone sclerosis and trabeculae extending onto the prosthesis. In the setting of a cemented femoral component, the cement mantle should be approximately 2 mm thick circumferentially and absent of radiolucencies at the bone-cement or implant-cement interfaces.

The importance of serial radiographs in the evaluation of the painful THA cannot be understated as they may guide the physician in assessing component migration, progression of radiolucencies or osteolysis, or new cortical irregularities that may indicate impending fracture, component subsidence, or potentially infection. Whenever possible, prior radiographs should be analyzed to assess a patient's progression to their current state (Fig. 7.4). Furthermore, if a patient is suspected to have an etiology of pain not in the hip (i.e., lumbar degenerative disease), imaging of that region should be performed. Lastly, a "pre-arthroplasty" radiograph is also useful in determining if there was an appropriate indication for the index THA procedure.

Aseptic loosening of a hip prosthesis is most reliably diagnosed on sequential radiographs that demonstrate component migration or subsidence after an infectious etiology is ruled out. It is critical that radiographs are performed in a rotationally controlled, standardized fashion to avoid a misdiagnosis based on variations in image acquisition. Loosening of a cementless femoral prosthesis is suggested in the presence of radiolucencies at the bone-implant interface of approximately 2 mm surrounding the component, or progression of these radiolucencies [42]. In addition, a "pedestal" sign may be seen at the distal end of the stem, indicating endosteal new bone formation due to stress transfer distally and the bone's response to support the tip of the stem [43] (Fig. 7.5).

Loosening of a cemented femoral prosthesis is suggested in the presence of radiolucencies at the cement-bone interface of more than 2 mm surrounding the component or progression of these radiolucencies, radiolucency at the implant-cement interface, or fracture of the cement mantle [44]. Furthermore, a grossly loose cementless or cemented femoral stem will often fall into a retroverted position, which can be appreciated on sequential cross-table lateral radiographs. The diagnosis of aseptic loosening of an acetabular component is assessed in a similar fashion, with a circumferential, progressive radiolucency suggestive of component loosening.

Plain radiographs are also useful in the assessment of periprosthetic osteolysis. Osteolytic

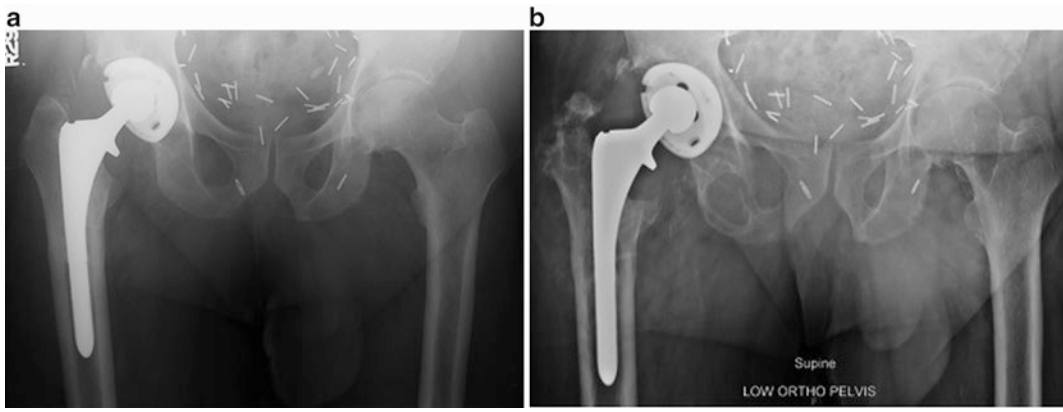

Fig. 7.4 Anteroposterior pelvis radiograph of a well-fixed, cementless THA performed in 1999 (**a**) versus the same patient in 2015 (**b**). Sequential radiographs reveal eccentric polyethylene wear and significant peritrochanteric osteolysis and bone resorption

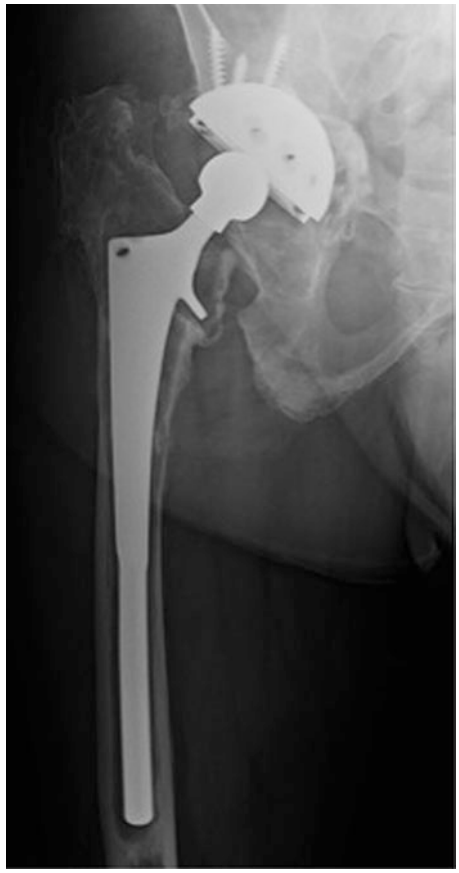

Fig. 7.5 Anteroposterior right hip radiograph demonstrating subsidence of a cementless femoral prosthesis and femoro-acetabular subluxation. The pedestal formation at the distal aspect of the femoral stem and subsidence of the calcar of the prosthesis is appreciated relative to the native anatomy, both indicating a loose femoral component

lesions are recognized as well-defined radiolucencies that can occur surrounding either the acetabular or the femoral prostheses [45, 46]. These lesions can present far from the articulating surface as hydrostatic pressure can drive joint fluid and debris around the prostheses during movement. Oblique radiographs of the pelvis (obturator and iliac oblique-Judet views) are often useful in defining the extent of osteolysis, yet they still can underestimate its true extent. Oblique radiographs are also useful in defining the integrity of the anterior and posterior columns (Fig. 7.6), but may miss subtle fractures or incongruities. A computed tomography scan is increasingly sensitive in defining the extent of osteolysis and remaining bone stock, and can be considered when evaluating a patient with significant bone loss [47].

Radiographic findings in the setting of chronic infection often include irregular radiolucencies suggestive of component loosening, bone destruction, and potentially periosteal reaction in the setting of a long-standing infection [48] (Fig. 7.7). Furthermore, a soft-tissue collection or effusion may be seen on radiographs or with more advanced imaging. A three-phase technetium bone scan can also be used to help to identify implant loosening, although this is a nonspecific test that cannot differentiate between septic an aseptic etiologies and it may demonstrate increased uptake for several years following an uncomplicated THA. Other potentially useful advanced imaging studies include an indium-labeled white blood cell scan or a positron emission tomography scan, although if there is suspicion for infection, aspiration of the hip joint sending the fluid for a synovial fluid white blood cell count with differential and culture remains the most reliable and cost-effective method of diagnosis.

Numerous advanced imaging modalities are available if plain radiographs including oblique views fail to reveal a diagnosis. Ultrasound can be used to evaluate for the presence of a joint effusion or periarticular fluid, and may also detect soft-tissue abnormalities such as iliopsoas or trochanteric bursitis. Furthermore, with increased awareness surrounding adverse local tissue reactions from bearing surface wear or corrosion, ultrasound has been shown to be a useful and cost-effective screening tool [18]. However, this modality is known to be highly user dependent.

As noted earlier, computed tomography is valuable in the evaluation of bone stock surrounding a THA, and also might reveal a fracture not visualized on plain radiography. In addition, this modality is useful in the assessment of component positioning, in particular acetabular anteversion, in the setting of hip instability. However, computed tomography is also limited by metal artifact. Magnetic resonance imaging (MRI) with metal artifact reduction sequences (MARS) can be tremendously helpful in the evaluation of soft-tissue masses,

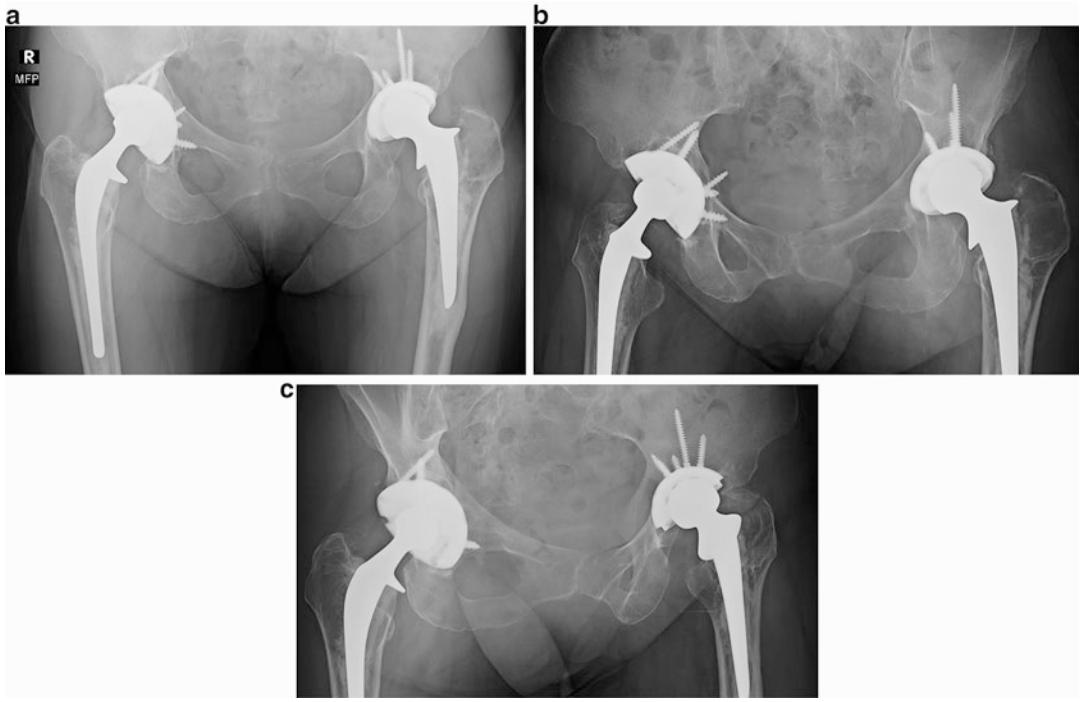

Fig. 7.6 Anteroposterior pelvis (**a**), obturator oblique (**b**), and iliac oblique (**c**) radiographs of a patient with periacetabular osteolysis and a loose, cemented femoral component. The anteroposterior view demonstrates osteolysis medially and superiorly, while the obturator and iliac oblique views demonstrate osteolysis of the anterior and posterior columns, respectively

soft-tissue injuries, infection, and adverse local tissue reactions. MRI has also been shown to be sensitive and specific in the detection of adverse local tissue reactions, though the physician must understand that the quality of images obtained may vary greatly based on the quality of the MRI utilized and the skill of the radiologist interpreting the images. Advanced imaging modalities will be discussed in further detail as tools in the diagnosis of perioperative complications in subsequent chapters of this book.

Laboratory Evaluation

Laboratory tests are an essential portion of the workup of the patient with the painful THA and include an erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) followed by selective joint aspiration if the serum markers are elevated or if clinical suspicion of infection is high. Fluid obtained is sent for a synovial fluid white blood cell count, differential, and culture. These studies together provide abundant information, especially in the setting of presumed sepsis. It is the authors' preference to obtain a minimum of an ESR and a CRP prior to undertaking a revision THA surgery, although the potential for false-positive findings can prove problematic. Additionally, if modular junction corrosion or failure of a metal on metal bearing is suspected, cobalt and chromium levels can be acquired.

The utility of ESR and CRP as indicators of infection has previously been reported [49–53]. Observing ESR and CRP rates for 1 year in 40 patients after THA, Aalto et al. noted that ESR was slightly elevated preoperatively, reached a peak on postoperative day 6, and decreased with time, though at 1 year it was still slightly elevated in most patients [49]. On the contrary, CRP was normal preoperatively, peaked by postoperative

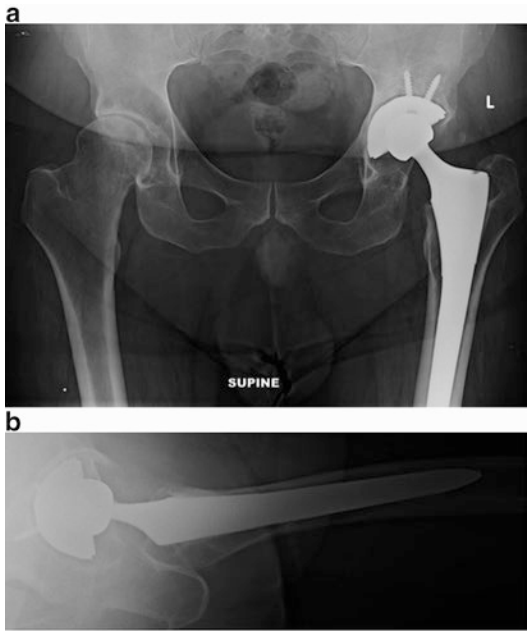

Fig. 7.7 Anteroposterior pelvis (**a**) and cross-table lateral (**b**) radiographs demonstrating a circumferential radiolucency around the acetabular component and radiolucent irregularities at the proximal femur suggestive of chronic infection. This patient was diagnosed with a periprosthetic infection based on an elevated erythrocyte sedimentation rate, C-reactive protein, and positive hip aspiration for *Propionibacterium acnes*

day 2, and on average normalized by 3 weeks after surgery [49]. Alone, the ESR has a sensitivity of 60–100% and a specificity of 65–94% in the setting of infection [50, 52, 53]. However, when combined with the CRP, accuracy in the identification of an infected THA is amplified [52, 54, 55]. Spangehl et al., in a population of 202 revision total hip arthroplasties, found that a normal ESR combined with a normal CRP has a sensitivity of 100% for excluding infection, as all infected THAs had at least one elevated inflammatory marker [52].

Because of the potential for false-positive cultures (and false negatives), routine preoperative aspiration in the setting of a painful THA is not practiced at our center. In a group of 270 aspirations obtained prior to revision THA, Barrack et al. had 13% false-positive cultures [56]. Instead, if the ESR and/or CRP are elevated, or if the patient's clinical picture is worrisome for sepsis, hip aspiration is performed by a skeletal radiologist under fluoroscopic guidance. Cutoff values to rule in infection are in alignment with the AAOS Clinical Practice Guidelines for periprosthetic joint infection, and will be discussed in further detail in subsequent chapters [57].

Summary

Despite the clinical success of total hip arthroplasty, surgeons will often be confronted with a patient who returns with a painful THA. It is essential that physicians take a systematic approach towards evaluation of these patients (Fig. 7.8). Potential etiologies of pain are vast, and include infection, component loosening, fracture, dislocation, soft-tissue impingement, bursitis, tendonitis, bearing surface wear and synovitis, hypersensitivity due to metallosis, and even implant fracture or failure. Obtaining a thorough history and physical examination is critical as it will narrow the differential diagnosis and also potentially avoid unnecessary testing. A radiographic examination should initially consist of anteroposterior pelvis and lateral imaging of the effected hip, with full visualization of the entire prosthesis. Based on the physician's differential, advanced imaging and laboratory markers can also be ordered. If an infectious etiology is suspected, inflammatory markers and potentially a hip aspiration should be performed.

While the potential etiologies of a painful THA are vast, a systematic approach will improve the likelihood of determining the diagnosis.

Case Solution

The femoral component consists of a dual-modular neck prosthesis and a cobalt-alloy femoral head. The acetabular component is in approximately 60° of abduction and 30° of anteversion as measured on anteroposterior pelvis and cross-table lateral hip radiographs, respectively (Fig. 7.1a, b). An infectious etiology was investigated using an erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), and fluo-

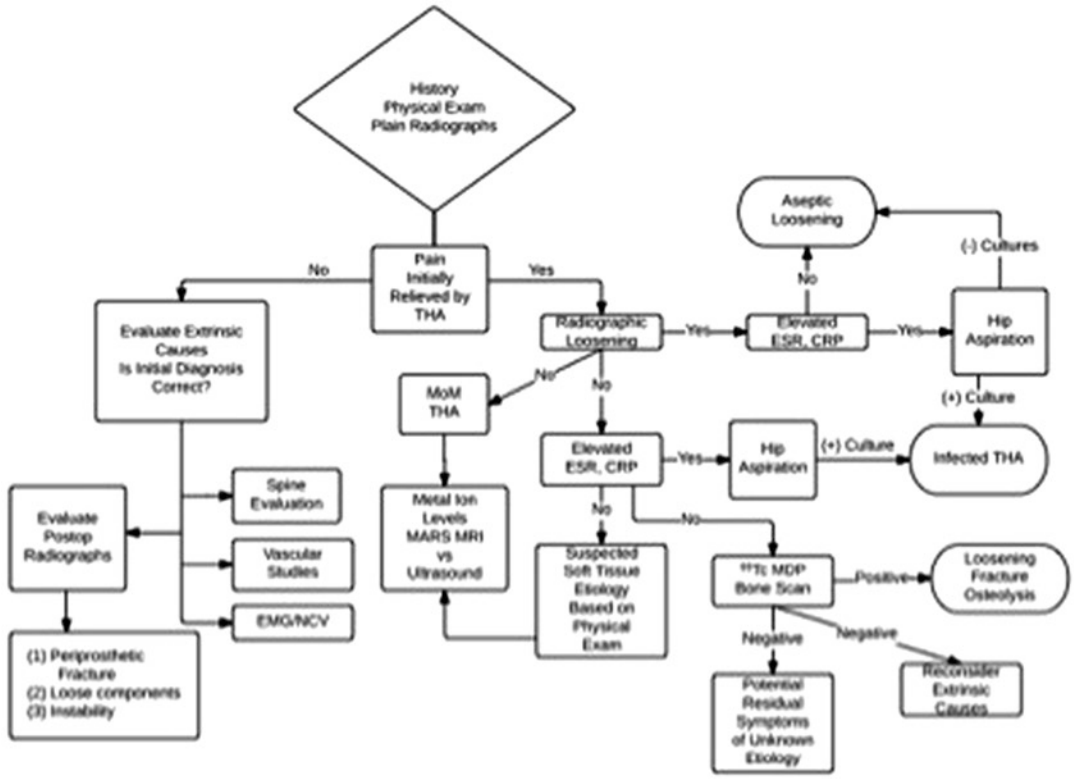

Fig. 7.8 The evaluation of pain after total hip arthroplasty

roscopic hip aspiration. The patient's ESR (5.0; normal range 0.0–25.0 mm/h), CRP (0.4; normal 0.0–9.0 mg/L), and hip aspiration (200 nucleated cells/uL, 8% neutrophils; no growth) were all normal. Cobalt and chromium levels were drawn, with the cobalt elevated at 9.2 ng/mL (normal 0.0–0.9 ng/mL) and chromium elevated at 2.2 mcg/L (normal 0.0–0.2 mcg/L). Three-dimensional imaging was performed to evaluate for the presence of an adverse local tissue reaction, but was unremarkable. Based on the patient's persistent pain the patient elected to undergo revision of her right THA to a non-modular revision femoral stem with a ceramic-on- polyethylene bearing surface for a presumed diagnosis of corrosion. In addition, despite having a well-fixed acetabular component, the acetabulum was revised due to its increased abduction angle and potential concern for anterior instability given the patient's physical examination and pain with extension, and external rotation of the lower extremity.

Intraoperatively, as expected both the femoral and acetabular components were well fixed. The capsular tissues were stained with metal debris and corrosion was present at the modular head-neck junction, but no large adverse local tissue reaction was present. The acetabular component was in significant abduction, and interestingly the prior surgeon had placed an elevated rim acetabular liner with the elevation located at the posterior-inferior location of the acetabulum, causing liner impingement in extension and external rotation. The femoral stem was revised to a non-modular, titanium, fully porous-coated femoral stem and a ceramic femoral head was used to remove potential etiologies of cobalt from the prosthesis. The acetabular component was revised using a revision titanium hemispherical shell with the goal of decreasing the abduction angle and improving stability to allow for equalization of her leg lengths (Fig. 7.9). At 1 year postoperatively, the patient reports no pain in her right groin or thigh and has resumed her baseline activities of daily living.

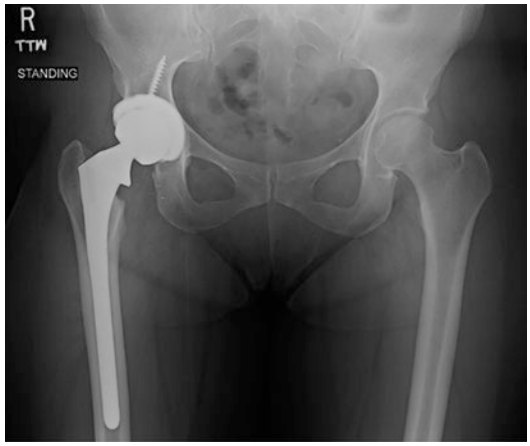

Fig. 7.9 Anteroposterior pelvis radiograph demonstrating revision of the patient's right total hip arthroplasty of both the acetabular and femoral components. Note the equalization of leg lengths

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Dislocation After Total Hip Arthroplasty

8

Glenn D. Wera, Nicholas T. Ting,
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Case Presentation

A 56-year-old male with a history of previous stroke, hepatitis C, and left hip avascular necrosis (AVN) presented for evaluation of progressive left hip pain at an outside hospital. His physical examination was remarkable for a limp, ipsilateral weakness with left upper extremity posturing, as well as a flexion and internal rotation contracture of the left hip. His radiographs showed femoral head collapse and secondary degenerative joint disease (Fig. 8.1).

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He subsequently underwent a cementless left total hip arthroplasty (THA) and did well until 1 year postoperatively when he presented with the new onset of left hip pain. Radiographs showed subluxation of the femoral head (Figs. 8.2 and 8.3). The patient underwent revision surgery and at that time the liner was found to be severely worn posterosuperiorly. The cup was revised as the locking mechanism was damaged and a 36 mm femoral head was used; an abduction brace was used postoperatively (Fig. 8.4).

Two weeks after the revision the patient dislocated posteriorly (Fig. 8.5). He was treated with another revision using an unconstrained tripolar construct (Fig. 8.6). Eighteen days later, he again dislocated posteriorly and was revised once again to a constrained liner (Fig. 8.7). Four months later he dislocated yet again (Fig. 8.8a, b) and was referred to one of us (GDW) for further evaluation and management.

Epidemiology

Instability is a leading cause of failure of total hip arthroplasties [1]. A review of the Nationwide Inpatient Sample (NIS) that evaluated 235,857 revision THAs between October 1, 2005, and December 31, 2010, showed that instability is the leading cause of revision at 22% [2]. Additionally, US Medicare data suggest an overall 3.9% dislocation rate after total

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_8

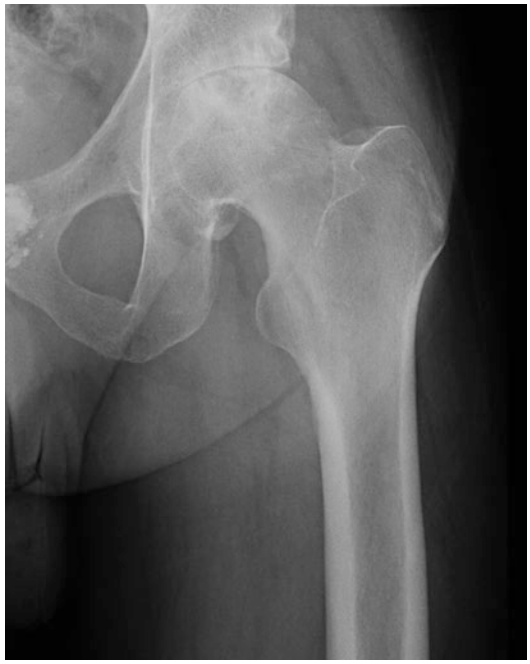

Fig. 8.1 Preoperative AP hip demonstrating left hip AVN with secondary degenerative changes prior to undergoing total hip arthroplasty

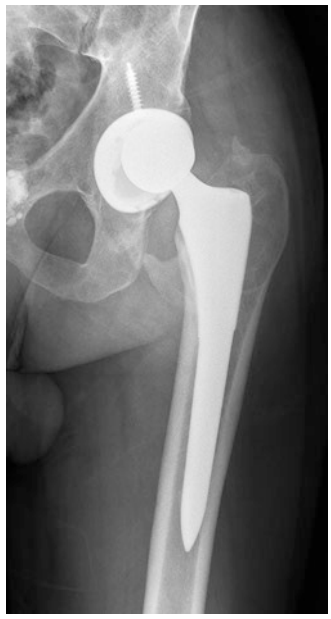

Fig. 8.2 AP hip demonstrating subluxation of the femoral head

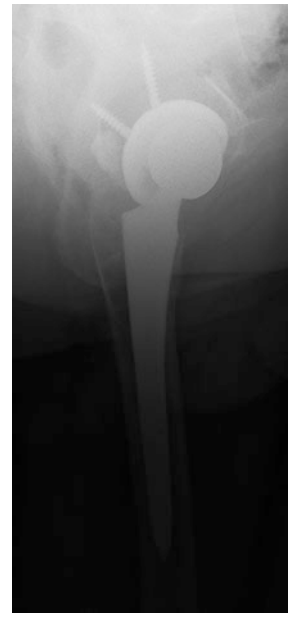

Fig. 8.3 Shoot through lateral hip suggesting subluxation of the femoral head

hip arthroplasty [3]. When we consider that 332,000 THAs were performed in 2010 in the United States, the need for an understanding of the etiology and corresponding treatment of the unstable total hip arthroplasty is clear.

Risk Factors for Dislocation

Classically, patient factors such as neurologic and psychological disorders, prior hip surgery, and noncompliance all increase the risk of dislocation after THA. Similarly, post-traumatic arthritis is associated with a higher risk of dislocation than primary THA for osteoarthritis [4]. Obesity has been linked to both a biomechanical predisposition to instability and higher readmission rates after primary THA [5, 6]. Likewise, alcohol abuse has been associated with higher general complication rates, including instability, after total hip arthroplasty [7]. Advanced age and an initial diagnosis of avascular necrosis are also associated with dislocation after primary THA [8].

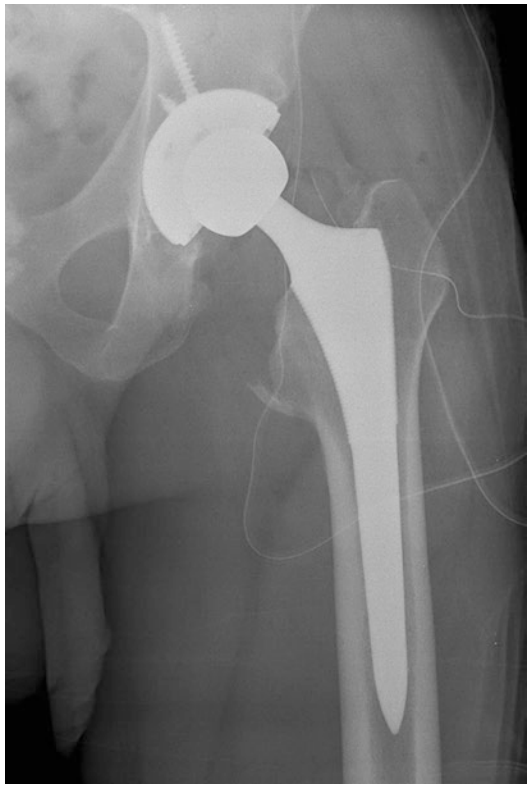

Fig. 8.4 AP hip after revision of the acetabular component

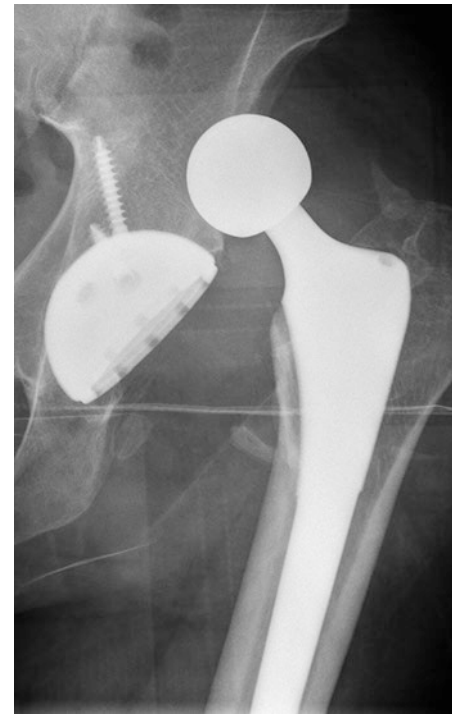

Fig. 8.5 AP hip demonstrating a posterior dislocation

Primary THA performed for an acute femoral neck fracture is another high-risk group with respect to instability risk [9]. The higher risk of dislocation in patients with an acute femoral neck fracture probably relates in part to having in most cases a relatively normal hip preoperatively with high range of motion, which has been shown to be a risk factor for dislocation in patients with degenerative joint disease as well [10]. Technical factors such as surgical approach, soft-tissue tension and offset, component positioning, impingement, femoral head diameter, acetabular liner profile, and surgeon experience likewise all effect the risk of dislocation [11, 12].

Revision THA carries a substantially higher risk of dislocation than primary surgery. Dislocation rates after revision THA are frequently reported to approach 10% with a history of prior dislocation, abductor deficiency, and higher Paprosky acetabular bone defects all increasing the risk [13].

Prevention

Avoidance of dislocation is one of the most important technical considerations of both primary and revision total hip arthroplasty. Surgical approach has been shown to influence dislocations rates as well. Some data suggest that anterior and anterolateral approaches are associated with lower initial dislocation rates after total hip arthroplasty [14]. However, additional complications such as fracture and sensory defects after anterior approach total hip arthroplasty may negate the stability benefit [15]. The posterior approach has been implicated in higher dislocation rates than lateral approaches but diligent repair of the short external rotators and capsule can minimize instability risk [16, 17]. Therefore, conclusive evidence that one approach is superior is not evident [18].

Femoral head size and component positions are critical components to stability. Larger femoral heads have demonstrated lower initial dislocation rates after primary total hip arthroplasty,

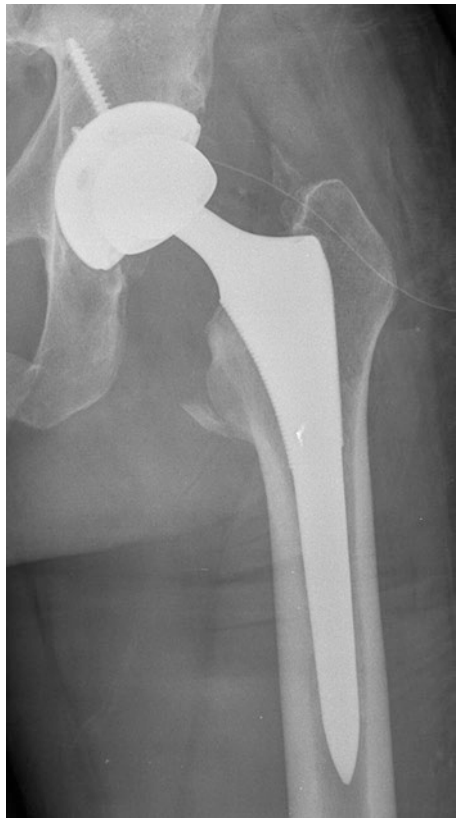

Fig. 8.6 AP hip after revision to an unconstrained tripolar construct

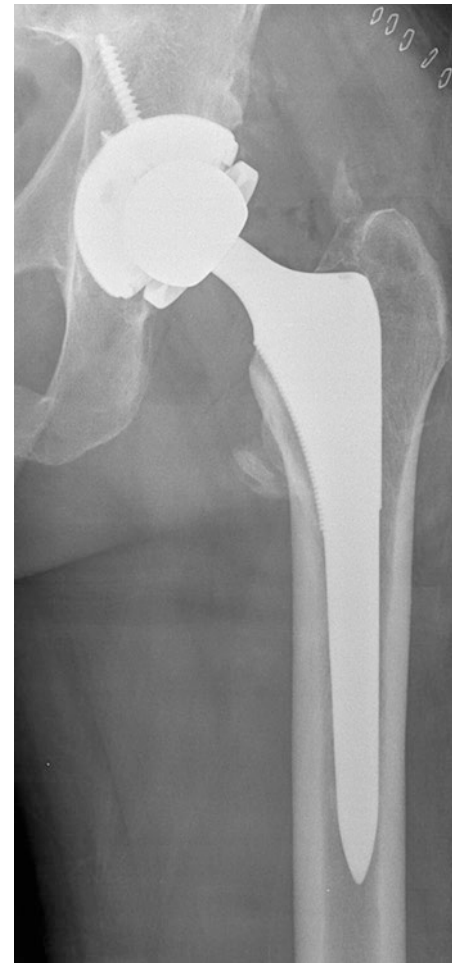

Fig. 8.7 AP hip after revision to a modular constrained liner

particularly in high-risk patients [19, 20]. Appropriate implant position has been advocated to avoid dislocation and early wear of components. Lewinnek et al. described an optimal acetabular position of 15 ± 10° anteversion and lateral opening of 40 ± 10° because dislocation rates were higher outside the "safe range" [21]. However, contemporary studies have demonstrated that dislocation rates after THA are low at about 2% with more than half of the dislocations occurring in cases with acetabular orientation within the safe zone [22]. Therefore, component positioning itself is probably just one factor that lowers the risk of dislocation and careful intraoperative trialing is important to lower the risk of instability.

One of the key steps a surgeon can take to reduce the risk of dislocation is to identify patients who are at high risk as outlined above and take measures in those specific cases to reduce the risk. Surgeons for example may consider using a larger head size in a patient with known risk factors. Another recent option is the use of dual-mobility bearings (Fig. 8.9). These constructs include a mobile polyethylene insert that yields a large jump distance that resists dislocation. While these bearings have their own risks, including that of intra-prosthetic dislocation, they have been advocated by some surgeons as an alternative in patients who are known to be a high risk for instability [20].

Diagnosis

The diagnosis of prosthetic hip dislocation after total hip arthroplasty is usually made by plain radiographs, history, and physical examination.

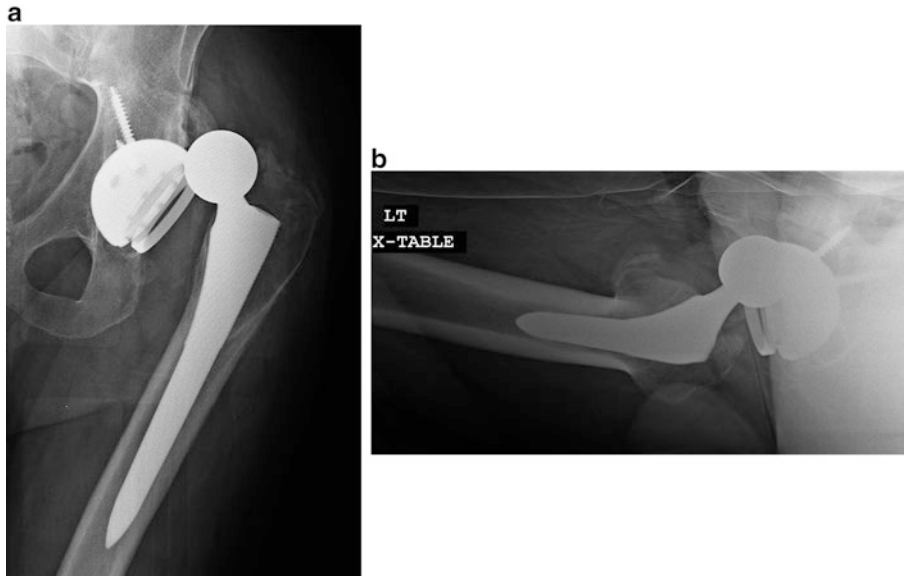

Fig. 8.8 AP hip (**a**) and lateral (**b**) demonstrating dislocation of the constrained liner

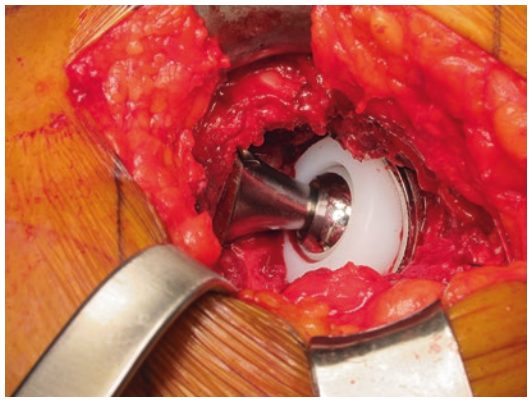

Fig. 8.9 Operative photograph of a dual-mobility construct featuring a mobile polyethylene insert that yields a large jump distance that resists dislocation

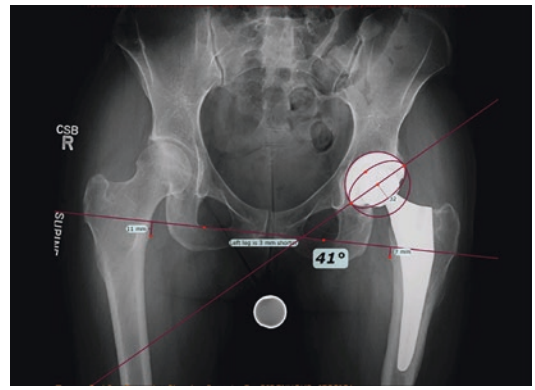

Fig. 8.10 AP pelvis demonstrating determination of cup abduction to be 41° and within the safe zone of Lewinnek. Multiple reference lines are acceptable including a trans-ischial line, trans-tear drop, or trans-obturator foramen line as depicted here

The patient will typically present with a shortened limb and external rotation with anterior instability or internal rotation with a posterior dislocation; confirmation of the direction of instability can be made with a shoot through lateral and is important to determine appropriate treatment.

Given the importance of component position on hip stability, a clear sense of the anteversion of the presently implanted components is critical to planning appropriate treatment as is an assessment of femoral offset and leg length; all of these factors are intimately connected when determining the overall stability of the hip construct. While plain radiographs can be used to assess component position (Figs. 8.10 and 8.11), we have found preoperative CT to be a more precise assessment tool. In order to accurately determine acetabular component anteversion, a CT of the entire pelvis (not just of the ipsilateral hip) is required. Further, in order to accurately determine femoral component anteversion, the CT must include a cut through the ipsilateral epicondylar axis of the knee (Fig. 8.12).

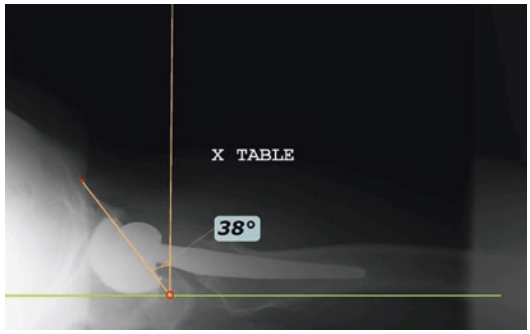

Fig. 8.11 Cross-table lateral view demonstrating 38° of anteversion with respect to the horizontal film edge as originally described by Woo and Morrey [23]

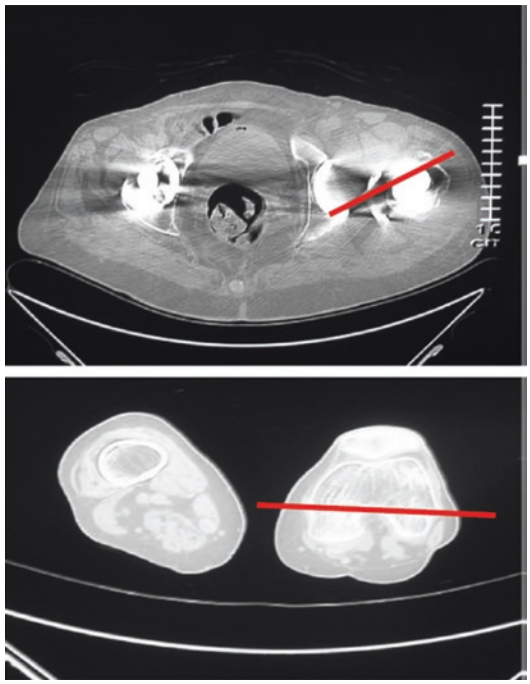

Fig. 8.12 Combined CT scan of the femoral neck and ipsilateral trans-epicondylar axis for determining femoral component anteversion. It demonstrates retroversion of the femoral prosthesis. Wera GD, Ting NT, Moric M, Sporer SM, Jacobs JJ, Paprosky WG, Della Valle CJ. The Causes and Management of Hip Instability: An algorithmic approach. Seminars in Arthroplasty 2015;26(3)131–135. *Reproduced with permission from Elsevier Ltd.*

Other factors that are important to consider when evaluating the patient who has dislocated include the patient's perception of their leg length. Further, an assessment of abductor muscle strength is critical to perform, given the influence of the abductor musculature on hip stability. Finally, prior to any revision procedure, an evaluation for periprosthetic joint infection with a serum ESR and CRP, followed by an aspiration of the joint if these labs are elevated or if the clinical suspicion for infection is high, should be performed [24].

Treatment

Nonoperative treatment of the dislocated THA includes prompt closed reduction, followed by in some cases the use of a knee immobilizer (our preference based on cost) or a hip abduction orthosis, and most studies suggest that this strategy will be successful in approximately one-half to two-thirds of patients who dislocate. In a retrospective review of first-time and recurrent dislocators following THA, Dewal et al. found that abduction bracing after closed reduction of THA dislocation is ineffective in preventing re-dislocation [25]. Likewise, Murray et al. found no significant difference in the 90-day dislocation rate among patients who wore a brace compared with the non-braced group following revision THA [26].

If the instability has become recurrent, our philosophy is to identify and treat the underlying etiology of the instability. Prosthetic hip dislocation can be classified according to the primary cause of instability including (1) acetabular component malposition, (2) femoral component malposition, (3) abductor muscle deficiency, (4) soft-tissue or bony impingement, (5) late wear of a polyethylene liner, and (6) unclear etiology (Table 8.1) [27]. In our experience, identification and treatment of the primary cause of instability are associated with a success rate of 85%.

Type I Acetabular Component Malposition

The appropriate orientation or "safe zone" of the acetabular component was described classically by Lewinnek as 40° of abduction and 15° of anteversion [21]. However, the idea that a single

Table 8.1 Classification system for the unstable THA

Type	Acetabular component orientation	Femoral component orientation	Abductor-trochanteric complex	Impingement	Late wear	Intervention
I	Incorrect	Correct	Intact	Absent	Absent	Acetabular component revision
II	Correct	Incorrect	Intact	Absent	Absent	Femoral component revision
III	Correct	Correct	Absent	Absent	Absent	Constrained liner
IV	Correct	Correct	Intact	Present	Absent	1. Remove sources of impingement 2. Upsize modular head and liner
V	Correct	Correct	Intact	Absent	Present	1. Modular component exchange 2. Upsize modular head and liner
VI	Correct	Correct	Intact	Absent	Absent	Constrained liner

Wera GD, Ting NT, Moric M, Paprosky WG, Sporer SM, Della Valle CJ. Classification and management of the unstable total hip arthroplasty. J Arthroplasty. 2012 May;27(5):710–15. *Adapted with permission from Elsevier*

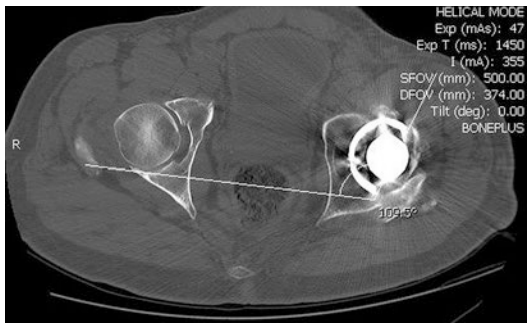

Fig. 8.13 CT scan of the pelvis of a patient demonstrating 19.5° of acetabular retroversion

safe zone exists has been questioned recently because up to 58% of dislocated hips occur in patients whose acetabular component is within the safe zone [22]. Nevertheless, the position of implants in cases of unstable total hip arthroplasties should be determined. In cases where the hip is unstable and the shell is clearly malpositioned (retroversion is most common), revision of the acetabular component and placing it in the appropriate anteversion will likely correct the problem. In general, at this time we also maximize femoral head size given its protective effect against dislocation; we also consider the use of dual-mobility bearings in this population. Acetabular component malposition is a leading cause of instability after total hip arthroplasty [27]. Both plain radiographs and CT scans may be utilized to verify implant position (Figs. 8.12 and 8.13) [28].

Type II Femoral Component Malposition

The incidence of femoral component malposition as the etiology of a dislocating hip prosthesis is low, with one small series suggesting a rate of 8% [27]. Interestingly, radiographic determination of femoral component anteversion can be a challenge on plain radiographs and improving this method is a current topic of research [29]. We advocate a CT scan in which the transepicondylar axis of the femur is included along with the neck of the femoral stem (Fig. 8.12). Treatment consists of revision of the femoral component which is much more challenging in most cases than revision of the acetabular component and hence the surgeon should have a clear plan preoperatively for removal of what is typically a well-fixed but inappropriately positioned stem. As with all revisions for instability, all aspects of the reconstruction must be optimized and we typically maximize femoral head size at the time of revision and once again consider the use of a dual-mobility bearing.

Type III Abductor Insufficiency

The abductor mechanism is composed primarily of the gluteus medius and minimus as well as the greater trochanter. Deficiency can arise from multiple surgical exposures, neurologic problems, greater trochanter nonunion, or superior gluteal

nerve injury. In cases of revision total hip arthroplasty abductor insufficiency in one series was the second leading risk factor for instability after prior hip dislocation [13]. In the setting of appropriate implant orientation abductor deficiency is a strong indication for a constrained liner as large heads alone are associated with a high failure rate, with some authors recently suggesting a dual-mobility bearing as a potential alternative [30]. However, limited durability and high failure rates are associated with constrained liners after total hip arthroplasty [31]. In cases of poor bone stock or tenuous cup fixation such as Paprosky IIIb acetabulae, constrained liners are problematic due to risk of shell loosening or catastrophic pullout of the prosthesis. In such cases, an initial dual mobility or unconstrained tripolar that can be converted to a constrained liner in a subsequent reconstruction is an attractive alternative. Soft-tissue reconstruction in an effort to restore the abductor such as muscle transfer has been reported in the literature; however our own experience with these techniques has been mixed [32, 33]. Likewise, various allograft reconstructions have been attempted with mixed results, especially with respect to gait [34]. This is a challenging group of patients and thorough preoperative education is required, as in our experience, the rate of failure and recurrent dislocation is clearly highest in this group of patients.

Type IV Impingement

Impingement is another major cause of instability after total hip arthroplasty with a prevalence of 9% in one series [27]. Sources of impingement may stem from bone, soft tissue, or prostheses [35]. Inadequate head-to-neck ratios, length, or offset may all contribute to impingement. In these cases we recommend removing sources of impingement and utilizing a larger femoral head.

Type V Late Wear of a Polyethylene Liner

Late dislocation can present many years following a previously well-functioning total hip arthroplasty [36]. As the liner wears there is a corresponding soft-tissue laxity that may have a permissive effect on dislocation [37]. Current research has hypothesized that wear-related particles may cause inflammation and muscle damage around the hip prosthesis, which may exacerbate soft-tissue laxity, and contribute to further overall instability. Some have suggested that ceramic-on-ceramic bearings may produce less of this effect and be an additional benefit of this bearing couple [38]. Treatment is a modular exchange of the bearing surface, once again maximizing femoral head size, while ensuring that the position of the cup and stem is acceptable; the surgeon should have a low threshold to revise particularly the cup if anteversion is not within an acceptable range.

Type VI Indeterminate Etiology

The unstable total hip arthroplasty that has appropriate component orientation, an intact abductor mechanism, no evidence of impingement, and lack of causative polyethylene wear is unstable for indeterminate reasons. In these difficult cases, a constrained liner is the indicated, albeit imperfect, solution with a dual-mobility bearing being a second alternative. Re-dislocation rates are high in this setting, with an odds ratio as high as 7.6 compared to other etiologies of instability [27].

Literature Review

The efficacy of revision total hip arthroplasty for instability in the literature is variable. As described earlier, we believe that a search for the primary cause of instability is the key to good results, and the variability of prior series may relate to blanket solutions without correcting the primary problem. Further, it is critical to keep in mind that all aspects of the reconstruction must be optimized to realize a low rate of recurrent failure.

An isolated exchange of modular components is an attractive option given its simplicity and low morbidity and registry data suggests that this is the most common strategy implemented in revision of the unstable THA [39]. However particularly variable results have been reported in the

literature, highlighting the critical importance of thorough preoperative planning and evaluation, to ensure that component position is acceptable as is soft-tissue balance of the hip. In one series 12 of 13 patients treated for recurrent instability were treated successfully with modular component exchange [40]. Similarly, Lachiewicz et al. reviewed 23 revisions for recurrent dislocation of modular total hip arthroplasty (THA) with retention of components; of these, there were 17 primary and 6 revision THAs. They found a dislocation rate of 18% at a mean follow-up of 4 years in the former group and a dislocation rate of 50% at a mean follow-up of 3 years in the latter [41]. Hence, if this strategy is planned, careful intraoperative trialing is mandatory as is a low threshold for revision of components that are not in optimal position.

As discussed above, a large femoral head maximizes head/neck ratio and increases the jump distance, and their use in the treatment of the unstable THA is integral in our experience. Highly cross-linked polyethylene has enabled increased femoral head size without a clinical meaningful increase in wear [42]. Further, in their recent retrieval study of 154 metal-on-polyethylene THAs, Triantafyllopoulos et al. showed that larger diameter heads do not necessarily increase the risk of fretting and corrosion at the head/neck taper [43], although this may be design dependent. Many authors have described favorable outcomes with the use of a large femoral head for the treatment of instability; however, most reports include a combination of treatments, oftentimes in combination with repositioning of the components [12, 42]. It is important to recognize, however, that large heads in and of themselves are oftentimes not adequate in the setting of abductor-deficient hips [44].

In the setting of recurrent instability secondary to neurologic impairment, abductor insufficiency, and frail patients with well-fixed components, constrained acetabular liners remain a common yet controversial treatment option. Constrained liners are considered a salvage operation used in only the most recalcitrant instability cases in which components and soft-tissue balancing have been optimized. Constrained liners can lead to accelerate wear or acetabular component loosening secondary to increased forces at the prosthetic interfaces; they have also been shown to decrease range of motion [45, 46]. Outcomes associated with the use of constrained liners in revision THA have been mixed, with dislocation rates ranging from 2.4 to 29% [47, 48]. Some of this is design dependent, with varying designs associated with variable success rates. Recently we have used dual-mobility bearings in many cases where in the past a constrained liner would have been used, and at short-term follow-up, the failure rate appears to be lower. Further study in this area will be needed to determine the efficacy of these bearings in these extreme situations.

Dual-mobility constructs have gained popularity due to their favorable head-to-neck ratio and resistance to dislocation. Like other large-diameter options, dislocation rates are low compared to head diameters below 36 mm [49]. Early results of THAs deemed to be at high risk for dislocation have been promising [50]. Additionally, dual-mobility bearings may be appropriate in cases where a constrained liner would have been used, including cases of abductor insufficiency. At short-term follow-up, the failure rate in our experience and in the literature appears to be low. In their review of 228 patients from the Swedish Hip Arthroplasty Registry revised for chronic instability, Hailer et al. reported a 2% re-revision rate for recurrent dislocation at a mean follow-up of 2 years and a survivorship of 99% at 2 years when re-revision for recurrent dislocation was considered the endpoint [51]. Likewise, in their series of 180 THAs revised to dual-mobility cups for recurrent instability, Mertl et al. reported a 4.8% one-time re-dislocation rate and a 1.4% recurrent re-dislocation rate following revision [52]. However, dual-mobility bearings do have potential problems, including the risk of intra-prosthetic dislocation and concerns regarding wear at the two interfaces [49, 53]. Further study in this area will be needed to determine the efficacy of these bearings and their long-term survivorship.

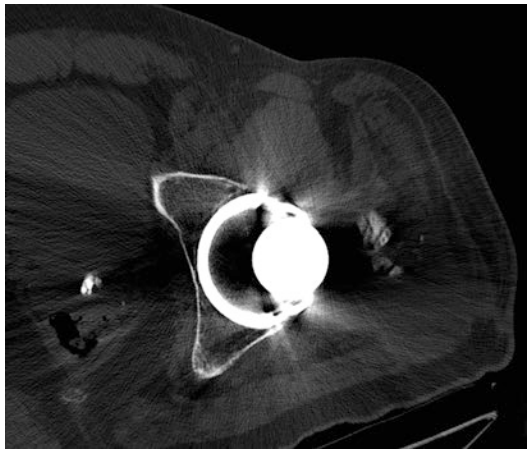

Fig. 8.14 CT scan of the pelvis of the patient prior to final revision. The acetabular component does not demonstrate adequate anteversion

Case Solution

In the case presented, the patient had a number of risk factors for instability, including a prior stroke with residual weakness of the extremity and an initial diagnosis of AVN. However, the plain radiographs (Fig. 8.7) and a subsequent CT (Fig. 8.14) suggested inadequate anteversion of the acetabular component (type 1 instability). Intraoperative findings were consistent with neutral acetabular component version, and appropriate femoral stem anteversion. The acetabular component was removed and a new acetabular shell placed in increased anteversion. The hip was trialed with the largest head size available for the cup and stem (44 mm) and the hip was stable throughout a range of motion. The patient has had no further dislocations (Fig. 8.15).

Summary

Management of the unstable total hip arthroplasty can be challenging. However, by identifying and correcting the primary cause of instability, the revision surgeon can provide the patient with the best chance of having a stable THA.

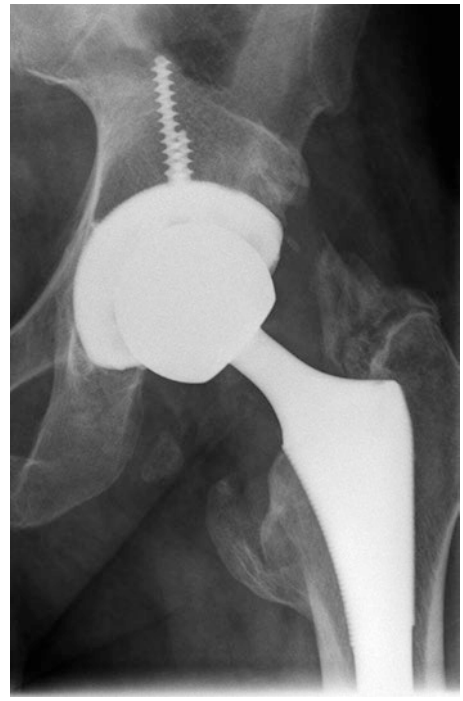

Fig. 8.15 AP hip 9 months after the last revision demonstrating satisfactory position of components and no evidence of dislocation

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9 Prevention and Treatment of Limb-Length Discrepancy in Total Hip Arthroplasty

Peter K. Sculco and Thomas P. Sculco

Case Presentation

A 72-year-old female presented with severe right-hip osteoarthritis refractory to conservative management. She is status post a left total hip arthroplasty 6 years ago and complains of a postoperative leg-length discrepancy with her left leg longer than her right (Fig. 9.1). She also complains of persistent low back pain and has a history of a lumbar fusion without neurologic symptoms. She does not wear a shoe lift but also does not feel even when she stands. She is indicated for a right total hip arthroplasty and would like her leg-length inequality to be addressed at the time of surgery.

Epidemiology

The incidence of limb-length discrepancy (LLD) after total hip arthroplasty (THA) ranges between 1% and 30% depending on the criteria for what constitutes a LLD [1–4]. While some studies have reported minimal functional consequences with a LLD of up to 2 cm, other studies have found that leg length differences greater than 5 mm to be associated with decreased patient satisfaction [5–8]. Beard et al. [6] found that patients with LLD > 10 mm had significantly worse Oxford hip scores and Mancuso and Sculco [9] found LLD to be an independent risk factor for worse clinical outcome after THA. Symptomatic LLD can result in a limp, low back pain, compensatory pelvic obliquity, increased energy consumption during gait, and nerve palsy [8, 10–12]. These functional limitations, combined with patient dissatisfaction, make leg-length problems the most common cause for litigation after THA [3, 8, 13]. For all of these reasons, achieving limb-length equality during THA is important and discrepancies should be minimized. However, achieving equal limb lengths is not always feasible. For example, if the operative leg is longer preoperatively, substantial shortening at the time of THA can lead to instability. The contralateral limb may have been shortened secondary to previous trauma, infection, skeletal dysplasia, or growth plate arrest. Conversely, the operative leg typically cannot be lengthened greater than 2.5–4 cm due to the risk of sciatic nerve injury [8]. Preoperative patient education is essential in these situations to modify postoperative expectations, so the patient is prepared for a residual LLD after THA.

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_9

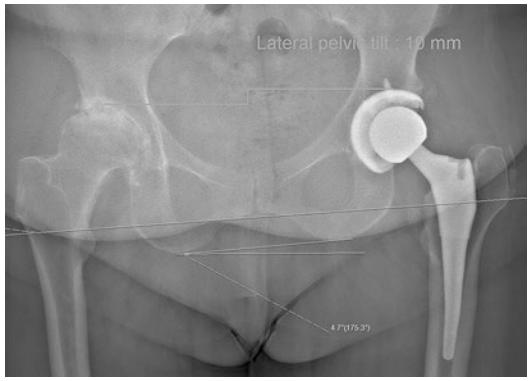

Fig. 9.1 Standing anteroposterior (AP) EOS (Paris, France) dual-planar radiograph demonstrating an uncemented left THA as well as severe right-hip osteoarthritis. Line drawn from the inferior obturator foramen to the lesser trochanter of each femur demonstrates a significant LLD of 1.4 cm in addition to a compensatory pelvic obliquity

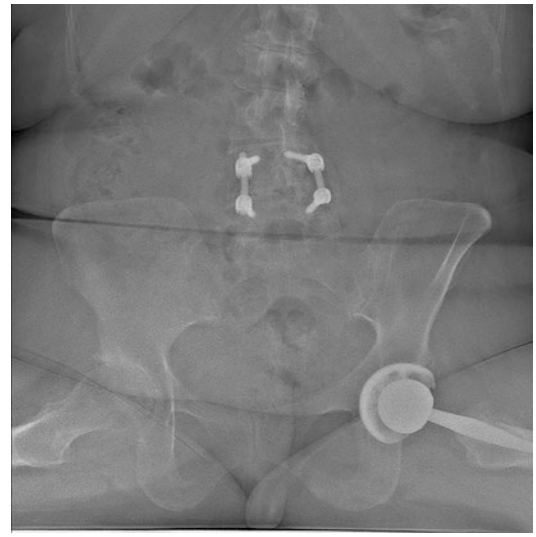

Fig. 9.2 Seated AP EOS preoperative radiographs demonstrate resolution of pelvic obliquity in the seated position confirming that the pelvic obliquity is flexible

Prevention

The preoperative patient history and physical exam should identify any extra-articular sources of LLD such as congenital lower extremity limb deformities, childhood growth plate arrest, trauma, infection, and any previous surgery. The history should also include the patient's subjective perception of limb-length inequality and use of a shoe lift on the operative or contralateral side. A tape measure can be used to determine true (structural) and apparent (functional) LLD. The true, or structural, length of the limb is measured from the anterior superior iliac spine to the medial malleolus. The apparent, or functional, LLD is a combination of the structural difference in limb lengths in addition to any changes in pelvic position or soft-tissue contractures that affect the position of the limb. The functional LLD is measured on each limb from the umbilicus to the ipsilateral medial malleolus. Any patient perception of leg-length inequality should be quantified with block testing in which blocks of varying heights are placed below the shorter limb until the patient feels equal limb lengths. Any soft-tissue contractures around the hip and knee should be identified as this leads to a functional limb-length discrepancy.

In addition the patient and radiographs should be assessed for the presence of a pelvic obliquity. A pelvic obliquity may be primary or secondary depending on the source. A primary pelvic obliquity originates from spinal pathology, such as scoliosis in the lumbosacral spine or prior lumbosacral fusion. A secondary (or compensatory) pelvic obliquity is due to structural limb-length differences or soft-tissue contractures that result in a functional LLD. The pelvis compensates for this by tilting superiorly or inferiorly in order for both feet to be in contact with the ground. Most secondary (or compensatory) pelvic obliquities are flexible and will naturally correct once the soft-tissue contracture or structural limb-length discrepancy has been addressed. Patients with a primary pelvic obliquity more often have a fixed pelvic obliquity. The way to differentiate between a fixed or flexible pelvic obliquity is to evaluate the patient in the standing and seated position [14]. A flexible pelvic obliquity will correct (as assessed by the location of the iliac crests) in the seated position. Radiographs of the patient in the case example demonstrate a change in pelvic obliquity from the standing to seated position. With a history of lumbar fusion, it is unclear whether or not this was a fixed or flexible pelvic obliquity. EOS radiograph taken in the seated position (Fig. 9.2) demonstrates radiographic

equalization of the iliac crests and confirms that the patient has a flexible pelvic obliquity that is compensatory and offsets the 1.4 cm limb-length discrepancy. Whether a pelvic obliquity is flexible or fixed affects preoperative templating and planned final limb position. A flexible obliquity should correct after surgery and does not have to be taken into consideration. A fixed obliquity will not correct and must be incorporated into the preoperative plan. In the case example, since the pelvic obliquity was confirmed to be compensatory and flexible, the right leg underwent planned lengthening to create leg-length equalization with the assumption that the pelvic obliquity would correct over time.

The radiographic evaluation of LLD prior to THA is critical to create a preoperative plan that will adequately restore limb length at the time of surgery. Limb-length differences can be measured on the AP pelvis radiograph by choosing two symmetric points on the pelvis (either the acetabular tear drop, the inferior or superior obturator, or the inferior aspect of the ischium) and two fixed reference points on each femur (most commonly the most medial or apex of the lesser trochanter) [15]. The difference between these two measurements reflects the estimated intra-articular LLD between the two limbs. In the majority of patients undergoing THA, the operative limb is a 2–3 mm shorter secondary to intra-articular cartilage loss and corrects when the native femoral head and acetabular center or rotation are restored after component placement.

Preoperative templating allows for estimation of implant size and expected component position in relation to anatomic landmarks. The projected leg lengthening at the time of surgery is equal to the difference between the projected acetabular center or rotation and the femoral head center of rotation [16]. The inferomedial aspect of the acetabular component is usually at the level of the acetabular teardrop or slightly inferior. The acetabular component should be positioned within the superior acetabular dome to the depth of subchondral bone. Next, the center of rotation of the femoral head should be marked. The femoral component that matches the proximal femoral size and shape while restoring the femoral center of rotation is selected and the location of the femoral neck osteotomy marked and measured in relation to the lesser trochanter. Figure 9.3 demonstrates the preoperative template of a patient with an 3 mm intra-articular LLD secondary to cartilage wear. With a systematic approach to preoperative templating and intraoperative execution the leg lengths can be reliably restored (Fig. 9.4). In regard to the accuracy of achieving limb-length

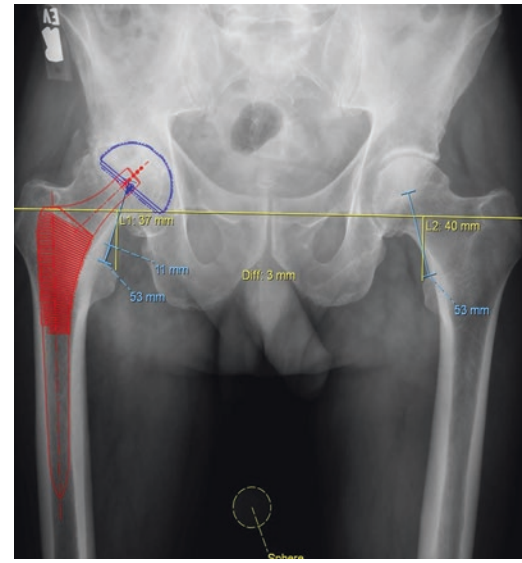

Fig. 9.3 Preoperative template for a patient with a 3 mm LLD secondary to right-hip intra-articular cartilage loss

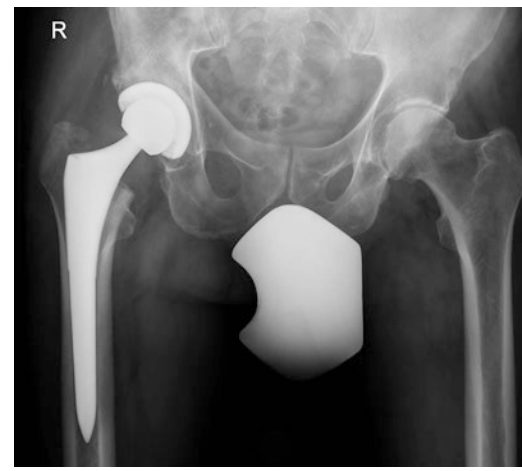

Fig. 9.4 Postoperative standing AP pelvis radiograph demonstrating accurate restoration of limb lengths and offset in accordance with the preoperative template

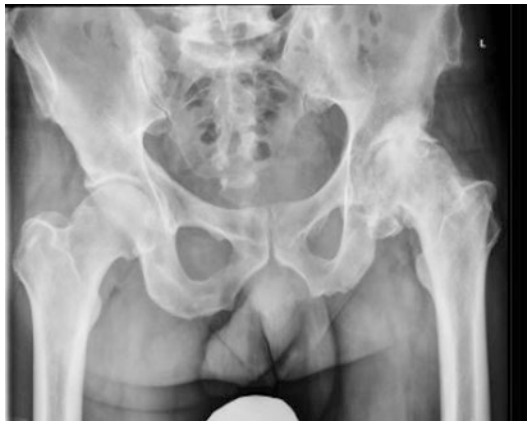

Fig. 9.5 Preoperative standing AP radiograph of a 47-year-old male with severe left-hip osteoarthritis in addition to a left-hip flexion and external rotation contracture. Preoperative templating could not be performed on the left hip as the vertical neck length and femoral offset cannot be accurately estimated due to soft-tissue contractures

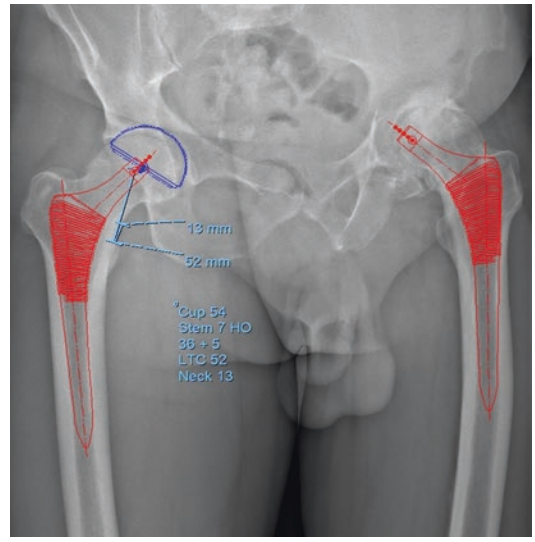

Fig. 9.6 Preoperative template performed on the normal contralateral hip allowing for accurate assessment of femoral and acetabular component placement, lesser trochanter to femoral head center distance, and location of femoral neck osteotomy. A high-offset femoral stem is required to restore normal femoral anatomy. Template overlaid on left hip demonstrates decreased projected femoral offset due to external rotation contracture

equality, Woolson et al. [17] used preoperative templating to determine the level of neck resection and reported that LLD was less than 6 mm in 86 and 97% within 10 mm after THA.

Occasionally, significant femoral head bone loss, or severe flexion and/or external rotation contracture, can make it difficult to accurately template and measure limb-length differences and lesser trochanter to center (LTC) distances. Figure 9.5 shows an AP pelvic radiograph of a 47-year-old male with severe left-hip osteoarthritis with a 20° flexion contracture and 30° external rotation contracture (Fig. 9.5). A flexion contracture will reduce the LTC measurement, while an external rotation contracture will underestimate true femoral offset (Fig. 9.6). In these cases, the contralateral hip can be used as a guide for appropriate templating (Fig. 9.6). When bilateral soft-tissue contractures or bony deformities exist, a computerized tomography (CT) scanogram or dual-planar radiographs can be utilized to obtain a more accurate assessment of limb length (Figs. 9.7 and 9.8). Utilization of the contralateral leg for limb-length measurements allowed for accurate limb-length restoration in this patient with resolution of his functional limb-length discrepancy (Fig. 9.9).

Utilizing the lesser trochanter to femoral head center is an accurate means to recreate the femoral head center of rotation but does not take into consideration the location of the acetabular component. The methods to assess cumulative changes in limb position that account for both acetabular and femoral component positions require the use of intraoperative markers on both the femur and pelvis. Commonly a Steinmann pin is placed into the ischium and a second pin is placed into the greater trochanter prior to hip dislocation. This distance is measured, the trial components are placed, and the hip is reduced and the distance between the two pins measured to calculate the change in limb length. Several measurement calipers have been designed to achieve this basic measurement method [6, 18–21]. The accuracy of this measurement is dependent on reproducing the same leg position for both measurements (before and after trial component implantation) as small changes in hip flexion of adduction will result in inaccurate measurements [22]. The other options for assessing both acetabular and femoral component position and overall limb length at the

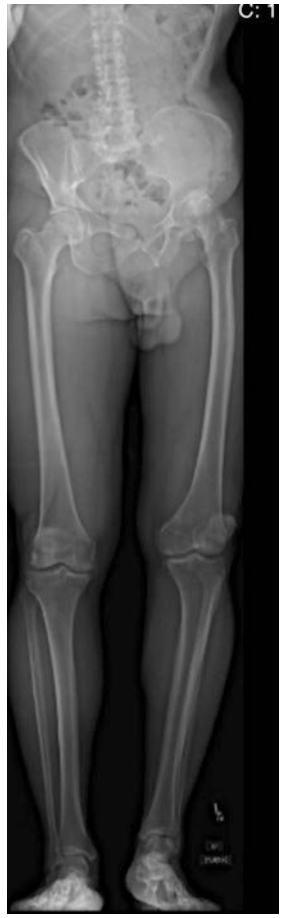

Fig. 9.7 Standing AP EOS demonstrating severe flexion and external rotation contracture resulting in a functional leg-length discrepancy. With this biplanar contracture the pelvis is unable to compensate with tilt of the hemi-pelvis. Without compensatory pelvic tilt, he has a functional LLD and stands with his left heel off the ground

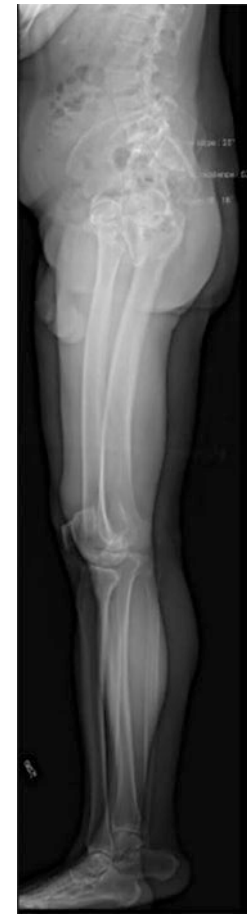

Fig. 9.8 Lateral standing EOS radiograph can be used to measure the length of each limb and without the shortening effect of the left-hip flexion contracture

time of surgery include intraoperative fluoroscopy, computer-assisted navigation, or robotic surgery [18, 23–27]. A recent study comparing conventional posterolateral, navigated posterolateral, and direct anterior with fluoroscopy showed no difference in leg-length accuracy; all three methods and approaches demonstrated a mean accuracy of 3 mm [26]. Regardless of the measurement technique or technology utilized, it is important to have a careful preoperative plan and a standardized method to assess limb lengths at the time of surgery. With a detailed understanding of a patient's preoperative LLD, presence of periarticular contractures leading to a careful preoperative template, and use of intraoperative checkpoints to assess changes in limb length, the risk of unexpected postoperative LLD can be minimized.

If substantial lengthening is required intraoperatively to obtain adequate stability, suboptimal component position should be suspected. In these cases, reorientation of the acetabular (more common) or femoral component (less common) into a more or less anteverted position may provide adequate stability without leg lengthening. Careful trialing along with a low threshold to get an intraoperative radiograph in cases that "just don't feel right" will help prevent this inadvertent lengthening.

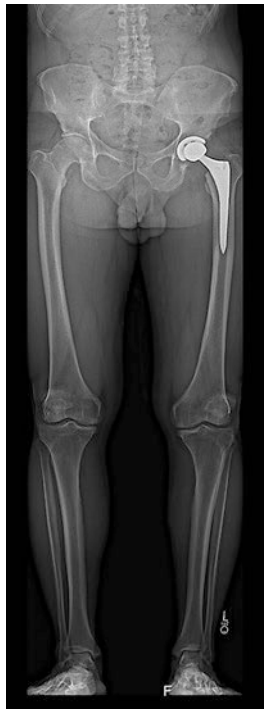

Fig. 9.9 Postoperative AP pelvis radiograph demonstrating accurate restoration of leg length and offset with resolution of flexion and external rotation contractures. Functional LLD has also resolved with both feet level on the ground

Diagnosis and Treatment of LLD After THA

The diagnosis of LLD after THA depends on both clinical and radiographic examinations. Foremost, it must be determined whether the postoperative limb-length differences are functional or structural. If structural, it must be determined if the source is intra- or extra-articular. Patients with severe abduction, flexion, or adduction contractures prior to THA may continue to have a functional LLD postoperatively and may take up to 6 months to normalize. During this time period the patient should avoid wearing a shoe lift [14].

Most patients will accommodate to LLD. Most patients with structural limb-length discrepancies do not require surgical treatment. Limb-length differences of 5 mm or less do not cause significant changes in gait and are often not recognized by the patient. For symptomatic patients early after surgery, physiotherapy for stretching and strengthening of the abductors is oftentimes helpful, to ameliorate an apparent LLD from an abduction contracture. If after several months the patient is still symptomatic, several studies have demonstrated that a simple shoe lift is satisfactory to ameliorate most functional limitations up to 2 cm in those who remain symptomatic [2].

Most patients with a LLD are managed with simple observation. The majority of patients with LLD will eventually adopt. In a study of 56 patients with a postoperative LLD mean of 9 mm, 12 (43%) perceived it at 3 months and 18 (33%) perceived it at 12 months postoperatively [28]. For those patients with persistently symptomatic LLD, most can be adequately treated with a shoe insert. Shoe inserts that fit inside shoe wear can be used to correct LLD of up to 2 cm. For those patients who cannot tolerate shoe inserts and who are increasingly symptomatic, surgery may be an option. If a THA is performed on a contralateral arthritic hip, then limb-length equalization can be achieved at the time of surgery (see Figs. 9.1, 9.2, 9.7, and 9.8). For patients without contralateral arthritis, revision surgery to shorten the limb can be considered, but should be done with caution to avoid postoperative instability. Depending on the source of the LLD, revision surgery may entail cup revision, modular head exchange, stem revision, or revision of both components. When evaluating these patients, it is important to determine if component anteversion is appropriate. A common scenario is inadvertent intraoperative lengthening to obtain soft-tissue stability when the underlying cause of instability is inappropriate version of the cup, stem, or both components. In these situations, component revision to appropriate version may allow the surgeon to substantially shorten the limb while maintaining acceptable component stability. The risk of postoperative instability may also be addressed with the use of a semi-constrained (i.e., dual-mobility construct) or constrained liner. Parvizi et al. [29] reviewed the outcomes of 21 patients who underwent revision and limb shortening for symptomatic LLD and reported that 19 of 21 were satisfied with the result without any cases of postoperative instability.

Another option for leg-length equalization is acute shortening of the ipsilateral limb through the distal femur. While this solution does create some compromises (e.g., the knees will be at different heights) it is a technically simple solution with low morbidity and risk to the patient [30]. Other options for treating significant (greater than 2 cm) lengthening after THA include distraction osteogenesis over an intramedullary nail which was performed in two cases with leg equalization and improvement of function [31].

Case Resolution

Even through preoperative radiographic limb-length discrepancy was 1.4 cm, her functional LLD based on block testing was 1 cm and this was the amount of planned right-limb lengthening at the time of THA. Preoperative physical examination and standing and sitting EOS radiographs demonstrated a flexible pelvic obliquity. The patient underwent an uncemented primary total hip arthroplasty through the posterolateral approach. A dual-mobility component was utilized in order to decrease the risk of postoperative instability in an elderly female with a history of previous lumbar fusion. A 52 mm acetabular component was inserted in the native hip center and lengthening was performed with increasing the desired LTC measurement from the native femoral LTC measurement. At 6-week follow-up standing radiographs demonstrated resolution of pelvic tilt (Fig. 9.10). The patient was walking without an assistive device, her low back pain improved, and limb length subjectively equalized.

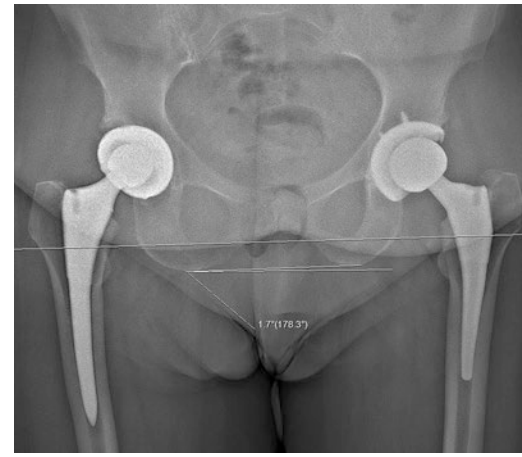

Fig. 9.10 Postoperative standing AP EOS radiograph of the case example demonstrating leg-length equalization and near resolution of flexible pelvic obliquity at 4-week follow-up. Leg lengthening was planned with increased distance of femoral neck resection and increasing femoral LTC

Summary

The preoperative evaluation of any patient undergoing a total hip arthroplasty should include an accurate assessment of preoperative limb-length inequality. Physical examination can identify true and apparent differences in limb lengths using a tape measure and blocks of known thicknesses. The presence of periarticular contractures and pelvic obliquity should be identified and incorporated into the preoperative template. Standing AP pelvis radiographs allow for intra-articular structural leg-length differences to be calculated. Preoperative templating is essential and allows for planned component sizing and position to reestablish the acetabular and femoral centers of rotation, calculated planned lengthening, and length of femoral neck osteotomy. Intraoperatively, the femoral neck resection length and distance from the lesser trochanter or the center of the femoral head can be used to assess limb length. Intraoperative calipers, fluoroscopy, or navigation can also be used to assess for the position of both the acetabular and femoral components. The patient needs to be advised preoperatively as to what leg-length differences can be corrected and those that will remain postoperatively. Most postoperative limb-length discrepancies are minimal, and are asymptomatic. Symptomatic patients can frequently be treated with physical therapy in the early postoperative period and in the rare case, when they remain symptomatic, a shoe lift. When the limb-length discrepancies are severe and shoe lifts are ineffective, revision surgery can be performed with reasonable outcomes.

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Chronic Deep Periprosthetic Infection

10

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Case-Based Introduction

A 64-year-old female presented with a total hip arthroplasty (THA) performed at another institution 5 years earlier. She recovered well after her index procedure and had no problems with wound healing postoperatively. Six months prior to presentation she developed increasing groin and buttock pain. Her pain was present at rest, and aggravated with any activity. Her symptoms had increased in severity over the preceding weeks but she had remained systemically stable. Presenting erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were 77 mm/1 H (reference range 0–29 mm/1 H) and 35 mg/L (reference range <8.0 mg/L), respectively. She underwent an aspiration of her hip and the quantitative leukocyte count was 13,500 cells with 89% polymorphonuclear cells. Her culture returned positive for methicillin-resistant *Staphylococcus aureus* (MRSA). Her presenting radiographs are shown in Fig. 10.1.

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Epidemiology of Periprosthetic Joint Infection (PJI)

Total hip arthroplasty (THA) is a successful and durable operation for end-stage arthritis of the hip [1]. The number of THAs performed annually in the United States continues to rise and is expected to hit four million by the year 2030 [2]. Chronic, deep periprosthetic joint infection (PJI) is a rare, but devastating, complication of THA that is associated with increased perioperative costs, extended duration of hospital stays, and compromised patient outcomes [3]. Though the incidence of PJI after THA is variable throughout the literature, most arthroplasty centers report an incidence somewhere between 0.2 and 2% for primary THAs and 2 and 4% for revision THAs [4–6]. Currently, infection is the third most common reason for THA revision [7].

Risk Factors Associated with PJI

Risk factors for the development of infection can be categorized into:

1. Non-modifiable patient risk factors
   (a) Male gender [8]
   (b) Revision surgery [9]
   (c) Active malignancy [9].
2. Modifiable patient risk factors
   (a) Smoking, alcohol, or drug abuse [10]

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_10

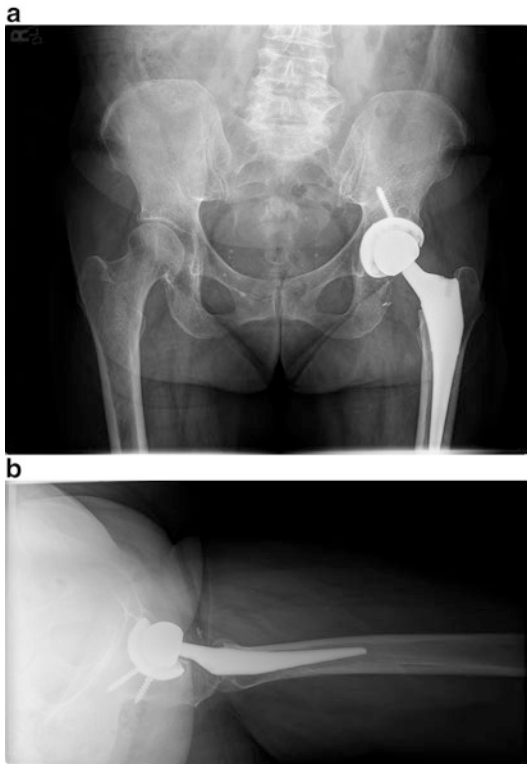

Fig. 10.1 AP (**a**) and lateral (**b**) radiographs of an infected THA upon presentation to our institution. The patient presented with a 6-month history of increasing groin pain and grew MRSA after hip arthrocentesis

   (b) Medical comorbidities [11]
      - Morbid obesity [8]
      - Malnutrition, hyperglycemia, uncontrolled diabetes mellitus [9]
      - Rheumatoid arthritis [6]
      - Preoperative anemia [9, 10]
      - Cardiovascular disease [12]
      - Chronic renal failure [10]
3. Intraoperative risk factors
   (a) Longer duration of surgery [4, 13]
   (b) Increased traffic in the OR [14, 15]
   (c) Though several other intraoperative factors influencing the risk of PJI have been proposed and studied (i.e., the use of laminar airflow and the use of full-body exhaust suits), none have been consistently proven to increase the risk of infection after THA [16].
4. Postoperative risk factors
   (a) Avoidance of invasive procedures within the first 3 months after surgery is recommended, if possible. Theoretically, this minimizes the risk of hematogenous spread and seeding of bacteria, but the specific procedures and the accompanying risk of infection have not been clearly established [17].
   (b) Increased length of stay has been shown to be an independent risk factor for PJI and patients should be encouraged to discharge when medically fit [18].
   (c) Prolonged wound drainage after THA has been associated with an increased risk of infection and should be recognized early and treated aggressively to prevent PJI [19].

Prevention of PJI

The single most important factor in the prevention of PJI is the use of perioperative prophylactic antibiotics [20]. Though the proper dose, duration, and type of antibiotic have not been definitively established [11], it is common practice to administer an antibiotic that targets the common offending microorganisms within 1 h prior to making skin incision, repeated every 3 h intraoperatively, and continued for 24 h postoperatively. Recently, there has been increasing interest in the routine screening of arthroplasty patients for the presence of common offending organisms in PJI such as methicillin-sensitive *Staphylococcus aureus* (MSSA) and methicillin-resistant *Staphylococcus aureus* (MRSA) [13]. There is some evidence that decolonizing these patients is associated with a lower risk of PJI [13], but further study is needed before this becomes standard of practice.

Prior to undergoing elective THA, all patients should undergo a thorough medical evaluation. Any modifiable risk factors that are identified should be optimized prior to surgery. A thorough patient history and physical examination in the immediate preoperative period are critical to ensure that there are no signs of active infection

in the body. Specifically, the skin around the operative extremity should be assessed for any signs of open wounds or superficial infections. Similarly, the oral cavity should be inspected for signs of tooth decay or gingival infection or abscess. Any active infection that is identified should be treated and resolved well prior to undergoing elective THA.

Patients should be instructed to thoroughly cleanse their skin with a chlorhexidine-based solution the night prior to the operation [14]. Though reports on hair removal preoperatively have been inconclusive [15], the authors still routinely remove the hair surrounding the surgical field. The use of hair clipper is superior to the use of a razor for hair removal [16]. The surgical site should be prepped thoroughly and in its entirety with either an alcohol-based or chlorhexidine-based preparation as iodine-based preparations have proven inferior [17].

Strict adherence to sterile technique during surgery is the cornerstone to preventing infection. The use of sterile drapes, a surgical gown, a face mask, and two sets of surgical gloves should be routine for all arthroplasty surgeons. Face masks prevent contamination from the respiratory system and surgical gloves have reported perforation rates of 3–18% during primary and revision hip and knee arthroplasty [18–22], which has been shown to increase the risk of infection [23]. Changing the outer gloves periodically throughout a THA appears to reduce surgical glove contamination [19], but its direct effect on infection prevention has not been established. Limiting traffic in and out of the operating room appears to lower the risk of PJI and should be encouraged for all arthroplasty surgery [24, 25]. Safe, but efficient, surgical technique can minimize the time the wound is open and has been demonstrated in numerous studies to decrease the risk of infection [4, 26]. In addition, numerous topical treatments have been studied. Vancomycin powder applied topically to the wound has had demonstrated effectiveness in spine surgery [27], and appears to achieve effective local concentrations [28] while not interfering with wear patterns of THA [29]. Additionally, lavage of the wound in a dilute Betadine solution prior to wound closure has been associated with lower rates of surgical site infection [30] and has been implemented in many practices across North America.

Diagnosis of PJI

All patients being evaluated for infection should be assessed with plain radiographs of the hip (an anteroposterior [AP] of the pelvis and an AP and lateral view of the hip), as well as an erythrocyte sedimentation rate (ESR) and a C-reactive protein (CRP). Radiographs may show lucency around the prostheses or scalloping of the surrounding bone [31]. An elevated ESR and a CRP, particularly when used in combination, can be highly sensitive markers for infection [32]. Additionally, all patients with suspected infection should undergo arthrocentesis of the hip to assess the quantitative leukocyte count in the synovial fluid and to attempt to culture an offending microorganism [33]. Though varying cutoff levels to diagnose PJI based on synovial fluid analysis have been reported [34, 35], in the authors' experience, a synovial fluid leukocyte count of 1700 cells (and/or a leukocyte differential of >65% polymorphonuclear cells) is both a sensitive and specific marker for late, chronic PJI in patients without inflammatory arthropathy.

Though the precise definition of deep PJI remains elusive and controversial, the Musculoskeletal Infection Society (MSIS) has adopted the following definition [36]:

1. There is a sinus tract communicating with the prosthesis
2. A pathogen is isolated by culture from at least two separate tissue or fluid samples obtained from the affected prosthetic joint
3. Four of the following six criteria exist:
   (a) Elevated serum erythrocyte sedimentation rate (ESR) and serum C-reactive protein (CRP) concentration
   (b) Elevated synovial leukocyte count
   (c) Elevated synovial neutrophil percentage (PMN%)

(d) Presence of purulence in the affected joint
(e) Isolation of a microorganism in one culture of periprosthetic tissue or fluid
(f) Greater than five polymorphonuclear cells per high-power field in five high-power fields observed from histologic analysis of periprosthetic tissue at 400 magnification

Treatment of PJI

The onset of patient symptoms is paramount to determining the correct treatment strategy for THA PJI. Periprosthetic joint infection can be classified into four categories based upon the timing of the diagnosis [37].

- Early postoperative infections are considered to be <4 weeks after the index arthroplasty.
- Chronic infections are infections diagnosed >4 weeks postoperatively or in patients that have had symptoms of infection for >4 weeks
- Acute hematogenous infections are characterized by the acute onset of symptoms in a previously well-functioning joint
- Infection diagnosed by obtaining positive cultures at the time of THA insertion without prior symptoms or diagnosis of infection

In early postoperative and acute hematogenous infections an attempt at prosthesis salvage is an option in certain patients. This is traditionally accomplished through an open irrigation and debridement, and polyethylene (PE) liner and femoral head exchange of the THA [38], followed by a course of intravenous (IV) antibiotics targeting the offending microorganism. Positive cultures obtained at the time of THA implantation or reimplantation should be treated with antibiotic suppression targeting the identified microorganism(s).

Patients with late, chronic PJI or patients with a failed irrigation and debridement and PE liner and femoral head exchange require removal of their implants. Although some authors advocate for the use of a single-stage exchange in the setting of chronic, deep PJI of the hip [39], the North American gold standard is a two-stage exchange of the implants [40–42]. Contraindications to performing a two-stage exchange are rare and include medical comorbidities that preclude the patient from safely undergoing surgery or femoral/acetabular bone stock that is inadequate to allow joint reconstruction.

The two-stage exchange protocol varies slightly from surgeon to surgeon and institution to institution, but in general consists of the following:

- First stage involves removal of all implants, debridement of the infected tissue, culture of the infected tissue, and a thorough irrigation of the wound.
- After completion of the irrigation and debridement, an antibiotic-loaded bone cement (ALBC) spacer is inserted into the hip to deliver local antibiotics for the weeks following the debridement.

The ALBC spacer is available in multiple varieties. Historically, a non-articulating spacer was used which consisted of an ALBC dowel placed into the medullary canal of the femur and a dollop of ALBC lightly pressed into the acetabulum. This provided an effective method for local antibiotic delivery, but provided poor hip function during the treatment phase of the infection. As such, most North American surgeons have migrated toward using an articulating antibiotic spacer, when possible. Two distinct types of articulating spacers exist. The first design is a cement-on-acetabulum articulation that consists of a prefabricated femoral component made from ALBC that is cemented into the femur after irrigation and debridement. This type of spacer is available in multiple varieties from several different vendors. The advantage of this type of prosthesis is its ease of insertion. The disadvantages are that it is made from lower dose antibiotics than one can mix into cement intraoperatively, they are available in a limited number of sizes, they have very little offset (and are prone to dislocation), and they necessitate a cement-on-acetabulum articulation which limits patient function (compared to metal-on-polyethylene designs) and can propagate acetabular bone loss.

This type of spacer can also be made from a mold, which allows the surgeon to place the desired dose of antibiotics into the mold. One manufacturer has a modular option, which allows the surgeon to vary femoral neck length to optimize stability.

The second design of articulating antibiotic spacer available is a metal-on-polyethylene articulation. This design consists of a cobalt chrome femoral component covered with ALBC coupled with an all-polyethylene acetabular component cemented into the acetabulum. The advantages of this spacer are that the surgeon is able to deliver higher dose antibiotics than are available in the commercially made spacers and that hip function is significantly better than with the cement-on-acetabulum alternative [43]. The disadvantage is that these spacers are technically more challenging to insert. Despite the technical demands associated with implanting these spacers, it is the strong preference of the authors to use the metal-on-polyethylene variety due to the advantages listed above. An antibiotic ratio of 3 g of vancomycin, 3.6 g of tobramycin, and 150 mg of amphotericin powder per 40 g batch of polymethylmethacrylate (PMMA) is preferred at our institution when fabricating these articulating spacers.

Following the first-stage procedure, the patient is treated with IV antibiotics targeting the offending microorganism, typically for a total of 6 weeks. Antibiotic selection and duration of treatment are chosen based on the microorganism(s) identified and its susceptibilities. The patient is then given a period of time (at least 6 weeks) off of antibiotics to ensure that the infection has been cleared and not temporarily masked by the antibiotics. Patients should be evaluated periodically between the first and second stages to assess their wound, serially follow the inflammatory markers (ESR and CRP), and confirm the absence of systemic illness and adverse reaction to the antibiotics. If after a period of (at least) 6 weeks off of IV antibiotics the inflammatory markers have trended downward or normalized and there are no outward signs of infection (draining or erythematous wound), reimplantation can be considered. In the setting of persistent elevation of the inflammatory markers, synovial fluid analysis of the hip can be of benefit. Shukla et al. [44] demonstrated that the synovial fluid WBC count, in particular, can be useful for identifying persistent infection. The authors found that a synovial fluid WBC count greater than 3528/μL had 96% specificity and 78% sensitivity for identifying persistent joint infection and can be a useful tool when considering reimplantation. Nevertheless, if evidence of infection persists after treatment, or is found at the time of reimplantation, definitive reconstruction should be delayed and consideration should be given to an additional debridement, antibiotic spacer exchange, and course of IV antibiotics.

Results

The success following a two-stage exchange protocol for chronic PJI of the hip has been universally excellent with reported rates ranging from 85 to 95% [45–48]. The virulence of the offending microorganism, thoroughness of the debridement, and patient comorbidities all play a role in the successful treatment of the chronic THA PJI. Optimal treatment outcomes are achieved by performing a thorough debridement, accurately identifying the offending microorganism, and providing appropriate antibiotics based on the microorganism's susceptibilities. Further, optimization of medical comorbidities (such as diabetes) and nutrition may improve results.

Toulson et al. [46] reported on 82 patients with infected THA treated with a two-stage exchange protocol. At a mean of 2 years of follow-up, the original infection was eradicated in 78/82 patients and 94% of the patients had undergone successful reimplantation. The authors concluded that a two-stage reimplantation protocol is a successful strategy for treating infections after THA. Similarly, Hoffman et al. [48] reported on 27 patients with chronic PJI of the hip treated with a two-stage exchange protocol utilizing an articulating antibiotic spacer. Of the 27 patients, 26 (94%) remained clinically free of infection at an average of just over 6 years postoperatively. The authors concluded that the

advantages of the two-stage exchange using an articulating antibiotic spacer included improved patient function during the treatment phase, successful treatment of infection, and facilitation of reimplantation.

Case Solution

The patient was scheduled for a two-stage exchange of her THA. A PROSTALAC® (Depuy, Warsaw, IN) spacer was placed after a thorough debridement during the first stage (Fig. 10.2). The patient was then treated with a 6-week course of IV vancomycin and allowed to remain weight bearing as tolerated. Following an 8-week antibiotic holiday, the patient's ESR and CRP had returned to normal at 13 mm/1 H and 5 mg/L, respectively. The patient was ultimately reimplanted with an uncemented acetabular component and uncemented modular fluted tapered femoral component. At 2-year follow-up, the patient was infection free without any antibiotic suppression (Fig. 10.3).

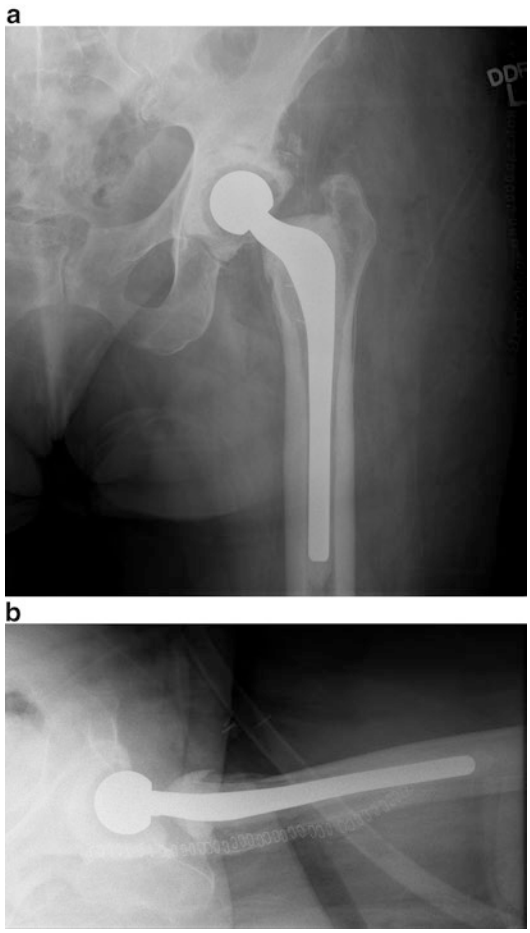

Fig. 10.2 AP (**a**) and lateral (**b**) radiographs after resection of the implants and insertion of a PROSTALAC® (Depuy; Warsaw, IN) spacer for local antibiotic delivery. Note that cement has been placed around only the proximal portion of the femoral implant to facilitate removal at the time of reimplantation

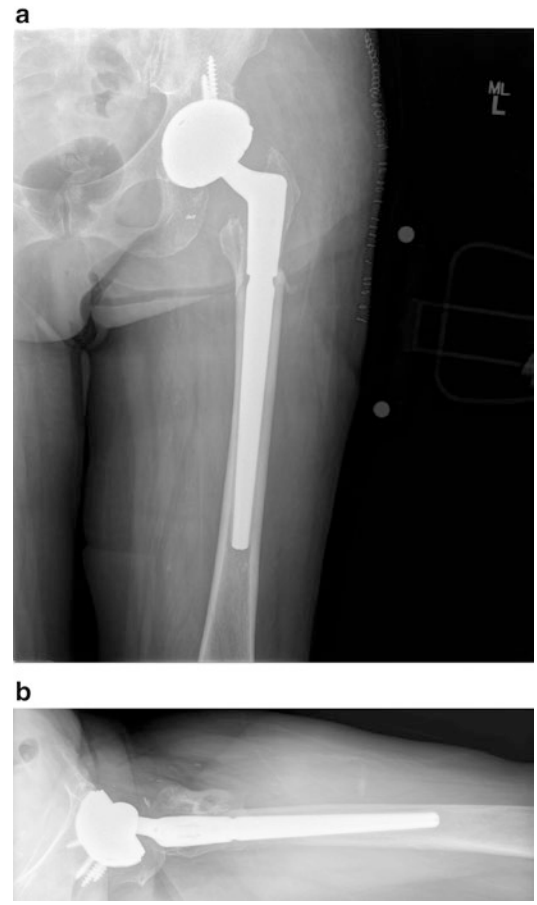

Fig. 10.3 AP (**a**) and lateral (**b**) radiographs after THA reimplantation utilizing an uncemented porous acetabular component and an uncemented modular fluted tapered stem. The patient has remained infection free at 2 years of follow-up

Summary

Deep PJI of the hip, though uncommon, is a devastating complication with significant patient morbidity. Preventative strategies targeting the modifiable preoperative, intraoperative, and postoperative risk factors are paramount to minimizing THA PJI. When chronic PJI does occur, however, treatment with a two-stage exchange protocol provides an excellent treatment strategy that has demonstrated consistently good results in eradicating infection.

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Periprosthetic Fracture of the Femur After Total Hip Arthroplasty

11

Khalid Azzam and R. Michael Meneghini

Case Examples

Case 1: An 86-year-old female who had undergone an uncomplicated total hip arthroplasty presented 5 months following her surgery after a ground-level fall with complaints of pain in her hip. X-rays revealed a periprosthetic femur fracture around a subsided femoral component (Fig. 11.1).

Case 2: A 45-year-old male with a history of slipped capital femoral epiphysis of his left hip that was treated with in situ pinning presented with end-stage arthritis of the hip (Fig. 11.2a). He is 6 ft tall and weighs 245 lbs. He had retained hardware from a previous failed attempt at removal. During his total hip arthroplasty, the hip was dislocated with the screw in place. The screw had previously been stripped. The neck cut was made, exposing the distal end of the threaded end of the screw, which was then extracted in a retrograde fashion. The femoral canal was then broached for a flat wedge tapered stem and the final implant was press-fit into the canal. In the recovery room, postoperative X-ray demonstrated a periprosthetic femur fracture at the tip of the femoral component (Fig. 11.2b). This had not been noticed intraoperatively.

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Background

The earliest case report of a periprosthetic femur fracture after total hip arthroplasty (THA), in 1954, was of a female who suffered an intertrochanteric fracture around the stem of a cemented hemiarthroplasty. The fracture was fixed using transfixing bolts and wire loops, and the prosthesis was reinserted [1]. In 1964, Parish and Jones [2] reported nine cases of femur fractures around Austin-Moore and Thompson prostheses. The authors classified the fractures according to the location of the fracture to intertrochanteric, proximal, mid-shaft, and distal fractures. Two years later, Sir John Charnley [3] described a periprosthetic femur fracture around a cemented Thompson prosthesis. She was treated with balanced traction and the fracture healed after 3 months [4].

Incidence

Periprosthetic femoral fractures may occur intraoperatively, or early or late postoperatively following THA. Depending on the femoral fixation

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_11

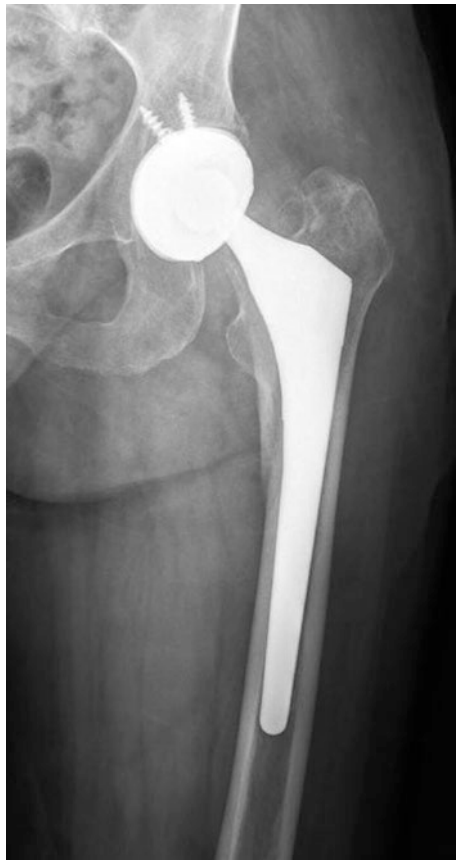

Fig. 11.1 Vancouver B_2 femoral fracture 5 months following total hip arthroplasty with subsequent stem subsidence

method used, differences in the incidence of intraoperative fractures have been reported. An incidence of 0.1–3.5% has been reported with cemented stems [4, 5]; however, an increase of intraoperative fractures has been reported with the introduction of uncemented stems [4, 6]. Schwartz et al. [7] studied 1318 consecutive uncemented total hip replacement arthroplasties and found 39 intraoperative fractures of the femur (3%), only half of which were diagnosed intraoperatively. A recent study from the Mayo Clinic registry [8] showed an intraoperative fracture incidence of 0.2% in 15,178 primary cemented and 3% in 17,466 uncemented THAs. The 20-year cumulative probability of postoperative periprosthetic femoral fractures was 2.1% after placement of a cemented stem and 7.7% with uncemented stems. In revision surgery, an even higher incidence has been reported. In 1999, Berry [9] reported an intraoperative fracture incidence of 3.6% in cemented and 20.9% in uncemented revision THAs. A review of the Swedish registry showed late femoral periprosthetic fracture to be the third most frequently reported cause for reoperations after THA (9.5% of the reoperations), after aseptic loosening and recurrent dislocation [10].

Etiology and Risk Factors

In a retrospective review of 93 periprosthetic fractures, Beals et al. [11] found that the most common mechanism of late fracture was a ground-level fall (84%). Several potential risk factors for periprosthetic fractures around THA have been studied including primary diagnosis, age, osteolysis, aseptic loosening, revision, and implant design type.

Primary Diagnosis

A matched case-control study of the Finnish registry showed that patients who had fracture as primary diagnosis for arthroplasty had a 4.4 times higher risk of periprosthetic fracture than those operated on for other reasons [12]. Similarly, analysis of 321 periprosthetic fractures reported to the Swedish registry showed that an index diagnosis of hip fracture was significantly more common than an index diagnosis of osteoarthritis or inflammatory arthritis in the fracture group ($p < 0.001$) [10].

Age

Cook et al. [5] examined a cohort of 6458 primary cemented femoral prostheses implanted from 1983 to 1999. Patients older than 70 years had a 2.9 times greater risk of sustaining a subsequent fracture. It is likely that increased age is associated with increased incidence of periprosthetic fractures due to a number of factors including osteoporosis, increased risk of falls, lower body mass index, higher incidence of osteolysis and loose stems, and a higher likelihood of having had a revision surgery [13].

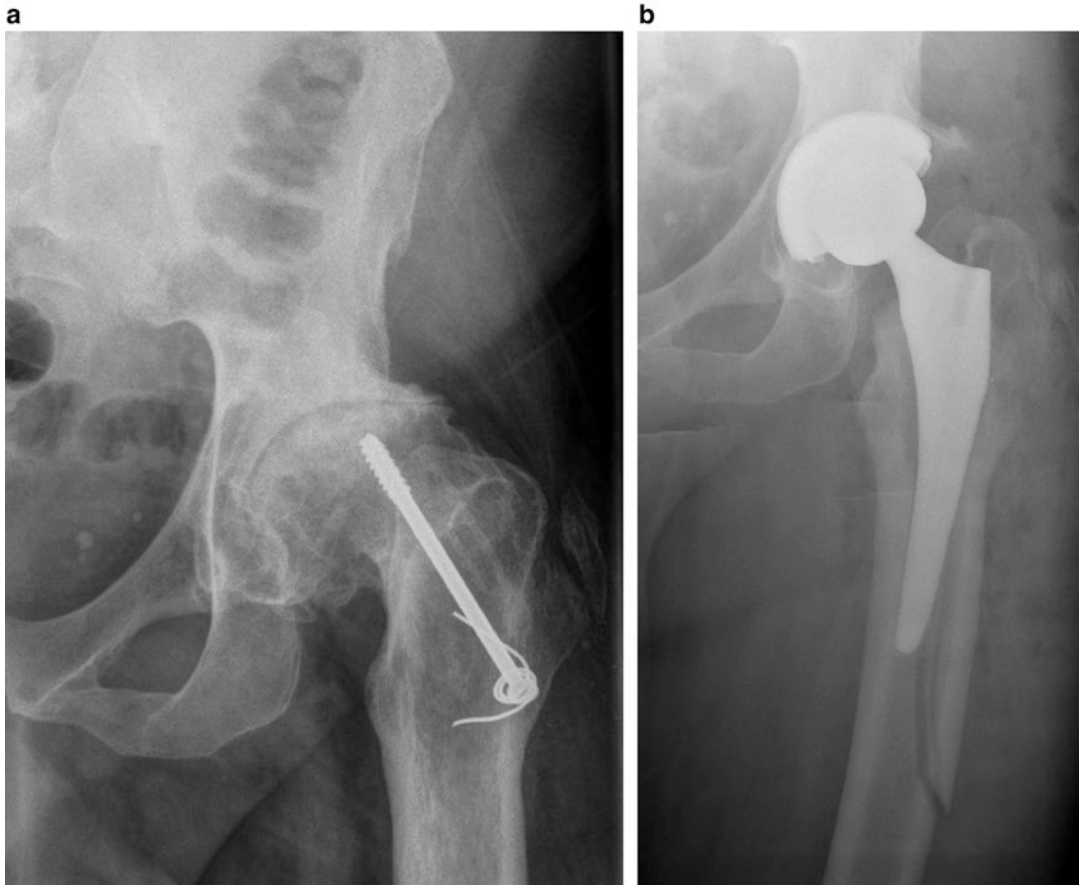

Fig. 11.2 (**a**) Preoperative radiograph demonstrating hip osteoarthritis following slipped capital femoral epiphysis. (**b**) Intraoperative femoral fracture in the diaphyseal region discovered postoperatively

Osteolysis

Late periprosthetic fracture associated with osteolysis has been recognized as a growing problem in arthroplasty [14]. The greater trochanter is a common area for osteolytic fractures because it is a large cancellous bone surface in proximity to the source of particle generation. The high stress imparted by the abductors in combination with the frequency of osteolytic lesions not infrequently leads to fracture in this area [14].

Aseptic Loosening

Loose implants have been demonstrated to be risk factors for periprosthetic fracture in several studies [10, 15–17]. In a review of 321 periprosthetic fractures reported to the Swedish National Hip Arthroplasty Register, Lindahl et al. [10] found that a high number of patients had a loose stem at the time of the fracture (66% in the primary THA group and 51% in the revision THA).

Revision Surgery

Revision total hip arthroplasty is frequently associated with bone loss and challenging implant fixation. Wear debris and resultant osteolysis can reduce available bone stock for fixation at the time of revision [13]. In a study of 215 Medicare beneficiaries who had periprosthetic femoral fracture between 2006 and 2008, a greater risk of periprosthetic fracture was associated with having had a revision total hip replacement [18]. In a

study of 64 patients who sustained an intraoperative fracture of the femur during revision hip arthroplasty with a diaphyseal fitting cementless stem, risk factors associated with an intraoperative fracture were a substantial degree of preoperative bone loss, a low femoral cortex-to-canal ratio, under-reaming of the cortex, and use of a large-diameter stem [19].

Implant Design Type

Little is known about how the design features of cementless implants affect a patient's risk for subsequent periprosthetic fracture. In a study of 111,899 uncemented femoral stems reported to the Nordic Arthroplasty Register from 1995 to 2009, the authors demonstrated an increased risk of fractures with the ABG II stem (anatomic design) and a decreased risk for the Corail stem (wedge design). Given that a wedge-shaped stem could be expected to more frequently act as a stress riser with its comparatively sharp corners compared with a rounded design, the authors concluded that these results were difficult to interpret [6]. Another study of 3964 primary THAs in which an alumina grit-blasted, proximally hydroxyapatite-coated femoral component with an exaggerated proximal taper angle was compared to five cementless, proximally fixed stems of different design showed an increased risk of early and late postoperative femoral fractures in hips implanted with that particular stem design. The stem was subsequently discontinued by the manufacturer [20]. In cemented stems, some studies have shown increased risk of fracture with a polished stem designed to subside in the cement mantle [6, 12, 21]. An inadequate cement mantle, with implant contact with the inner and distal femoral cortex, has been correlated with long-term loosening, femoral osteolysis, and subsequent risk for fracture [21].

Evaluation

Since the fixation status of the implant is a critical aspect to the treatment algorithm, it is essential that the examiner elicit any signs and symptoms that may suggest implant loosening prior to the injury, such as start-up thigh pain. The injured limb's neurovascular status and soft-tissue condition should be carefully documented. Preoperative planning should include identification of previous surgical scars, review of previous operative reports, and appropriate workup for infection in patients with previously symptomatic implants. Synovial fluid WBC count and neutrophil percentage are the best tests for diagnosing prosthetic joint infection and have similar cutoff values as when used for detecting infection in patients without a periprosthetic fracture [22]. High-quality standard anteroposterior and lateral radiographs of the affected hip and femur as well as any previous radiographs, if available, should be reviewed in an attempt to determine the stability and fixation status of the implant if possible [23].

Classification

The Vancouver Classification (Table 11.1) is currently the most widely used and accepted and is based on fracture location with subtypes

Table 11.1 Vancouver classification of periprosthetic femur fractures after total hip arthroplasty

Vancouver classification of periprosthetic femur fractures		
Type	Fracture location	Subtype
A	Trochanteric region	A_G: fractures that involve the *greater* trochanter
		A_L: fractures that involve the *lesser* trochanter
B	Around the stem of the femoral component, or extend slightly distal to it	B_1: the implant is stable
		B_2: the implant is loose and the bone stock around the femoral component is adequate
		B_3: the implant is loose and the bone stock around it is inadequate to support traditional femoral implants
C	Well distal to the stem	

in the B-type fractures based on implant fixation status and bone loss [24].

Prevention

Prevention of periprosthetic femur fractures around total hip arthroplasty begins with careful preoperative planning and identifying patients who are at risk of such a complication. Attention to preventing and identifying small intraoperative fractures is critical so that they can be addressed intraoperatively. Prevention of late periprosthetic femoral fractures is best accomplished through routine clinical and radiographic follow-up [13]. Regular monitoring of patients allows for early detection of osteolysis and aseptic loosening, and thus facilitates timely revision surgery.

In a review by Tsiridis et al. [16], several preventive measures for periprosthetic femur fractures were identified. Preoperatively, attention to careful component templating and identifying at-risk patients is of paramount importance. Intraoperatively, fractures could be prevented by careful dislocation of the hip and by following proper technique of femoral canal preparation and careful insertion of the final prosthesis.

In revision settings, it is important to obtain adequate surgical exposure, which may involve various peri-trochanteric osteotomies to aid with prosthetic alignment and component or cement removal. Both careful reaming and avoidance of eccentric or varus directions when using the reamers are important and may be facilitated by judicious use of radiographs during femoral preparation and implant insertion. It may be of value to strengthen the femur prophylactically by using cerclage wires prior to femoral preparation and implant insertion, and it is the authors' practice to place a prophylactic cerclage wire just distal to the osteotomy site if an extended trochanteric osteotomy is used to prevent iatrogenic fracture propagation. If a fracture has already occurred, cerclage wiring can be used to prevent it propagating further and should be placed sufficiently past the most distal extent of the fracture to protect the intact femoral canal. Cement removal is most safely achieved by splitting it radially and at several levels or by using ultrasound. Cortical defects and osteolytic lesions should be bypassed when possible. Cortical strut grafts may be used prophylactically to reinforce cortical defects and other stress risers. Postoperatively, good-quality anteroposterior and lateral radiographs of the entire length of prosthesis should be obtained before weight bearing to exclude unrecognized fractures.

Treatment of Late Periprosthetic Femur Fractures

Treatment of periprosthetic fractures after total hip arthroplasty is summarized in Table 11.2.

Type A Fractures

Type A_G fractures are stable when minimally displaced because they are securely positioned

Table 11.2 Treatment of femur fractures after total hip arthroplasty

Type A (trochanteric)	
• AG	• Trochanteric plate fixation for large, markedly displaced fractures
	• Nonoperative treatment for late, osteolysis-related fractures
• AL	Nonoperative treatment
Type B (stem region or slightly distal)	
• B1	Confirm implant stability, reduction, and internal fixation of displaced fractures using a locked plate-cable system
• B2	Stem revision, bypass with a long-stem prosthesis by minimum of two cortical diameters, supplemental cerclage cables as needed
• B3	• Reconstruction with a long, fluted modular stem that engages any remaining isthmus, cable fixation of the fracture pieces around the proximal body of the implant
	• Allograft-prosthetic composite versus proximal femoral replacement in cases where fluted stem fixation is not possible
Type C (well distal to the stem)	Fixation according to the fracture type, making sure that the fixation construct overlaps the tip of the femoral stem to avoid leaving weak segments of bone

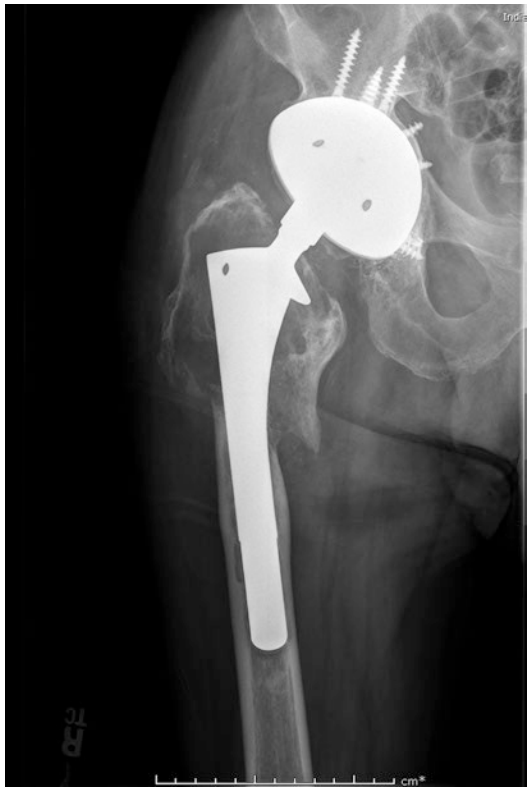

Fig. 11.3 Extensive trochanteric osteolysis and fracture around a well-fixed cylindrical stem

by the tendons of the vastus lateralis and the abductors, which prevent further displacement and proximal migration. This fracture is usually related to wear-debris osteolysis of the greater trochanter (Fig. 11.3) [25]. Nonoperative treatment for several months to allow bone healing or stable fibrous union before revision for osteolysis is typically recommended. A hip abduction brace may help reduce pain while the fracture is healing [14].

If the greater trochanteric fragment is large and markedly displaced, and the remaining bone is satisfactory to gain fixation, then early revision to restore abductor mechanism continuity with internal fixation of the greater trochanter to its bed or to an advanced position may be considered [14]. Type A_L fractures as an isolated injury can usually be ignored unless there is a distal extension involving the medial cortex that has destabilized the fixation status of the femoral stem [25].

Type B Fractures

Nonoperative treatment has been practiced in the past [3, 26], but because of its high morbidity, surgical treatment of these fractures has been established as the preferred treatment. Internal fixation may be used either alone or in combination with stem revision. The stability of the original implant, amount of bone loss, and configuration of the fracture itself are the basic factors that influence the decision-making process. Lindahl et al. [27] found that a major risk of failure in the treatment of these fractures is misinterpretation of the stability of the stem and misclassifying type B_2 fractures as type B_1, resulting in treatment with plate fixation without revision of the stem. This fact necessitates a careful assessment of the fixation status of the femoral stem in every type B periprosthetic femur fracture with additional confirmation intraoperatively.

Type B_1 Fractures

Due to the femoral component being well fixed, the principal strategy of type B_1 fractures is internal fixation of the periprosthetic bone without femoral revision. Different fixation techniques were tested and compared in an in vitro study by Schmotzer et al. [28]. The authors compared allograft struts with wire cerclage (18-gauge Vitallium, Howmedica), allograft struts with multifilament cable cerclage (Dall-Miles, 2 mm stainless steel, Howmedica), bypassing the fracture with a long stem (PCA, Howmedica), long stem with allograft struts and cerclage, plate (Synthes, Paoli, PA) with cables proximally and bicortical screws distally, and plate with unicortical screws (4.5 mm, Synthes) proximally and bicortical screws distally. The authors concluded that cables were significantly stronger and more appropriate than standard cerclage wiring and that compression plating with combined proximal cables and unicortical screws should be preferred over proximal wire fixation alone [28].

Cable-Plate System

In an early effort to provide rigid fixation around the femoral construct of a THA, Berman and Zamarin [29] introduced the Dall-Miles plate-cable

system (Stryker Howmedica, Mahwah, NJ) in a case report in 1993. The system included 1.6 and 2.0 mm braided Vitallium alloy cables, small and medium sleeves, medium and large grips, and plates of varying length. Cable tensioners were used to tighten the cables. It also allowed unicortical screw fixation with cable augmentation proximal to the fracture, in addition to bicortical screws distal to the fracture.

Four years later, Haddad et al. [30] documented their use in a small series of four periprosthetic fractures that all had excellent clinical outcomes. The study of Sandhu et al. [31] reported the outcome of 20 fractures treated with this system. All of the fractures united with no fixation failures over a postoperative period of 1–4 years. However, two type B_1 fractures later collapsed into varus, and both of these cases were treated with a plate fixed only with cables. Based on these results, the authors recommended that fixation of the plate with cables alone should be avoided because of the torsional instability of the construct [32]. Similarly, Dennis et al. [33] in a biomechanical study showed that plate constructs with proximal unicortical screws and distal bicortical screws or with proximal unicortical screws, proximal cables, and distal bicortical screws were significantly more stable in axial compression, lateral bending, and torsional loading than a plate with cables alone, plate with proximal cables and distal bicortical screws, or two allograft cortical strut grafts with cables. Tsiridis and colleagues [34] reported failure by fracture of the Dall-Miles plate in two out of three B1 fractures. The plates were stabilized with cables proximally and bicortical screws distally below the tip of the femoral component.

Compression Plating

The first description of compression plating of periprosthetic femoral fractures was by French authors [35]. In 1992, Serocki et al. [36] treated ten periprosthetic femur fractures with 4.5 mm broad dynamic compression plates. The authors identified one limitation of these plates, which only allowed 7° and 25° of screw angulation when trying to avoid the stem. A prospective study of plate fixation of Vancouver B_1 fracture types was published in 2005 by Ricci et al. [37] who evaluated 37 cases. Indirect reduction techniques were applied in all cases, sometimes preserving a soft-tissue bridge over the fracture site to minimize the operative trauma to the soft-tissue envelope, and reduction was achieved using fluoroscopy and traction. Fixation was accomplished with a standard 4.5 mm broad DCP in 27 of the 37 cases, which was secured on the bone via unicortical or bicortical screws and cables. No strut allografts or cancellous bone grafts were used to augment the osteosynthesis and all fractures united at an average of 3 months. The authors emphasized that the plate must be of sufficient length to bypass the implant by a minimum of six screws and that soft-tissue dissection should be minimized to preserve blood supply and facilitate osteosynthesis.

Locking Plates

Locking plates carry the advantage of both axial and angular stability because the screw heads are locked to the plate body by a threaded interface. They also provide the option of preservation of fracture-site vascular supply via use of minimally invasive insertion techniques [38]. Fulkerson et al. [38] performed a biomechanical comparison of standard Ogden plate-cable systems with the locking plates for fixation of fractures at the tip of well-fixed cemented stems (B_1 fractures). The locked plating constructs used a 4.5 mm broad locking compression plate (LCP) that was secured to the cadaveric femur, with three unicortical locking screws proximally and three bicortical distally. The Ogden constructs consisted of stainless steel plates that were fixed via three 1.8 mm steel cables in the proximal fragment and three non-locked bicortical screws distally. The locked plate was stiffer than the Ogden plate in axial compression and torsional loading, but not in lateral bending. The two constructs also showed different modes of failure during torsional loading. The LCP failed by lateral cortex fracture through the proximal screw holes, and the Ogden cable-plate system failed through the proximal cable cutting through the lesser trochanter. Locked plate construct cement mantles

exhibited no evidence of cracks or gross loosening at the cement-screw interface.

Cable-ready locked plates with screw holes that allow combination of polyaxial locking and non-locking screw fixation have gained popularity in fixation of periprosthetic fractures of the femur. These plates allow insertion with less invasive techniques that allow preservation of soft-tissue attachments. Locked screws allow better fixation in osteoporotic bone, especially when using unicortical screws in the proximal fracture segment. Non-locking screws have the advantage of being angled to gain fixation in bone anterior and posterior to the femoral stem. They also allow compression across transverse or oblique simple fracture patterns. Cables augment fixation in the proximal segment and allow addition of strut cortical grafts to enhance stability and provide a mechanical and potential biological advantage in osteoporotic bone. Despite all these theoretical advantages, Dehghan et al. [39] in a recent systematic review of the literature showed that locking plates had a significantly higher rate of nonunion (3% vs. 9% $P = 0.02$) and a trend toward a higher rate of hardware failure (2% vs. 7%; $p = 0.07$) compared with cable-plate systems. The authors cited suboptimal surgical technique (such as inadequate fracture reduction), overreliance on the locking plate to gain stability, and use of an excessively stiff construct to bypass the fracture area as potential reasons for the higher nonunion rate compared to conventional unlocked plates.

Strut Grafts

In a retrospective review from 4 centers, 40 patients with a fracture around a well-fixed femoral stem were treated with cortical onlay strut allografts without revision of the femoral component [40]. Nineteen patients were treated with cortical onlay strut allografts alone, and 21 were managed with a plate and one or two cortical struts. Thirty-nine (98%) of the 40 fractures united, and strut-to-host bone union was typically seen within the first year. There were four malunions, all of which had <10° of malalignment, and one deep infection. There was no evidence of femoral loosening in any patient. The authors concluded that cortical onlay strut allografts act as biological bone plates, serving both a mechanical and a biological function and that their use, either alone or in conjunction with a plate, led to a very high rate of fracture union. Despite the lack of a control arm in which only plates are used for fixation, the authors suggested that cortical strut grafts should be used routinely to augment fixation and healing of a periprosthetic femoral fracture. They explained that healing of the strut graft to the host bone involves formation of a zone of highly vascularized mesenchymal tissue. Osteoclasts subsequently create cutting cones in the graft, which is then invaded by vascular buds. The graft remodels and is at its weakest between 4 and 6 months and therefore is vulnerable to mechanical failure unless the fracture has already healed [41].

Disadvantages of strut allografts are increased cost, potential to transmit disease, and that the host femur must be extensively exposed to place the struts which may heavily disrupt the blood supply that is so critical to healing. On the other hand, strut grafts have several advantages. The modulus of elasticity of the struts is similar to that of the host bone and, thus, they are less likely to cause stress shielding. The struts unite with the host bone and eventually make the bone stronger, in addition to stimulating healing of the fracture [42]. The surgeon must therefore weigh the proposed benefit from the additional support provided to an underlying osteoporotic native bone by strut grafts as it heals against the risk of greater dissection necessary to apply them [25].

In an attempt to define more specific criteria for the use of strut grafts, Corten et al. [43] proposed a surgical algorithm that resulted in union of 29 out of 30 periprosthetic fractures treated at their center. In addition to maintaining a high index of suspicion for stem loosening and for testing implant stability intraoperatively if there is any doubt, their algorithm called for the use of locked plates without strut grafting only in those fractures where the medial cortex was not comminuted and could be anatomically reduced. The authors called for refinement of the current treatment algorithm that is based on the Vancouver classification, especially with regard to treating B1 fractures in order to define the most appropriate and biomechanically sound fixation option in individual situations. Buttaro et al. [44] recommended caution when using locked plates alone

in treatment of type B_1 fractures based on their results of three plate fractures and three plate pullouts in a series of 14 fractures. All of the failures in their series except one were observed in patients in whom a cortical strut allograft had not been used. In a review of 16 femoral fractures around well-fixed total hip implants, Wood et al. [45] recommended using cortical struts in cases of failed hardware and revision fixation. It appears that the issue of whether lateral plates alone provide enough stability for these fractures, or do strut grafts need to be added, warrants further investigation. We do not use strut grafts routinely in the fixation of periprosthetic fractures, except in cases of severe osteopenia and after failed previous locked plate fixation.

Type B_2 Fractures

When the stability of the implant is questionable, it must be tested intraoperatively. Pike et al. [25] suggested that if the distal aspect of the stem is exposed at the fracture site, it may be tested for instability by generation of shear force along the longitudinal axis between the implant and bone or cement proximally. They recommended using a pointed reduction forceps on the femur and a Kocher forceps grasping the stem tip. If this is not possible, a formal arthrotomy is necessary to gain adequate exposure to exclude stem loosening.

When the femoral component is loose, extramedullary fixation alone has been shown to yield poor results. It is recommended that the stem be revised to a longer stem to bypass the fracture site by at least two cortical diameters when using a fully porous stem. Based on the results of an in vitro study, Schmotzer et al. [28] postulated that newer long-stem revision prostheses that provide distal fixation (flutes or porous coating) likely improve the stability across the fracture site even if no extramedullary support, such as a plate or strut graft, is used. O'Shea et al. [46] treated 22 fractures with a fully porous coated stem (Solution, DePuy, Warsaw, IN) and supplemental cerclage wires with or without a strut graft. Of the 22 patients, 17 had a satisfactory outcome with a Harris Hip Score >80 while 4 patients had subsidence of their stems. One patient developed a deep infection and was revised to tumor prosthesis. Ko et al. [47] treated 12 patients with Vancouver B2 fractures with a conical fluted stem. At an average follow-up of 56.5 months, all 12 reconstructions showed a stable prosthesis and solid fracture union. Two patients had poor outcomes because of significant leg shortening in one patient and a new fracture in the other.

Type B_3 Fractures

Severe proximal femoral bone loss makes it even more challenging to achieve good femoral component and fracture fixation as is seen in a Vancouver B3 periprosthetic fracture (Fig. 11.4). Options for treatment of such challenging fractures include

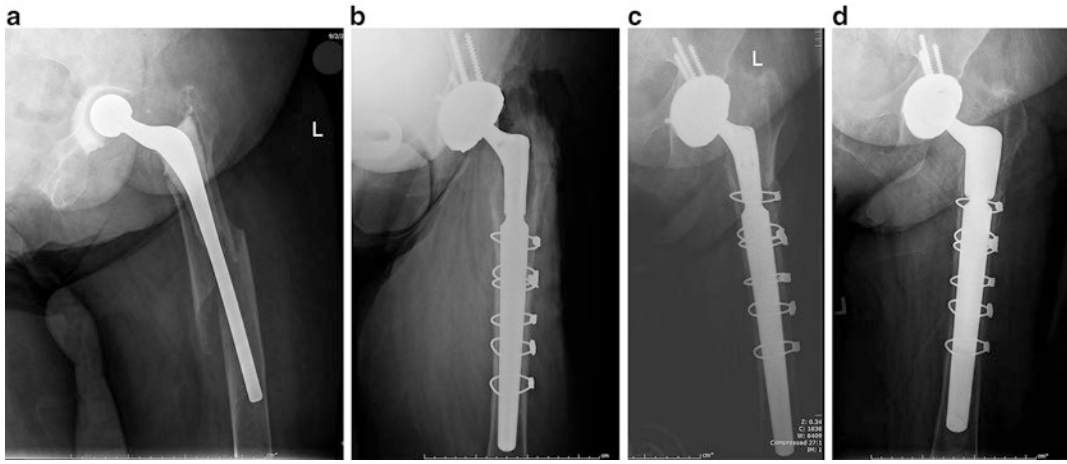

Fig. 11.4 (**a**) Vancouver B_3 fracture around a temporary hip spacer. (**b**) Patient underwent a revision with modular fluted tapered stem that (**c**) later subsided and (**d**) was revised to a larger diameter modular fluted tapered stem

long cylindrical or fluted stems, with or without cortical strut grafting, allograft-prosthetic composite, or proximal femoral replacement. The optimal method of reconstruction depends on the patient's physiologic demands, fracture extent and location, and degree and severity of bone loss.

Long modular fluted tapered uncemented stems with retention of the proximal femur have been successfully used by Berry et al. [48] who treated eight patients with a modular fluted tapered grit-blasted titanium stem. Seven patients were available for follow-up. The revision stem was potted distally and the fractured fragments were pulled together around the stem using cerclage cables while preserving their muscular envelope. At a mean follow-up of 1.5 years, he found that all implants were stable and all fractures had healed. Munro et al. [49] treated 55 patients with Vancouver B_2 and B_3 fractures with a modular titanium fluted stem. Cortical onlay allografts were used in 14 of the B_3 fractures. They reported one nonunion, stem loosening in one patient, and infection in another patient. They did however notice a 24% rate of subsidence on radiographic evaluation.

Springer et al. [50] reported on a series of 35 Vancouver type B3 fractures treated with revision arthroplasty. The authors recommended the use of allograft-prosthesis composites or tumor prostheses in patients with severe damage to the proximal part of the femur, and uncemented, fluted, tapered stems that gain axial and rotational stability distal to the fracture in select cases. In a retrospective case series of 44 Vancouver B2 (25 patients) and B3 (19 patients) periprosthetic femur fractures treated with fluted, modular, tapered stems at the same institution, the authors reported good radiographic healing and stable femoral stems in 43 out of 44 cases (98%) at an average follow-up of 4.5 years. Five patients (11%) had recurrent instability and two patients developed deep infection [51].

In femoral fractures in which bone loss extends past the femoral diaphysis, and the geometry of the remaining femur will not support an uncemented stem, reconstruction with tumor prosthesis or an allograft is indicated. Blackley et al. [52] reported their experience with 63 total hip arthroplasties in 60 consecutive patients revised with a proximal femoral allograft-prosthesis construct. The success rate, defined as a postoperative increase in the Harris Hip Score of greater than 20 points, a stable implant, and no need for additional surgery related to the allograft, was 77% (37 of 48 hips). They used a transtrochanteric approach and a step-cut osteotomy of the femur to stabilize the host-graft junction. Stems were cemented into the allograft and press-fit into the distal femur. Haddad et al. [53] reported on 40 proximal allograft reconstructions in which the stem was cemented into the allograft and the host femur. There were four early revisions (10%) for infection and allograft nonunion, junctional nonunion in three patients (8%), instability in four (10%), and trochanteric nonunion in 18 patients (46%). Despite the high revision rate (13 out of 40 patients), the authors recommended continued use of structural allografts for failed total hip replacements with loss of proximal femoral bone.

Klein et al. [54] reported on a series of 21 patients with B_3 fractures treated with a proximal femoral replacement. Intraoperative hip instability with adequately positioned components was addressed with constrained liners. At the latest follow-up, the average Harris Hip Score was 71 points (range 56–90). All stems were stable at the latest follow-up (mean, 3.2 years). Dislocation occurred in two hips. The authors concluded that proximal femoral replacement for the treatment of these difficult fractures is a viable option for low-demand patients [54]. Lessons learned from this experience suggest that if an allograft prosthetic composite or a proximal femoral replacement is used, the risk of instability is high and the surgeon should thus consider the use of a constrained liner or a dual-mobility bearing.

One technical pearl that may be helpful to the surgeon is the liberal use of an extended trochanteric osteotomy (ETO) in these challenging cases [55]. The ETO is made down to the fracture site, and the loose stem is more easily removed. A prophylactic cerclage wire is then placed distal to the fracture site to protect the intact femoral diaphysis. In general we have found that a modular tapered stem is useful in

these scenarios as the isthmic segment for distal fixation is frequently short. The distal intact diaphysis is reamed for the distal segment of the stem, which is then impacted until axial stability is obtained. The modular proximal bodies are then used to recreate leg length, and once engaged in the proper version, the proximal fragments are cabled around the revision stem, taking care to respect the blood supply. This technique facilitates exposure as well as preparation and implantation of the diaphyseal engaging stem under direct visualization.

Type C Fractures

This fracture pattern is characterized by being well distal to the implant and is treated based on the existing diaphyseal femur fracture algorithms except that intramedullary fixation is not viable due to the presence of the femoral stem. In addition, the presence of the femoral stem typically necessitates bypassing the tip of the existing femoral stem proximally. A study of 17 patients with type C periprosthetic femur fractures treated with internal fixation using a locking compression plate (LCP) bridging the implant in place showed fracture union in all cases. Less invasive surgery was performed on 15 patients and open surgery at the fracture site in two cases. They reported one bending-type mechanical complication of the plate [56]. Once again it is important to extend the span of the fixation plate past the tip of the stem so as to avoid leaving a segment of weak bone between the stress risers of the stem tip and proximal end of the plate [25].

Case Solution

Case 1: The fracture was classified as Vancouver B_2 fracture (i.e., loose stem with adequate bone stock). Intraoperatively, the femoral stem was noted to be subsided deeply into the femur and the fracture was identified running from the medial calcar through the lesser trochanter distally on the anterior aspect. The femoral component was removed easily and two cerclage cables were passed around the proximal femur, one proximal and one distal to the lesser trochanter. The femur was then revised with a diaphyseal-engaging, modular tapered stem. During trial reduction, an audible crack was heard and it was noted that there was a trochanteric fracture at the site of the proximal cable. This was reduced anatomically and fixed with a trochanteric claw (Fig. 11.5). The fracture went on to heal and the stem was stable at 6 months postoperatively.

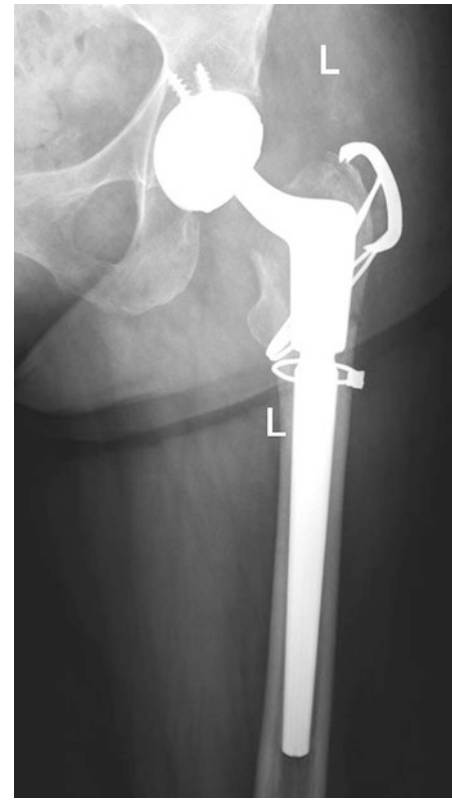

Fig. 11.5 Vancouver B_2 femoral fracture treated with cerclage wire fixation, trochanteric claw plate, and revision to a modular tapered stem

Case 2: The fracture was deemed unstable and the patient was taken back to the operating room for a femoral component revision. Two Dall-Miles cables were placed around the fracture and snugged primarily but not to the terminal tightness. The clamps were left on. The hip was then dislocated and the femoral component removed. The Dall-Miles cables were tightened further leading to an anatomic reduction of the fracture

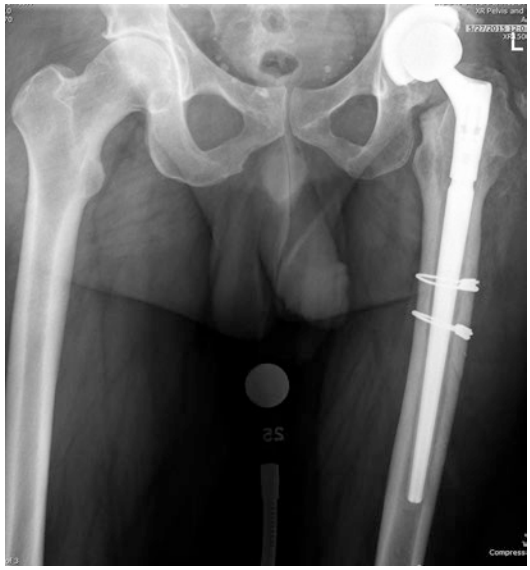

Fig. 11.6 The patient was taken back to the operating room and the femoral component was revised to a diaphyseal-engaging stem extending at least two cortical diameters past the distal extent of the fracture

fragments. They were clamped appropriately. The femur was then revised with a diaphyseal-engaging, modular tapered stem extending at least two cortical diameters past the distal extent of the fracture (Fig. 11.6). The fracture went on to heal and the stem was stable at 6 months postoperatively.

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Acute Pelvic Discontinuities

12

Nicolas Reina, Matthew P. Abdel,
and Daniel J. Berry

Case Presentation

A 70-year-old female with an unremarkable past medical history underwent an uncemented right total hip arthroplasty at an outside institution. During impaction of the press-fit acetabular component, a fracture of the posterior column was noted by the referring surgeon. The acetabular component was then removed and the posterior column was plated. A larger acetabular component was subsequently impacted with supplemental screw fixation (Fig. 12.1a, b). The patient was allowed to be partial weight bearing postoperatively, but had a subsequent fall. As such, she was then transferred to our institution for definitive management. Upon presentation, she was shortened and externally rotated on the operative limb. However, she was neurovascularly intact. Multiple radiographs (Fig. 12.2a–d) revealed an acute pelvic discontinuity with catastrophic failure of the acetabular reconstruction.

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Introduction

Pelvic discontinuities consist of a lack of continuity between the superior hemipelvis and inferior hemipelvis. While typically encountered in failed total hip arthroplasties (THAs) with massive bone loss, acute pelvic discontinuities may also occur during primary THAs due to excessive acetabular reaming or impaction of press-fit acetabular components. A thorough history and physical examination are paramount, but radiographic analysis remains the cornerstone of such a diagnosis. Indications of a pelvic discontinuity include a visible fracture line, obturator ring asymmetry, and medial migration of the inferior hemipelvis with disruption of Kohler's line [1].

Many classifications have been proposed to describe periprosthetic bone loss in revision THAs. Paprosky et al.'s [2] is the most commonly utilized scheme, but the American Academy of Orthopedic Surgeons (AAOS) [3] also has a classification scheme available. In the Paprosky classification, there is no specific classification for a pelvic discontinuity. However, they can occur with type IIC or IIIB defects. Based upon the AAOS classification, pelvic discontinuities are considered a type IV defect [3]. Berry et al. [1] further subclassified these type IV defects into three subtypes: type IVa (association with cavitary or mild segmental bone loss), type IVb (large segmental or a combined defect), and type IVc (any lesion on a previously irradiated acetabulum).

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_12

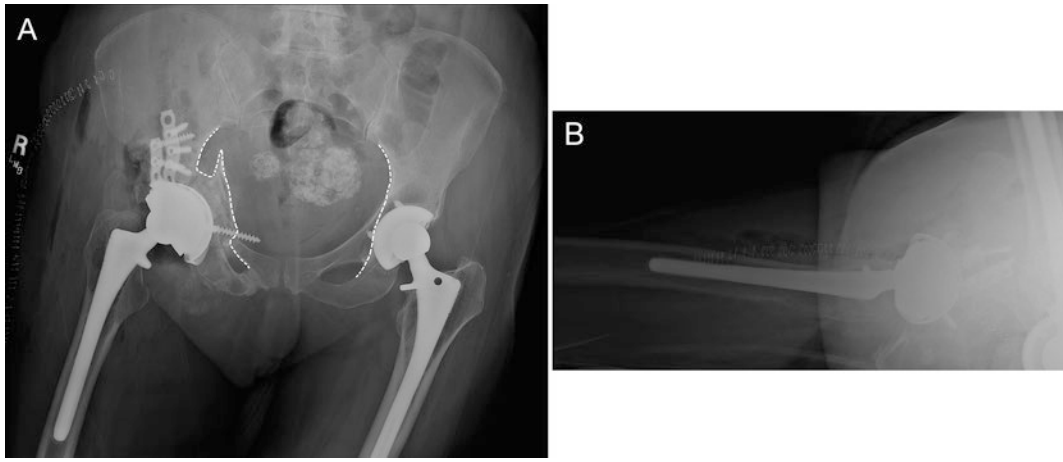

Fig. 12.1 (**a**) Anteroposterior (AP) pelvic and (**b**) lateral immediate postoperative radiographs of a 70-year-old female who underwent an uncemented primary THA at an outside institution. On the AP radiograph, there is disruption of Kohler's line and asymmetry between the obturator foramens. On the cross-table lateral, a fracture of the posterior column is noted. All of these findings are concerning for an acute pelvic discontinuity. The *dotted line* on the *right* hemipelvis indicates the disrupted ilioischial line, whereas the *dotted line* on the *left side* indicates the intact ilioischial line. *Images courtesy of Michael J. Taunton, M.D.*

Epidemiology

The true epidemiology of pelvic discontinuities after primary THA is difficult to assess. However, most literature suggests that the incidence is between 1 and 5% [4–6]. The Mayo Clinic reported an incidence of 0.9% in 3505 revisions [7]. Given the fact that primary and revision THAs are projected to increase by 174% and 137%, respectively, by the year 2030 [8], it is likely that pelvic discontinuities will continue to be an increasing burden.

Risk Factors

There are several risk factors that may predispose patients to an intraoperative pelvic discontinuity. Those factors include:

- Female gender [9]
- Rheumatoid arthritis [1]
- Poor bone quality
- History of radiation [1, 10]
- Press-fit acetabular components [11]

There are a few scenarios that deserve special attention. Postmenopausal women have a particularly increased risk of acute pelvic discontinuity given their smaller acetabuli and lower bone density [12]. In addition, the use of press-fit acetabular component is a risk factor for pelvic discontinuities. While Springer et al. [11] highlighted the risk of an intraoperative pelvic discontinuity due to over-reaming of the acetabulum, others have shown an increased risk of fracture with under-reaming and impaction of uncemented acetabular components [12, 13].

Prevention

There are several preventative measures that may reduce the risk of pelvic discontinuity during a primary THA. Foremost, a safe and adequate exposure of the acetabulum is essential. The importance of such an exposure is highlighted by the fact that cup malpositioning is more common in obese patients where exposure is often compromised [14]. In addition, patients with poor bone quality (i.e., postmenopausal females with osteoporosis) deserve special attention to avoid overly aggressive placement of retractors.

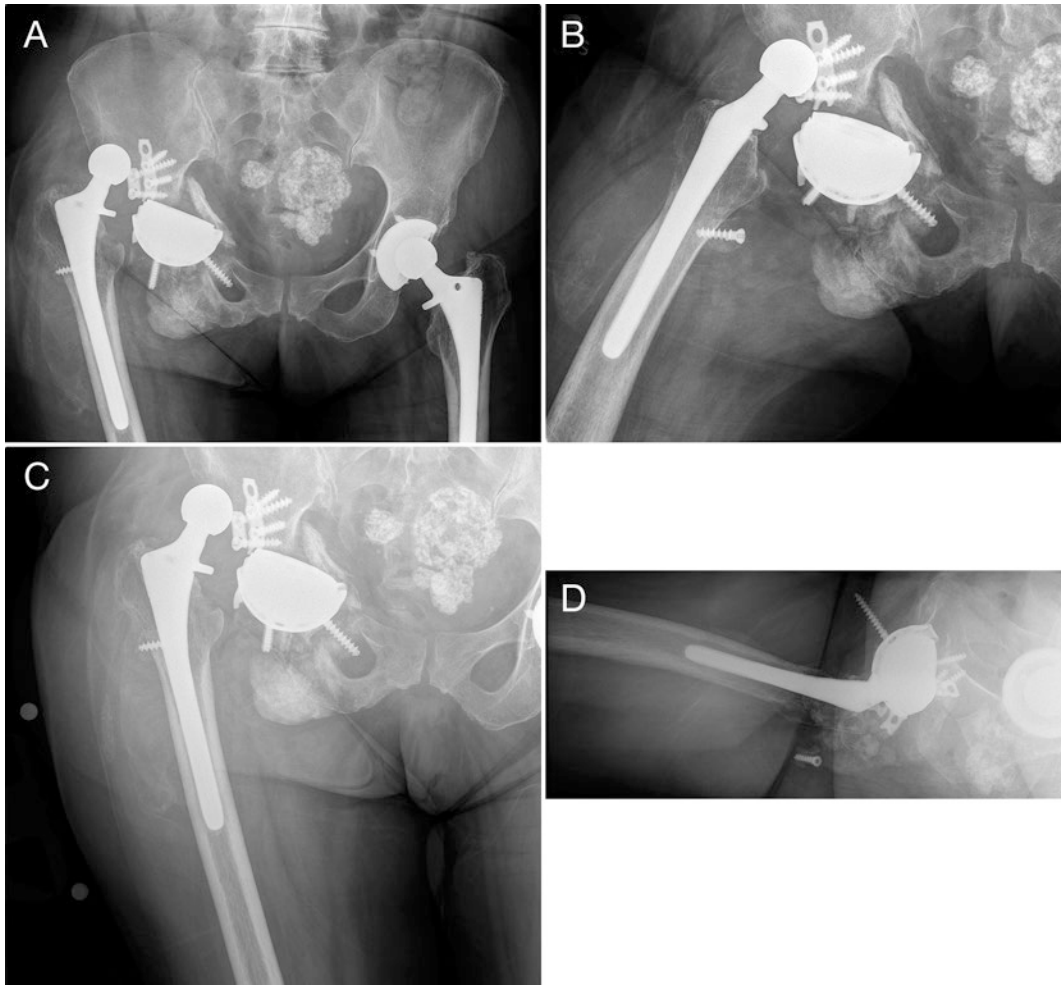

Fig. 12.2 (**a**) Anteroposterior (AP) pelvic, (**b**) oblique, (**c**) AP hip, and (**d**) cross-table lateral radiographs of the above patient when she presented to our institution several weeks later. In conjugation, the radiographs reveal an acute pelvic discontinuity with catastrophic failure of an attempted open reduction and internal fixation with plating. *Images courtesy of Michael J. Taunton, M.D.*

Once an adequate exposure is obtained, the surgeon must carefully ream the acetabulum, taking into account the preoperative templating, sharpness of the reamers, quality of the host bone, and particular implant system being utilized. Over-reaming can lead to major defects, particularly when the acetabulum is reamed asymmetrically. In some scenarios, the surgeon may consider line-to-line reaming to minimize aggressive impaction of the acetabular component. If an uncemented acetabular component is impacted and an adequate press-fit is not obtained, the surgeon should remove the acetabular component to ensure that a discontinuity was not inadvertently created. Intraoperative imaging in orthogonal planes should also be considered if suspicion for an intraoperative fracture exists.

Diagnosis

While a thorough history and physical examination are important, most pelvic discontinuities are diagnosed on imaging studies. All patients should have a basic set of radiographs including an anteroposterior (AP) pelvis, AP hip, and a lateral hip.

With these views, the anterior column can be evaluated via the iliopectineal line, while the posterior column can be evaluated via with ilioischial line (Fig. 12.1). A disruption in either of these lines is concerning for a pelvic discontinuity. Judet radiographs are often very helpful, including an iliac oblique and obturator oblique [15]. Martin et al. [16] recently showed that radiographic indicators of a pelvic discontinuity include either a fracture line identified on two orthogonal views (i.e., AP pelvis and true lateral radiograph or both Judet views) or a fracture line identified on one view (AP pelvis, Judet view, or true lateral radiograph) associated with evidence of pelvic rotation or pelvic asymmetry (Fig. 12.1). The above criteria was accurate in diagnosing 94% of pelvic discontinuities without advanced imaging. Moreover, the combination of an AP pelvis, a lateral hip, and Judet views led to an accurate diagnosis in nearly all cases.

However, advanced imaging, particularly thin-cut (i.e., 1 mm) computerized tomography (CT) scans are playing an increasing role in both the diagnosis and management of patients with pelvic discontinuities. When compared to radiographs, CT scans incrementally allow for assessment of remaining columnar bone, as well as amount of remaining superior dome, anterior wall, and posterior wall. Three-dimensional reconstructions are increasingly useful for the diagnosis of a pelvic discontinuity as well [17]. Contemporary higher quality CT scans have been available through the use of metal artifact reduction sequences (MARS). Additional techniques can lead to more precise evaluation. Recently, Fehring et al. [18] reported a novel technique where CT scans were reformatted into 45° Judet views. This allowed for an increase in the sensitivity of diagnosing pelvic discontinuities by 18%.

Nonoperative Treatment

The treatment of an intraoperative pelvic discontinuity primarily depends on when the discontinuity is recognized. If noted intraoperatively, pelvic discontinuities should be treated operatively (as noted below). However, if only appreciated postoperatively, then a discussion must occur between the patient and the surgeon to discuss management options. Nonoperative management is reserved for frail patients who cannot tolerate a second operative procedure.

Operative Treatment

The surgical treatment of pelvic discontinuities is demanding given the fact that both fracture and implant fixation must be addressed. The first goal is to restore a biomechanically continuous pelvic ring connecting the superior and inferior aspects of the pelvis (and thus acetabulum). The second is to obtain a stable reconstruction based on rigidly fixed implants.

Open Reduction and Internal Fixation (ORIF) with Plating

In the majority of acute pelvic discontinuities, there is minimal bone loss. As such, open treatment with plating of the posterior column and bone grafting of the fracture is typically successful [19]. Traditionally, plate fixation is achieved by placing three screws superior and three screws inferior to the pelvic discontinuity. Plate stability is critical as it creates compression forces on the fracture to promote healing. Autologous bone grafting may also be considered. After the pelvic ring is restored with osteosynthesis, a highly porous uncemented acetabular component can be placed with supplemental screws through the acetabular component and into host bone. If ORIF and plating do not provide adequate stability to allow for placement of an acetabular component, then one of the below reconstructions is recommended.

Cup-Cage Construct

When stability cannot be achieved with ORIF via plating in the setting of an acute pelvic discontinuity, consideration should be given to a

cup-cage construct [9, 20, 21]. With this technique, a highly porous acetabular component is placed on host bone with proximal screws placed into the ilium and inferior screws placed in the ischium. In essence, the acetabular component serves as an "internal plate." Thereafter, a cage is placed from the ilium to ischium with supplemental superior and inferior screws for additional "splinting" of the fracture while healing of the construct occurs.

Highly porous implant surfaces have been developed that promote bone ingrowth and are also associated with higher coefficients of friction against bone to increase initial implant stability [10]. Our preference is to use a tantalum acetabular component (Trabecular Metal™ [TM]; Zimmer; Warsaw, IN) given its high porosity, high coefficient of friction, modulus of elasticity that is similar to cancellous bone, and excellent track record in challenging scenarios [10, 22, 23]. The cage is fixed to the bone by screws into the ilium superiorly with the inferior flange typically placed directly into the ischium. As the cup we prefer is non-modular, the liner is then cemented into the construct, with the least amount of constraint preferred to minimize bone-implant loads. However, in some rare circumstances, a dual-mobility construct or constrained liner is needed. Ultimately, the stability of the construct is based upon the highly porous acetabular component, supplemental cage, and numerous additional screws for adjunctive fixation [24].

Distraction Method

A third option in the management of acute pelvic discontinuities is the use of the distraction method as popularized by Paprosky and Sporer et al. [25]. The method is based upon gaining pelvic stability by distraction of the discontinuity through elastic recoil of the pelvis, and by fixing the superior and inferior hemipelvises to a highly porous metal cup or augment with screws, thereby unitizing the superior and inferior aspects of the pelvis. To date, there is only one published report in the revision setting [25].

Custom Triflange

This is a very limited role for custom triflanges in the treatment of acute pelvic discontinuities given that a CT scan is required, as is a prolonged manufacturing period. In the future, and with the advent of rapid 3-D printing, there may be a role for such a reconstruction in select group of patients.

Literature Review

Historically, the sole use of anti-protrusio cages and reinforcement rings in the treatment of pelvic discontinuities has been associated with high failure rates, ranging from 50% at 3.3 years of follow-up [26] to 60% at 6.9 years of follow-up [19].

When adequately managed, acute pelvic discontinuities have shown acceptable outcomes. Rogers et al. [27] found 100% survivorship free of revision at a mean of 34 months in 9 patients with acute pelvic discontinuities (i.e., diagnosed within 12 weeks of index primary THA) treated with posterior column plating and a revision tantalum acetabular component. Of note, 67% of patients in this series also had autologous bone grafting. Stielh et al. [19] reported ten cases of chronic pelvic discontinuities treated with ORIF and plating. Eight patients had plating of both columns, while one had plating of the posterior column and one of the anterior column only. At a mean follow-up of 33 months, seven of ten had healed. However, there were four revisions at most recent follow-up (two for infection and two for aseptic loosening).

The cup-cage construct has recently gained popularity as an option for reconstruction of pelvic discontinuities [21, 28]. While typically reserved for chronic pelvic discontinuities, similar techniques and principles can be used to manage acute pelvic discontinuities that are not amenable to ORIF with plating. Abolghasemian et al. [29] compared 26 pelvic discontinuities (24 patients) treated with a cup-cage construct to 19 patients treated with a cage alone. At a mean follow-up of 82 months, 68% of the cage-alone group had failed, as opposed to 15% in the

cup-cage group. As such, the 7-year survival rate was 87% for cup-cage group. Amenabar et al. [9] confirmed those findings and later reported that 4 of 45 cup-cage patients had to be revised for aseptic loosening at a mean follow-up of 77 months.

While rarely indicated for acute pelvic discontinuities, minimal literature does exist on the use of the distraction method [30]. Sporer et al. [25] reported on 20 chronic pelvic discontinuities in patients treated with this method. At a short mean follow-up of 4.5 years, the authors found that one patient had radiographic evidence of loosening and was revised. Four additional patients had some radiographic evidence of loosening, but were not revised as they were asymptomatic.

There is a higher risk of complications following revision for pelvic discontinuity. These are complex procedures with a substantial risk of nerve injury related to the use of cages and adjunctive screws as well as a real risk of vascular injury. Further, most studies suggest a substantial risk of both dislocation and infection. Further, as noted above, even in cases where rigid fixation of the implant and pelvis is obtained, failure of fixation can also occur.

Case Solution

In this particular case, the patient had previously failed an attempt at open reduction and internal fixation (ORIF) with a plate and uncemented hemispherical component (with supplemental screw fixation). Moreover, there was significant bone loss. As such, a custom triflange (Fig. 12.3a, b) was utilized along with 200 cm^3 of allograft bone. At 2 years of follow-up, the patient was fully weight bearing without pain, but did require the use of a cane given some abductor weakness (Fig. 12.4a–d).

Summary

Pelvic discontinuity remains one of the most difficult complications to manage after THA. Careful preoperative imaging and planning are the first steps before surgery to identify the discontinuity

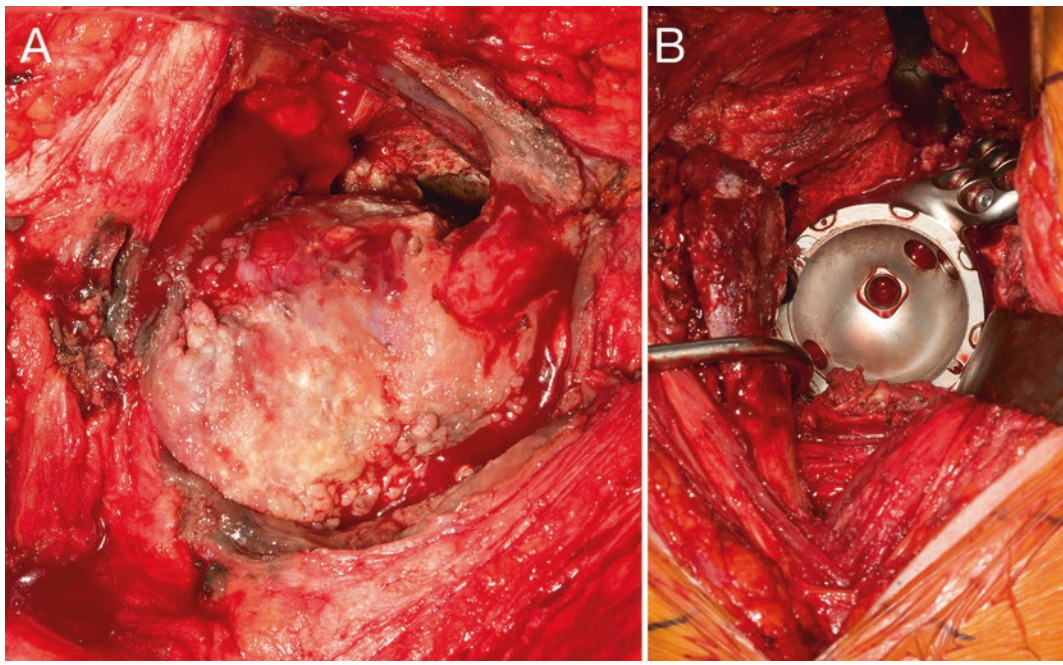

Fig. 12.3 (**a**) Intraoperative figure depicting the pelvic discontinuity with dissociation of the superior and inferior hemipelvises. (**b**) Intraoperative image with the custom triflange implanted. *Images courtesy of Michael J. Taunton, M.D.*

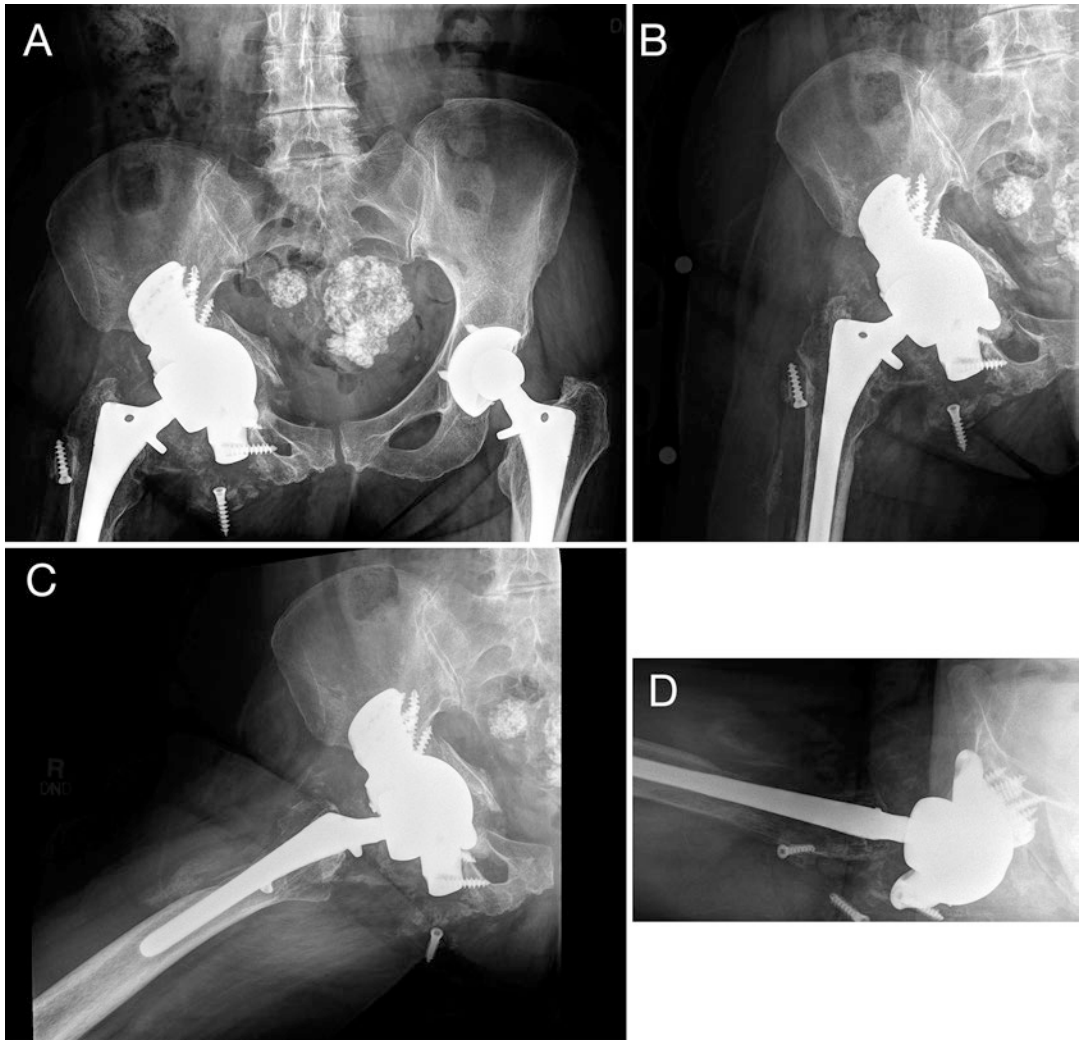

Fig. 12.4 (**a**) Anteroposterior (AP) pelvic, (**b**) AP hip, (**c**) oblique, and (**d**) cross-table lateral radiographs of the above patient at 2 years of follow-up. *Images courtesy of Michael J. Taunton, M.D.*

and plan for management. The AAOS classification as modified by Berry can be used to assess and plan for appropriate management. Guidelines for the management of this complication include obtaining both rigid fixation of the pelvis and the revision implant. Patients should be warned, however, that the risk of complications and problems following this challenging complication is high.

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Wear and Osteolysis of Polyethylene Bearings

13

James A. Keeney

Case

A 65-year-old female presents 14 years after undergoing a primary left total hip arthroplasty (Fig. 13.1). Her hip had functioned well for a number of years, allowing her to resume her normal lifestyle. Over the past 2 years, she has noted a progressive increase in left groin and buttock pain. Over the past 3 months ago, she has noticed a squeaking sensation in her left hip during ambulation. She has started to use a cane to help manage her pain. The patient was referred for evaluation and treatment.

Epidemiology

Osteolysis and component loosening have been identified among the most common mechanisms for late total hip arthroplasty (THA) failure [1]. During normal activity, wear particles are released from metal-on-polyethylene (M-O-P) and ceramic-on-polyethylene (C-O-P) bearing surfaces. Adhesion and abrasion between the femoral head and polyethylene insert are the primary mechanisms for wear. Hydraulic pressure produced during normal hip movement forces joint fluid and polyethylene wear debris through the "effective joint space" [2].

Areas of the host bone-implant interface that are not sealed by circumferential bone contact, osseointegration, or polymethylmethacrylate (PMMA) cement bonding can allow access for polyethylene, metal, ceramic, or PMMA particles to the implant-bone interface. When exposed to particulate wear debris, macrophages initiate and osteoclasts mediate the process of bone resorption around initially stable implants [3, 4]. NFkappaB ligand (RANKL), produced by osteoblastic stromal cells, fibroblasts, or activated T-cells, binds to receptors on the surface of osteoclast precursor cells and stimulates them to convert into active osteoclasts [5, 6]. Among biomaterials used in total hip arthroplasty, polyethylene has the highest potential to induce osteolysis, with submicrometer-sized particles more strongly associated with the osteolytic process than macroscopic debris [7]. Osteolysis also appears to be associated with more rapid release of polyethylene debris from the bearing surface, with higher volumetric wear and linear rates greater than 0.2 mm/year implicated with the development of radiographically evident osteolysis [8].

The radiographic presentation of osteolysis differs based on the patterns of particle access through the effective joint space around cemented and cementless total hip arthroplasty prostheses.

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_13

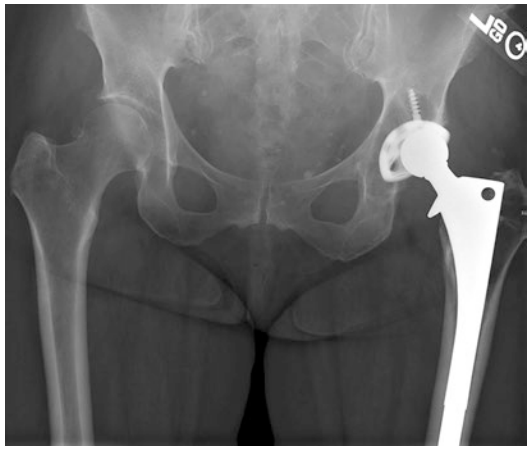

Fig. 13.1 Case example (preoperative AP radiograph)

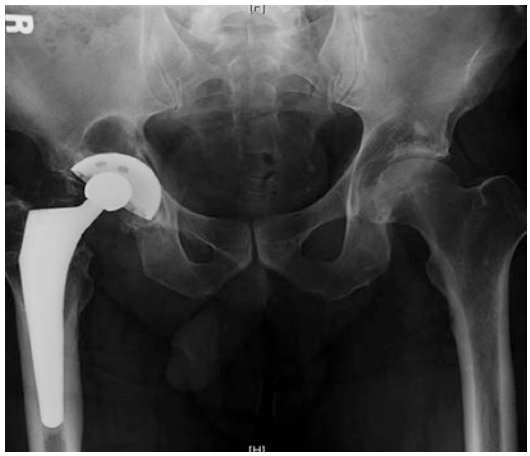

Fig. 13.2 Focal osteolysis behind a cementless acetabular component

For cemented components, the osteolytic process advances in a linear fashion along the cement-bone interface, beginning at the joint surface and extending to the most distant areas of bone-implant contact. The patterns of linear osteolysis around femoral and acetabular implants were first reported by Gruen and DeLee, respectively [9, 10]. When osteolysis develops in association with well-fixed, cementless components, the process results in a focal expansion within areas of the bone-host interface where the particles are able to gain access (Fig. 13.2) While implants may initially remain mechanically stable, progressive focal (balloon) osteolysis can undermine implant fixation and result in late loosening.

Risk Factors Associated with the Complication

A variety of factors have been associated with either accelerated wear rates or catastrophic polyethylene liner failures. Kennedy et al. [11] reported an association of vertical acetabular component malposition with higher rates of osteolysis and linear polyethylene wear. Patil et al. [12] estimated that polyethylene liners placed in a position >45° of inclination were subject to a 40% increase in linear wear using a finite element analysis model. The utilization of larger head sizes and thinner polyethylene inserts has been associated with higher rates of wear and osteolysis with conventional polyethylene liners in total hip arthroplasty [13]. Berry et al. [14] reported catastrophic polyethylene liner failures only among inserts less than 5 mm thick. Polyethylene degradation can be accelerated under conditions intrinsic to the material. Sterilization processes used in the late twentieth century were occasionally performed in an oxygen-containing environment and this was associated with higher rates of wear and osteolysis [15, 16]. This process is notably magnified when the polyethylene remains in a non-implanted inventory for extended periods of time (shelf life). Puuolaka et al. [17] noted that polyethylene inserts with a shelf life greater than 3 years had a substantially higher rate of wear and osteolysis than those with a shorter time before implantation.

Prevention

Irradiation introduced during the process of ultrahigh-molecular-weight polyethylene (UHMWPE) sterilization was noted to have an effect of reducing the linear and volumetric wear rate of polyethylene [18]. This cross-linking process increases the wear resistance of the polyethylene material in exchange for decreasing

its fracture resistance. Several studies have now demonstrated a substantial reduction in the wear rate of highly cross-linked polyethylene used in contemporary total hip arthroplasty through the first 10 years after implantation, even when performed among younger patients [19–21]. The use of a ceramic femoral head has demonstrated reduced wear rates when used with a conventional polyethylene bearing, but the benefits have not yet been substantiated when coupled against a highly cross-linked polyethylene liner [22, 23]. Improvements in the durability of highly cross-linked polyethylene have contributed to the availability of larger femoral heads for primary total hip arthroplasty. Selection of femoral head size for an individual patient should take several factors into account: patient factors associated with hip dislocation (female gender, diagnosis other than osteoarthritis), acetabular component size, and minimum polyethylene liner thickness, and risk for wear of the replaced acetabular liner during the expected remaining years of a patient's life. While the stability of hip replacement constructs is improved with the use of larger femoral head sizes, increased contact between the larger femoral head and polyethylene liner can contribute to higher rate of volumetric polyethylene wear [24].

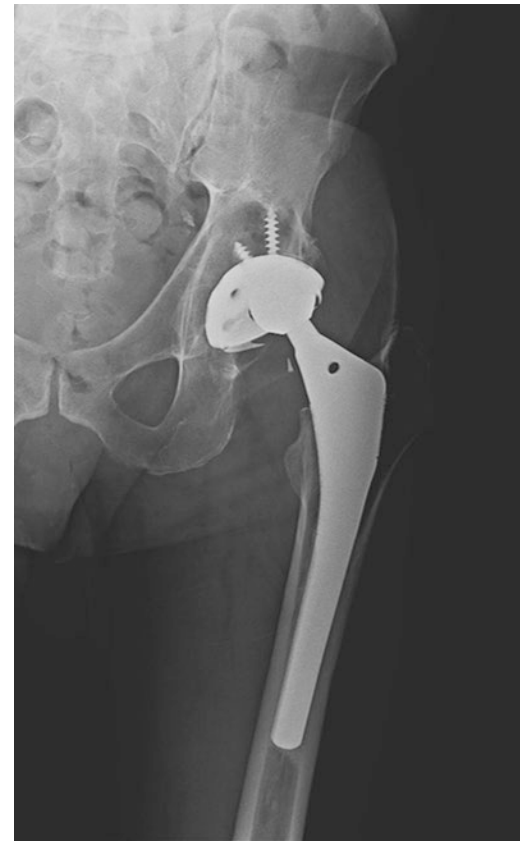

Fig. 13.3 Asymptomatic superolateral polyethylene wear and associated focal osteolysis

Diagnosis

The diagnosis of polyethylene wear can be made from a review of radiographic imaging studies, particularly when the femoral head migrates in a superolateral direction (Fig. 13.3). The amount of linear wear occurring in an acetabular component may be harder to define for components placed with less than a 40° inclination angle as wear will occur more medial or central within the acetabular liner. Osteolysis can be noted by the presence of osteopenia and loss of normal trabecular architecture around the implant. Iliac and obturator oblique Judet radiographs may be helpful in defining the presence of osteolysis, size of the defects, and integrity of the posterior and anterior columns. Cross-sectional imaging using computed tomography (CT) scan can provide greater detail of the characteristics and size of osteolytic defects and may be helpful [25] (Fig. 13.4).

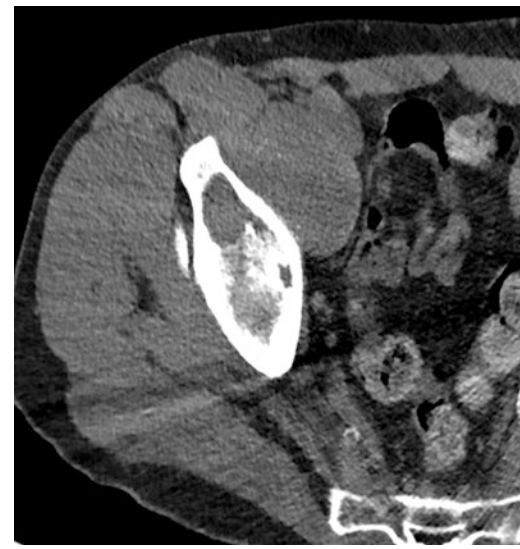

Fig. 13.4 CT scan visualizing posterior column osteolytic defect

Treatment

Nonoperative Treatment

Asymptomatic patients with contained osteolytic defects may be treated without surgery. Symptoms of weakness around the hip may be addressed with rehabilitation and minor symptoms of discomfort may be alleviated with analgesic or anti-inflammatory medication. If a nonoperative treatment approach is considered for any patient after an initial diagnosis of osteolysis, consideration should be given to early radiographic follow-up (3–6 months), particularly if the lesion is larger. Annual surveillance of nonoperatively treated radiographic osteolysis would be recommended on an ongoing basis. Decision making regarding the appropriate timing of surgical intervention has not been clearly defined. Factors to consider include the age and activity level of the patient, track record of the implanted components, and patient preference. For example, in a younger, fit, active patient the threshold to recommend revision surgery will oftentimes be lower even if small areas of osteolysis are identified whereas continued observation is typically chosen in elderly patients with more medical comorbidities that may limit their activity and increase the risks of surgery.

Operative Treatment

Symptomatic patients with loose implants and patients with large osteolytic defects that threaten long-term implant stability should be approached with operative management. A variety of surgical approaches may be considered for the treatment of polyethylene wear and osteolysis. The specific approach that is selected for a given patient is dependent on the size of the osteolytic lesion, stability of the arthroplasty components, integrity of the implant's locking mechanism, availability of structural bone for biologic fixation of revised components, and consideration of the age and overall physical health of the patient requiring surgical treatment. The decision to remove well-fixed components should occur with thoughtful consideration of the bone quality behind the implant and the availability of implants that are best suited to manage a spectrum of deficiencies on either the acetabular or the femoral sides of the hip. Given that instability is a common complication of isolated bearing surface changes, careful consideration must be given to component position when determining if component revision or retention is more appropriate. Regardless of the treatment approach selected, exchange of the polyethylene material and femoral head are central components of any revision procedure to address the bearing surface "wear generator."

Component Retention

Component retention and bone grafting of osteolytic defects can be coupled with revision of the femoral head and polyethylene liner for patients with stable components, contained osteolytic defects, and a functioning acetabular liner locking mechanism [26]. It may also be reasonable to consider cementing a new acetabular liner into a retained acetabular shell if the locking mechanism is not mechanically sound but the position of the component is good and the metal shell is large enough to cement the desired liner into place [27, 28]. The major reported complication associated with a component retention approach is postoperative dislocation, and patients with smaller acetabular components may have a higher rate of mechanical failure of cemented liner fixation [29, 30].

There are three major decisions that are made during a component retention approach in revision hip surgery: (1) polyethylene material and design, (2) femoral head material, and (3) femoral head size. The decision on implant selection should take into account the desire to prevent prosthetic component instability—the most common complication after isolated head-liner exchange—and also the considerations of bearing surface wear and potentially adverse impact of placing a new modular femoral head onto a retained femoral implant.

Polyethylene Material and Design

Improvements in highly cross-linked polyethylene materials have been associated with low rates of polyethylene wear even when used for young and active patients with femoral head sizes 32 mm or less [19, 31–33]. Contemporary polyethylene bearings provide several options that may be beneficial in different revision settings: neutral or elevated rims, neutral or lateralized offset, constraint, or combination of a mobile-bearing polyethylene femoral head against a metal acetabular liner (dual mobility). Kremers et al. have demonstrated a low risk for midterm re-revision when highly cross-linked polyethylene liners are utilized and no increase in risk of failure associated with the use of an elevated rim liner [34]. Specific acetabular components may provide the option for using either a constrained acetabular liner or a dual-mobility femoral head coupled with a metal acetabular liner. Both of these may be useful for cases where acetabular component position is acceptable, but hip abductor musculature does not provide adequate dynamic support.

Femoral Head Material

When combined with conventional polyethylene acetabular liners, ceramic femoral heads had demonstrated lower wear rates than cobalt chromium femoral heads [22]. Although contemporary studies assessing wear for hips using highly cross-linked polyethylene have not defined lower wear rates when ceramic heads are utilized, consideration may be given for the use of a ceramic femoral head among very young patients who are undergoing hip revision surgery for polyethylene wear with or without osteolysis. When the retained femoral component is made from a cobalt-chromium alloy, the selection of a cobalt-chromium femoral head should have limited potential for adverse trunnion-related behavior. When the retained femoral component is made from a titanium alloy, consideration may be given to the use of a ceramic femoral head, particularly if a large-diameter or long-length femoral head is selected [35]. Whenever a ceramic head is considered for use in a revision setting, the use of a titanium sleeve adapter provided by the femoral component manufacturer would be appropriate.

Femoral Head Size

While femoral head diameters ≥36 mm may improve hip stability during revision THA, studies have associated these larger head sizes with increased volumetric wear [24, 36]. Selecting a larger femoral head size can contribute to a lower risk for postoperative dislocation after revision during an isolated femoral head and polyethylene liner procedure. The decision to select a femoral head 36 mm or larger for use during a revision surgery should take into account three main considerations: (1) Can adequate stability be achieved with a femoral head 32 mm or less? (2) Does the diameter of the acetabular component support revision to a 36 mm or larger diameter femoral head with adequate retained polyethylene thickness? (3) Does the patient's age support a greater weight being given to the importance of hip joint stability over long-term considerations of polyethylene wear?

The author performs revision surgery through a posterior approach. If the acetabular component position is in a low amount of anteversion (<20°) and the femoral component is not excessively anteverted, consideration is given for the use of a polyethylene liner with an elevated rim. A neutral polyethylene liner trial is selected if combined femoral and acetabular component anteversion is greater than 45°. A constrained liner is utilized for patients with inadequate hip abductor support (structural or functional) when accommodated by the acetabular component design. Consideration is occasionally made for a dual-mobility component if appropriate for the acetabular component system under the same considerations. For younger or more active patients with an acetabular component <60 mm diameter, strong consideration is given for the use of a 32 mm femoral head. For older patients (>70 years) with acetabular components ≥56 mm in diameter, a 36 mm femoral head is generally selected. Physiologic age is used to guide femoral head size determination for patients between 60 and 75 years of chronological age. Cobalt-chromium femoral heads are used for most cases, except in rare cases where corrosion is noted on the trunnion where a cobalt-chromium femoral head has been removed.

Component Revision Approaches

Patients with loose or poorly positioned components are treated with component revision. The selection of specific implant fixation techniques should be guided by an understanding of host bone structural support in the acetabulum and femur for biologic implant fixation. The author's preference is to utilize the surgically based classification systems proposed to guide decisions on component selection and treatment of major bone deficiencies [37–39]. A variety of techniques may be considered in acetabular revision surgery for major osteolysis. These may include the use of highly porous implants, allograft augmentation of cavitary or structural bone defects, porous metal augmentation of structural bone deficiency, acetabular distraction with highly porous revision components for pelvic discontinuity, impaction grafting, and use of reconstruction cages [40–46]. For femoral revision surgery, commonly utilized treatment options include extensively porous coated stems, cylindrical monoblock or modular tapered stems, impaction grafting with cemented femoral implants, and endoprosthetic (oncology) prosthetic reconstruction [47–50].

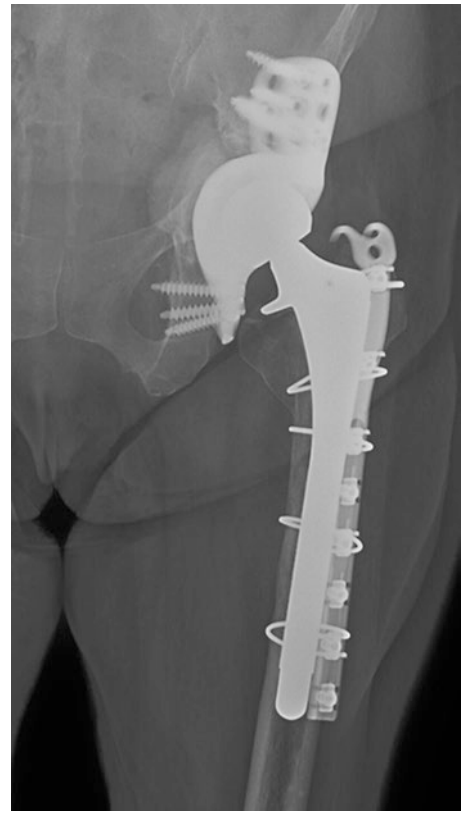

Fig. 13.5 Reconstruction of an acetabular defect with a custom triflange component

Acetabular Component Revision

Cases with contained acetabular defects can be managed with focal bone grafting and revision acetabular components. Consideration should be given to provide structural support to superolateral defects involving more than 30% of the component rim. This may be accomplished using either allograft bone or structural augments. A variety of revision options exist for the treatment of major medial or superomedial structural deficiencies including revision cementless components, cup-cage constructs, reconstruction cages, or custom acetabular components (Fig. 13.5).

Femoral Component Revision

The author's preference is to use monoblock cementless femoral components for most femoral revisions where proximal metaphyseal support is present and diaphyseal fixation of at least 5–6 mm can be achieved. For cases where a bowed femoral component ≥200 mm length is used and the proximal femur is intact, flexible reaming of the femoral canal between 0.5 and 1.5 mm greater than the size of the selected femoral implant may be necessary to avoid fracture during trial and implant component insertion. Placement of a prophylactic cable around the femoral diaphysis corresponding to the isthmus of the canal may be helpful to prevent intraoperative fracture. Femoral deficiencies with an intact isthmus, but less than 5 mm of bone available for biologic fixation, are generally treated with a modular tapered stem (Fig. 13.6) which is better able to achieve axial and rotational stability over a short length of femoral isthmus. For patients with severe proximal femoral deficiency, either a modular tapered stem or an

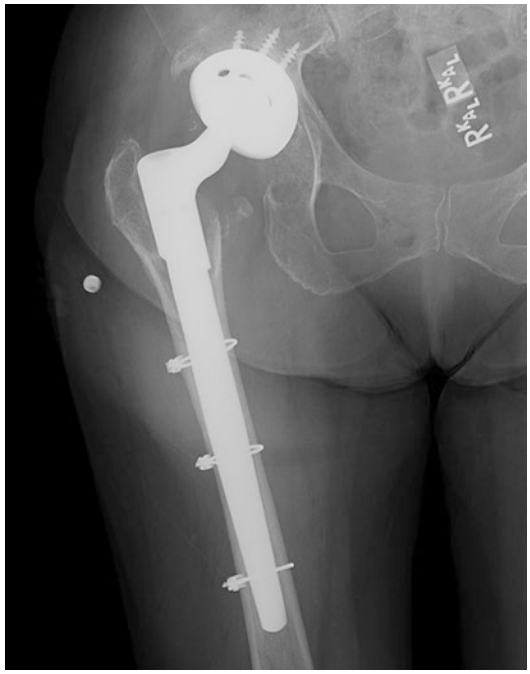

Fig. 13.6 Paprosky IIIB femoral deficiency treated with modular tapered cylindrical stem

endoprosthetic replacement prosthesis may be considered. For patients with severe deficiencies of both the metaphyseal and diaphyseal regions of the femur, an endoprosthetic replacement approach is our preference.

Case Solution

The patient who presented with polyethylene wear debris and focal osteolysis around a well-fixed shell was treated with an acetabular component revision. The considerations that influenced a decision for component revision included the patient's relatively young age, absence of an effective locking mechanism, and damage to the preexisting shell due to loss of the polyethylene liner. The acetabular component was removed with a specialty tool used to remove the implant, and the acetabulum was prepared with expansion of the acetabulum and grafting of contained acetabular defects. The polyethylene insert was replaced with a highly cross-linked polyethylene and was

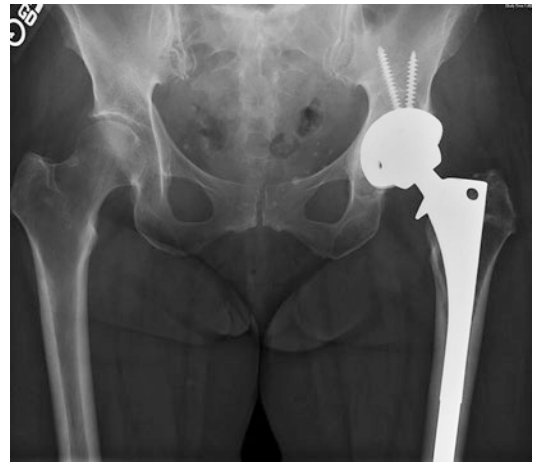

Fig. 13.7 Case example (Postoperative AP Radiograph): Acetabular component revised. Primary THA component was small without an adequate locking mechanism. 36 mm cobalt-chromium femoral head used with cobalt-chromium alloy femoral implant

increased in size to accommodate a larger femoral head to support prosthetic joint stability (Fig. 13.7).

Summary

Polyethylene wear, osteolysis, and component loosening is the most common sequence of late component failure in total hip arthroplasty. The longevity of contemporary total hip arthroplasties appears to have been improved with the introduction of highly cross-linked polyethylene, but more time is necessary to determine whether larger femoral heads can be safely used without an increased risk of late failure related to polyethylene wear, focal osteolysis, or linear osteolysis and component loosening. A well-fixed and well-positioned acetabular component with an intact locking mechanism may be managed with a component retention approach as long as periprosthetic stability is assessed well and assured. Acetabular component revision may be considered for patients with malpositioned components, components where mechanical stability of the revised acetabular liner cannot be achieved, or where revision of the acetabular liner results in prosthetic instability.

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14 Complications of Ceramic-on-Ceramic Bearings: Fracture, Stripe Wear, and Squeaking

Yadin David Levy and William Lindsay Walter

Case Presentation

An 81-year-old healthy female patient presented to the clinic with a new onset of grinding and clunking sensations during flexion in her right hip 15 years after a primary total hip arthroplasty (THA). The right hip received a cementless SecurFit (Stryker; Mahwah, NJ), a size 7 femoral stem (Stryker) coupled with a cementless 52 mm SecurFit cup (Stryker) and 32 + 0 mm Alumina Forte (BIOLOX forte, CeramTec AG, Plochingen, Germany)femoral head resulting in a third-generation CoC articulation. The onset of the audible grinding and clunking was precipitated by an event where there was transitory acute pain which appeared during a yoga pose. Clinical evaluation following the appearance of noises demonstrated painless hip movement with 0–110° of flexion. However, at 110° of flexion, there was a reproducible crunching noise followed by a clunk when moving to extension. Radiographic evaluation consisting of both radiographs (Fig. 14.1a, b) and a computer tomography (CT) scan (Fig. 14.2a–c) demonstrated a broken ceramic liner with ceramic particles embedded in the joint capsule. Assessment of the implant positioning showed an acetabular cup placed in 40° of inclination and 19° of anteversion.

Epidemiology

Despite the superior tribological properties of ceramic, these bearings are associated with a unique complication—fracture. Since the initial development of ceramics, specific efforts have been made to lower the fracture rate. Overall, with each generation of ceramics, there have been improvements in the manufacturing and regulatory processing leading to a smaller grain sizes and change in composition, hence producing a more fracture-resistant material. An evaluation of a large number of ceramic heads from the first three ceramic generations demonstrated a progressive reduction in the fracture rate [2]. Similarly, a clinical evaluation of data acquired from the French national agency for safety of drugs and medical products (Agence nationale de sécurité du médicament et des produits de santé) determined improved fracture rate of the femoral head between the third and fourth generation of ceramics [3]. However, this evaluation concluded that there

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_14

were no significant changes in the rate of fracture for the acetabular liner. Overall, with contemporary bearings the rates of ceramic fracture are extremely low [1]. It is estimated that with the fourth generation of ceramic the fracture rate is very low with liner fractures being more common than head fracture (0.03% and 0.003%, respectively) [3]. The fracture rates of various studies reporting on ceramic fractures are summarized in Table 14.1. Due to the fact that ceramic fractures are relatively uncommon with the later generations of ceramics, they are generally reported as sporadic case reports and smaller retrieval studies. This may document higher fracture rates up to 13.4% [4] which may give a misleading estimate to the actual fracture rates. Despite the very low rate of fractures associated with modern ceramics, it is still a documented phenomenon, which requires further surgical intervention.

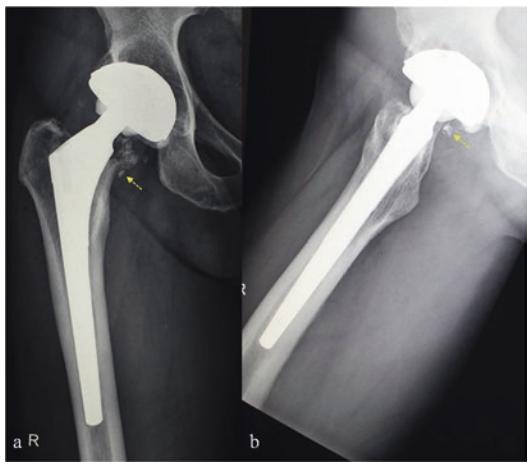

Fig. 14.1 Anteroposterior (**a**) and axial (**b**) radiographs of the right hip demonstrating ceramic fragments embedded in the joint capsule

Risk Factors

Ceramic fractures can occur either on the head or on the liner, and can be spontaneous or as a consequence of trauma. Risk factors can be classified as those related to implant design, technical factors, implant positioning, and/or material characteristics.

Head Fractures

The design factors associated with head fracture are head diameter and head length. A 28 mm head size has a higher risk of fracturing compared to a 32 or 36 mm head. A short neck length similarly has a higher fracture rate compared to longer neck length. These observations are clinically supported and believed to be caused by a reduced distance between the corner of the bore and outer surface of the head which can predispose to fracture formation due to ease of crack propagation [5–7]. Thus in our practice we try to avoid the use of a 28 mm ceramic head with a short neck length in order to minimize head fracture complication. In addition to lower head fracture rates, another potential advantage for large-diameter heads is linked to increased head-to-neck ratio, consequently increasing the range of motion while decreasing micro-separation and neck-to-rim impingement which may lower ceramic acetabular liner rim fracture [8].

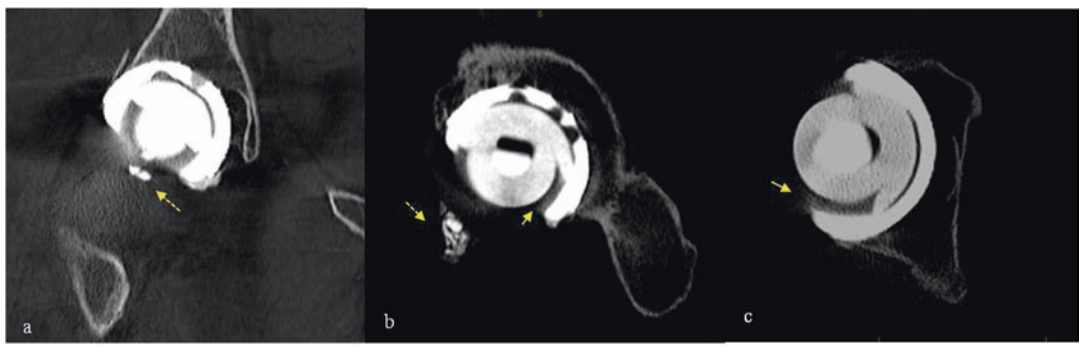

Fig. 14.2 Computer tomography scan of the right hip with coronal (**a**), sagittal (**b**), and axial (**c**) views of the ceramic articulation demonstrating broken ceramic fragments (*dashed arrows*) and broken ceramic liner (*solid line arrows*)

Table 14.1 Material properties and fracture rates of ceramic femoral heads and acetabular liners

Ceramic generation	Grain size (μm)	Fracture rates: head (%)		Fracture rates: Liner (%)
		Willmann [2]	Massin et al. [3]	
First generation	7.2	0.026	–	–
Second generation	4.5	0.014	–	–
Third generation	1.8	0.004	0.18	0.086
Fourth generation	0.6	–	0.0013	0.025

Technical issues are related to the cleanliness of the taper, as well as the head impaction force. A contaminated taper covered with debris and blood can lead to uneven load distribution on the head which may facilitate fracture formation [9]. The buildup of excessive loads in specific regions (point loading) can lead to the ceramic burst fractures. The trunnion is designed with sequential threadlike patterns that provide even load distribution onto the femoral head. When the head is secured onto the trunnion these threads are permanently deformed, locking the head with the stem taper. The centralization of the head onto the taper is important to obtain optimal head alignment and positioning. According to the manufacture guidelines this can be surgically achieved by a slight turning motion when positioning the femoral head onto the trunnion followed by a sufficient impaction load [10]. Positioning of the head without additional impaction is not sufficient for a secure lock between the head and the stem taper [10].

Acetabular Liner Fractures

Similar to ensuring the cleanness of the stem taper prior to head impaction, it is important to ensure the cleanness of the acetabular shell prior to liner insertion as this can prevent point loading. Liner insertion and position within the cup are critical to prevent liner chipping. It is important to recognize that titanium acetabular cups can deform up to 0.6 mm upon insertion [11]. The deformation of a modular acetabular cup might be more critical with the use of a larger femoral head size due to the reduced liner thickness in order to accommodate the use of a larger femoral head in a smaller acetabulum [8]. In such cases, it might be beneficial to use a preassembled cup to avoid micro deformities during impaction.

In contrast to polyethylene liners, which can undergo deformation to adapt to the cup, ceramics' inherent rigidity will not tolerate such changes. Therefore, in cases where the bone is hard, reaming line to line instead of under-reaming may be beneficial in reducing the overall cup deformation. A malpositioned or tilted liner within the acetabular shell (canted liner) can cause uneven load distribution, chipping, or dissociation. In case of dissociation, the liner can be repositioned to a canted state, which may lead to fracture [12]. To protect the ceramic from potential chipping upon insertion, a metal back ceramic liner where the metal exceeds the ceramic rim was introduced. However, this did not solve the problem and created other problems such as neck-to-rim impingement, reduced range of motion, and squeaking. It is critical to ensure centralization of the liner prior to impaction. Following impaction, it is important to inspect that the liner is uniformly flush against the cup rim.

Abnormal cup positioning has been shown to be associated with impingement, edge loading, excessive wear, metallosis, and squeaking [13]. The overall importance of cup positioning, impingement, and edge loading was further explored using a finite elemental analysis model [14, 15]. This model demonstrated excessive cup anteversion and inclination increased the risk for impingement, subluxation, and edge loading leading to liner fracture, which is in agreement with clinical retrieval studies [16–18]. Despite the limited literature regarding ceramic fracture and cup positioning, it is important to consider optimal cup positioning in order to reduce the potential occurrence of a liner fracture and the associated complications mentioned previously. In summary, in order to prevent ceramic liner fracture specific care should be taken when determining cup positioning, inserting, and securing a ceramic component during THA.

Diagnosis

The clinical presentation of a broken ceramic component may be either symptomatic or asymptomatic. Symptomatic presentation can be varied and may present as an acute sharp pain, or an audible sound (squeaking/other form of noises) which may vary throughout the hip arc of motion. Patient assessment should include a thorough history, physical examination, and radiographic assessment. Clinical examination may reveal limited range of motion and an appearance of clunks, grinding, and/or new noises. Radiographic assessment is conducted via anteroposterior (AP) pelvis and hip radiographs which may demonstrate ceramic particles embedded in the synovium and joint capsule (Fig. 14.1). In addition, an eccentric position of the head can be detected. A CT scan should always be performed to further assess the fracture pattern which has a special importance if the liner fracture is suspected, as this is more difficult to detect clinically [19]. Moreover, CT is beneficial for assessing component positioning and plays an important role in the evaluation of patients with newly appeared noise such as squeaking. The appearance of squeaking has been shown to have a clinical association with ceramic fractures [20, 21]. Joint aspiration and synovial fluid microanalysis were described as early diagnostic tools for ceramic liner fractures [17]. Ceramic fragments with a 5 μm diameter were associated with the presence of liner fractures. However, the role of aspiration in early detection of ceramic liner fractures requires further clinical assessment using larger patient cohorts.

Treatment

In the case of a ceramic fracture, revision surgery is always recommended and should be performed urgently. During revision surgery, multiple irrigations of the joint and a complete synovectomy should be performed in order to reduce the ceramic particles within the joint, ultimately reducing the risk of third-body particle wear. Following removal of the ceramic particles, inspection of the trunnion and the cup should be conducted. In the case of ceramic liner fracture, the acetabular metal shell will be damaged or deformed and should be replaced. In the case of ceramic head fracture, the trunnion most probably will be deformed due to its direct loading by the ceramic acetabular liner. In these cases we advocate for stem replacement. In rare cases where the femoral trunnion is macroscopically undamaged and the stem is well fixed, it is possible to consider retaining the stem as its removal can be associated with increased patient morbidity and impairment in hip function.

Generally, the literature supports the use of taper sleeves with a new head if the surface of the trunnion is not macroscopically damaged. A damaged trunnion surface will require stem removal and replacement [22, 23]. If a damaged trunnion is retained, it is theorized that it will lead to an uneven load distribution on the femoral head which can lead to ceramic fractures due to point loading [2, 24].

If the acetabular or femoral components are malorientated, removal of the component is advocated.

For bearing selection in revision surgery, the literature is in agreement that a CoC or a CoP bearing should be utilized [25, 26]. A conversion to a MoP is not recommended due to the scratching effect of the ceramic particles on the metal femoral head potentially leading to excessive wear of the head and the polyethylene [25, 26]. Studies evaluating the use of CoC in revision THA show good clinical results [27, 28].

Literature Review

Ceramic-on-ceramic bearings were developed in the 1970s to reduce wear and osteolysis traditionally associated with metal-on-polyethylene bearings. The two tribological properties important about CoC bearings are their hardness and wettability. The higher hardness allows ceramics to be highly polished and produce a lower surface roughness, hence providing a high resistance to scratching and wear. However, ceramics are a brittle material. Good wettability provides a uniform thin fluid across the bearing interface, which eliminates the frictional forces acting across the bearing.

Ceramics are a nonmetallic material that can be classed into crystalline or amorphous structures [29]. The localized density variation, grain size distribution, and porosity of ceramics identify the variation in their mechanical properties [29]. In the early 1970s, alumina was the chosen oxide ceramic. Clinical publications of alumina CoC demonstrated high clinical failure rates predominately due to aseptic loosening, and a high rate of ceramic fractures [30–32]. This was mainly associated with the lack of ingrowth surface and the variability in the manufactured material standardization of the alumina [8, 33].

In 1985, the development of zirconia was promoted due to its superior biomechanical strength in comparison to alumina [34, 35]. Zirconia has three different phases known as monoclinic, tetragonal, and cubic. The tetragonal stage is the strongest biomechanically; however it is unstable. Conversion from a tetragonal to a monoclinic phase creates a toughened ceramic. However, it is associated with volumetric change. Therefore, stabilization with yttrium oxide is used in combination with zirconia. The use of yttrium provides small tetragonal particles to exist within a stable state below the transformation temperature. In case of a crack formation, the tetragonal grains within the matrix will fill the void formed of the crack while constricted by neighboring grains which are still in the tetragonal stage. This fabrication process improved fracture resistance; however it produced an increase in surface roughness potentially leading to excessive wear [36, 37]. Early clinical experiences with zirconia/alumina and zirconia/zirconia generated large volumetric wear. Therefore, zirconia could be only coupled with polyethylene [38, 39]. By the end of the twentieth century and due to these wear characteristics zirconia has been withdrawn from the market [40, 41].

The high fracture toughness of zirconia and the high hardness and good wear characteristics of alumina are the two key material properties which are desired to be preserved in modern ceramics. Modern ceramics undergo better material control and improved manufacturing processes which optimize the grain sizes and density. Currently, alumina matrix composite is the dominating ceramic in clinical use. Alumina FORTE (BIOLOX forte, CeramTec AG, Plochingen, Germany) is a third generation of ceramic material which is composed of ultrapure alumina, zirconia, and yttrium. To further improve the fracture resistance of ceramics, a fourth generation of ceramic was introduced, which included the addition of strontium oxides in the form of platelets within the alumina matrix. The impregnation of the strontium platelets deflects the path of crack propagation, hence improving the fracture resistance, as a higher energy is required to cause catastrophic crack propagation.

Table 14.2 represents a variety of clinical studies which have reported on ceramic fractures for both the acetabular liner and femoral heads. However, as discussed previously, the fracture rate fluctuates in relation to the cohort size.

Results of revision surgery due to ceramic fracture are variable. A multicenter study reported on the results of 105 revision THAs due to early-generation ceramic head fracture. At a mean fol-

Table 14.2 The head and liner fracture rates for the different generations of ceramics

Author	Number of hips	Fracture rate (%)		
		Head	Cup	Total
Ceramic first and second generation				
Winter et al. [42]	100	8	0	8
Hannouche et al. [43]	3300	0.2	0.2	0.4
Boutin et al. [32]	560	0.5	0	0.5
Griss et al. [30]	130	6.9	0	6.9
Boehler et al. [4]	67	13.4	0	13.4
Ceramic third generation				
Koo et al. [6]	367	5	0	1.4
Lee et al. [44]	86	2.3	0	2.3
Park et al. [7][a]	577	2.4	1.2	3.6
Lusty et al. [45]	301	0	0	0
Choi et al. [46]	173	0	0.6	0.6
Traina et al. [47]	61	0	1.6	1.6
Ceramic fourth generation				
Baek et al. [48][b]	94	0	0	0
Hamilton et al. [49]	345	0	0.9	0.9
Hwang et al. (case report) [50]	1	–	+	
Morlock et al. (case report) [51]	1	–	+	

[a]11/14 broken heads were 28 mm diameter
[b]One liner dissociation

low-up of 3.5 years 33 patients (31%) needed further revisions. The survival rate was significantly worse when the cup had not been changed, when the new femoral head was made of stainless steel, when a total synovectomy had not been done, and when the patient was less than 50 years old [26]. Another study reported on the long-term results of eight patients who had revision THA due to ceramic fracture. At 10.5 years following revision surgery none of the patients had further revision surgery. A link between the results and a thorough synovectomy performed at the time of revision surgery was suggested [52].

The outcomes of revision surgery with newer generation of ceramics are limited. A study evaluating 24 THAs undergoing revision of third-generation CoC due to fracture demonstrated unfavorable results when the femoral stem was retained as compared to patients in which the stem was changed. The authors suggested that a possible explanation is related to the fact that newer generations of ceramics are harder and therefore can create larger damage to the Morse taper; thus the authors advocated for stem exchange [23].

Case Solution

Following diagnosis of the fractured liner, the patient underwent revision surgery. During the procedure, the ceramic insert was found to be broken and an effort was made to remove all fragments of ceramic, including an extensive synovectomy. There were no signs of neck-to-rim impingement. The acetabular cup was removed and a new cup was fixed with two screws followed by the insertion of a ceramic acetabular liner. The femoral stem taper was evaluated and showed no macroscopic surface deformation. As such, it was fitted with an adapter sleeve and a new ceramic femoral head (revision ceramic head). Following revision surgery, the hip noises disappeared and the patient had pain-free full hip range of motion. Postoperative radiographs were acceptable (Fig. 14.3). The broken ceramic fragments and the ceramic head were sent to a research laboratory and were further analyzed. The femoral head demonstrated a characteristic stripe wear pattern and the overall volumetric wear rate was high (19 mm^3). The regions of wear showed a roughened surface with grain pullout. The ceramic liner fragments similarly had a roughened appearance when examined under a scanning electron microscope. The ceramic liner showed a characteristic wear region on the edge of the ceramic liner representing edge loading which is commonly observed in ceramic retrievals.

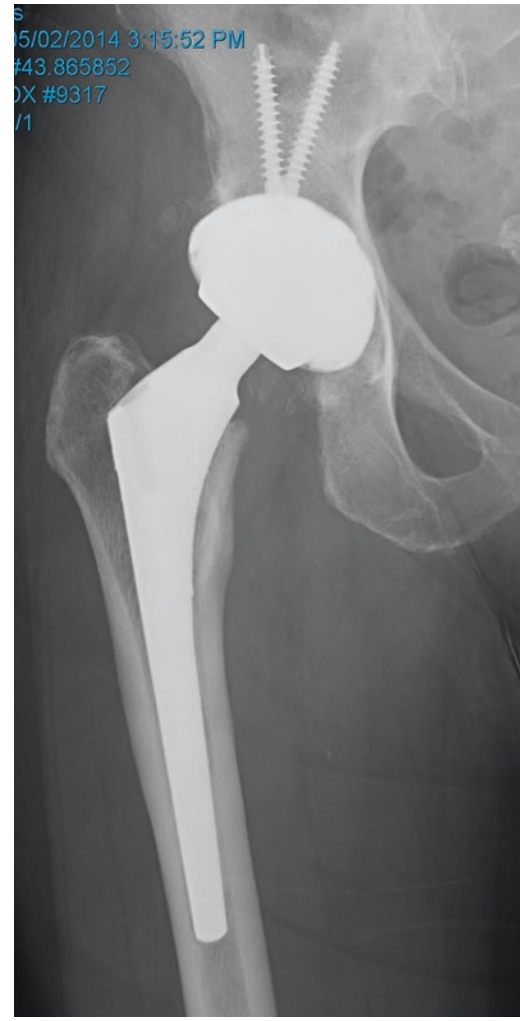

Fig. 14.3 Anteroposterior radiograph of the right hip after revision surgery with exchange to a new ceramic-on-ceramic construct. Note the diminution in the ceramic fragments embedded in the joint capsule

Edge Loading, Stripe Wear, and Reaction to Wear

During the manufacturing process of a ceramic acetabular liner, a sharp edge is generated inside the rim [53]. During hip movement, the femoral head loads against the sharp edge of the cup resulting in edge loading [8]. This in turn will lead to the formation of long narrow area of damage (strip wear), along the femoral head and the edge of the cup (Fig. 14.4). Stripe wear has been reported for first- and second-generation ceramic bearing, and initially was associated with steep cup angles, revision surgery, and young patients [54]. Since no cup coating was found in these early generations of ceramic bearings, component migration was common. Thus, it was initially hypothesized that the formation of the strip wear was linked to cup migration. However, similar stripe pattern can be seen in well-fixed and well-positioned third-generation ceramic articulations [55]. A retrieval study of third-generation ceramic bearings demonstrated that wear on the acetabular component always involved the edge [53]. The location of the wear patch may indicate whether edge loading occurs during deep hip flexion (posterior edge loading) or during walking and hip extension (anterior superior edge loading) [53]. It was also observed that insufficient anteversion will lead to posterior edge loading while anterior edge loading is associated with increased cup anteversion and inclination [53, 56]. Posterior edge loading is more commonly seen in comparison to anterior edge loading, and may be associated with micro-separation of the femoral head during the swing phase [55]. Neck-to-rim impingement, bony impingement, medial soft-tissue bulk, and reduction in soft-tissue tone can lead to subluxation-relocation motion and this can produce a wider stripes and scratches along the head [53]. Overall, it was suggested that edge loading is a normal mechanism in CoC articulations. The wear produced by edge loading is unavoidable [45, 53, 57] but considered clinically insignificant as the produced wear volumes are very low to generate osteolysis [8].

Increased wear has been linked to improper implant positioning. Therefore, during surgery the verification of proper acetabular positioning, soft tissue, and hardware impingement is essential. The biologic reaction produced by the ceramic wear particles differs from the reaction toward metal (tissue necrosis) or polyethylene debris (osteolysis). Synovium obtained from ceramic retrievals demonstrated a small number of macrophages predominantly in the fibrous connective

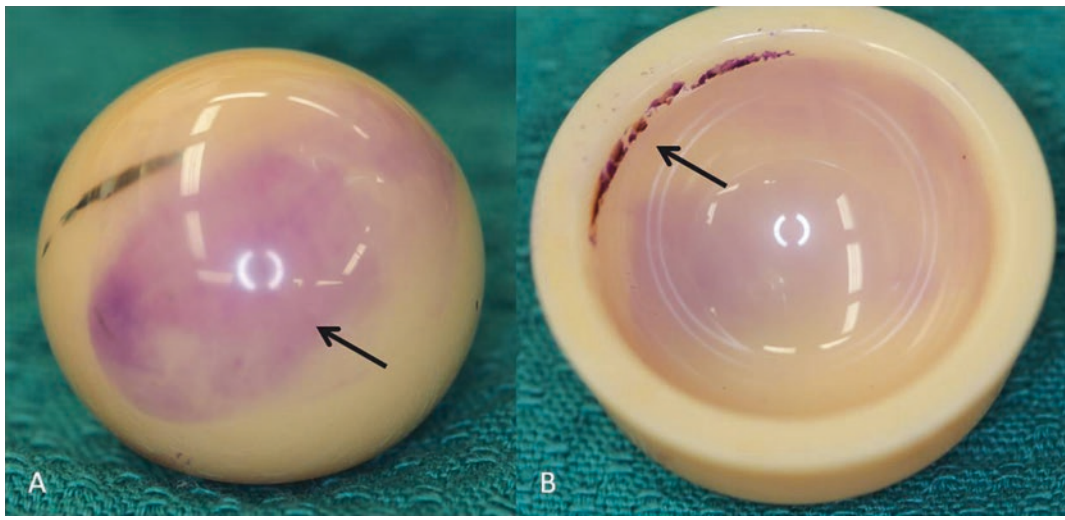

Fig. 14.4 Ceramic retrieval showing stripe wear patch on the ceramic femoral head (**a**) and the corresponding edge loading mark on the ceramic acetabular liner (**b**)

tissue, rare multinucleated giant cells, and minimal necrosis. Therefore, it was suggested that the inflammatory changes in the pseudocapsule of CoC hips may be clinically insignificant [58]. Furthermore it was demonstrated that impingement between the neck of the stem and the cup rim may be responsible for metal debris. Others suggested that debris produced by ceramic bearing has an advantage as it produced a dense fibrous tissue which can be observed during CoC THA revision surgery and might have a role in joint stabilization and dislocation prevention [59].

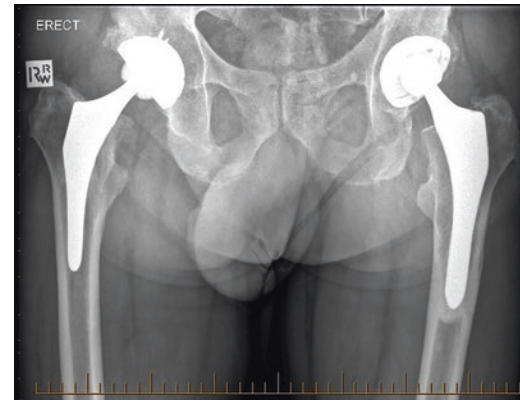

Fig. 14.5 Anteroposterior radiographs of the right hip demonstrating ceramic-on-ceramic articulation and abduction angle of 51°

Squeaking

Case Presentation

A 78-year-old male presented to the clinic with intermitted squeaking from his right hip. The squeaking appeared 6 months prior to the clinical consultation. Eleven years prior, the patient had undergone an uncomplicated right THA due to osteoarthritis. The patient received an ABG II cementless femoral stem size 4 (Stryker), a 54 mm cementless ABG II cup (Stryker) with a 54/32 mm alumina forte third-generation ceramic liner, and a 32 + 4 mm ceramic alumina forte femoral head. Currently, the patient described intermitted sound appearing while arising from a chair and during deep hip flexion while playing bowls. There is no associated pain or squeaking during walking. Physical examination depicted excellent pain-free hip range of motion. The noise was not reproducible during clinical evaluation. Radiographs showed a well-fixed implant with no signs of damage. The abduction angle was measured to be 51° (Fig. 14.5).

Epidemiology

Squeaking is an audible phenomenon most commonly described for CoC articulations. However, it has also been associated with MoM bearings [12, 60–63]. Squeaking is defined as a high-pitch, audible sound that occurs during movement of the hip joint. It is produced by a forced vibration generated by a driving force resulting in a dynamic response [64]. The forced vibration is a consequence of edge loading, third-body particles, rim impingement, and reduction in joint interface lubrication [65]. The dynamic response is the amplification of these vibrations in the components. When the amplification reaches the human audible range, a squeak can be heard. A recent meta-analysis acquiring data from the Australian National Joint Registry estimated that the rate of self-reported squeaking was 1.2% while studies evaluating squeaking with specific questionnaires had a rate of 4.2% [66]. It is estimated that 0.2% of squeakers will undergo revision surgery due to squeaking [66]. Despite the superior tribological properties of ceramic articulations within THA, squeaking as a complication deters surgeons from using CoC bearings. This may partially explain the trend in the declined use of CoC bearings within THA as reflected by the United Kingdom National Joint Registry [67] and the United States [68].

Risk Factors

Squeaking is a multifactorial phenomenon where the different factors are interlinked and probably cannot be separated [64, 69]. These multiple factors are classified in relation to patient characteristics, implant factors, and surgical factors.

Implant Factors

Ceramic bearings function optimally under wet conditions. Due to their hydrophilic nature, a thin fluid film at the articular interface forms [70]. The loss of this lubrication layer between the articulating surfaces reduces sliding and increases friction. Other conditions that may facilitate increased friction at the joint interface (e.g., edge loading, stripe wear, metal transfer, and excessive debris) can promote formation of more intense vibrations [53, 64, 71]. If the vibrations are amplified to a frequency of an audible range, a squeak can be heard. Laboratory testing utilizing pristine bearings could not produce squeaking. However, in the presence of edge loading and stripe wear, squeaking can be produced [57, 72]. Clinical and retrieval studies report on the formation of squeaking 6 months from the index THA, but not immediately postoperatively, indicating that increased activity levels may coincide with the formation of the strip wear [45, 53, 57, 73–75]. Retrieval analyses of squeaking hips matched with silent hips showed edge loading and stripe wear for both; however the patients with squeaking hips had larger stripe scars and demonstrated 45 times higher wear rate [57].

Stem design and metallurgy have an effect on squeaking. Clinical studies have shown higher rates of squeaking when a thin profile stem with a thin neck is used [63, 73, 74]. One study reported seven times less squeaking rate in patients receiving the Omnifit stem (Stryker) compared to patients receiving an Accolade stem (Stryker). The difference in stem geometry, composition, and taper dimensions can explain the variations between the squeaking rates. These design factors can influence the component's natural resonance frequency. Generally, the natural frequency of the ceramic component is outside the audible range. However, the previously discussed conditions can produce vibrations which can be further amplified in the stem and cup. Such amplified vibrations can bring the sound frequency to an audible range. For instance, the thinner stem diameter of the Accolade creates a more flexible stem and its small taper diameter results in a lower bending stiffness. Both of these factors can amplify the vibrations leading to an increased stem resonance [76]. In support of these observations, an in vitro study showed that stiffer (cobalt chrome vs. titanium) and smaller stems demonstrated a higher critical friction factor that correlates with clinical squeaking [45, 77].

Large-diameter fourth-generation ceramic components (>36 mm) were introduced at the end of 2008. The clinical outcome results of these bearings are limited, with squeaking rates reported to be as high as 20.7% [78]. This observation can further stress the role of inherent stem resonant properties [79]. Large-diameter heads generate excessive forces on the trunnion. In suboptimal lubrication conditions, these forces can be amplified lowering the resonant frequency of the stem, thus increasing the propensity to squeak.

Patient Factors

Several patient demographic factors such as age, sex, height, and weight may play a part in squeak generation. A recent meta-analysis showed that the only significant patient demographic factor was an increase in body mass index [80]. Other studies did not show a similar trend; however these studies could link squeaking with younger patients [69], males [46], and taller patients [63, 69]. In contrast, others could not show any correlation between squeaking and patient demographic factors [74, 75]. Thus, these occasionally conflicting and mixed results preclude the clear correlation between specific patient demographic characteristics as a potential risk factor relating to the occurrence of squeaking. Additionally, it has been reported that patients with hyperlaxity have a higher rate of squeaking [71, 78]. This has been associated with excessive range of motion which can lead to impingement, micro-separation, and edge loading.

Surgical Factors and Squeaking

Prosthetic component orientation is considered to play a role in squeak formation. Acetabular component malpositioning can theoretically facilitate conditions leading to impingement, edge loading, and increased wear. Cup malpositioning can facilitate direct impingement between the femoral neck and the rim of the cup which can lead to a titanium squeak (as opposed to the classical ceramic squeak) [56], as reported by a retrieval study [57]. While some studies showed reduced risk for

squeaking if the acetabular component placed within a 25 ± 10° of anteversion and 45 ± 10° of inclination [56, 81] other studies did not exhibited a similar tendency [46, 63, 74, 75, 80]. Another factor related to the soft-tissue tension of the hip joint, a loose joint will promote micro-separation and subluxation of the head which can further facilitate edge wear.

Prevention

The main prevention to squeaking is by addressing the above-mentioned possible elements contributing to squeak formation. These include patient factors, implant selection, and meticulous surgical technique. Despite no reported clinical uniformity, tall, heavy males or patients with hyperlaxity should be further cautioned. In order to reduce the forces at the taper junction, stem resonance, and forces transmitted to the bone stem interface, a relatively long and stiff stem with a large taper should be preferably chosen. This is of significant importance when a large-diameter (>36 mm) ceramic head is used. Meticulous surgical technique, particularly with respect to acetabular component positioning, can lead to reduced rates of edge loading and prevent excessive wear and squeaking. Nevertheless, since squeaking is a well-documented complication that has a psychological implication on patients (such as embarrassment and anxiety), proper consultation prior to surgery is critical [62]. It has been reported that of 24.6% squeaking patients following CoC THA, only 7.5% recalled being warned of such a potential complication prior to surgery [62]. It is important to provide the patients with a proper realistic outcome expectation and appropriate informed consent with respect to the possible bearing complications. This further allows patients to understand and agree to the use of ceramic bearings. Moreover, besides improving patient psychological concerns proper consultations can prevent litigation against surgeons.

Diagnosis

Clinical and radiographic evaluations are the diagnostic tools used in the assessment of squeaking patients. Clinical assessment involves a thorough history and physical examination covering patient factors such as age, sex, height, weight [46, 64, 69, 71], and ligament laxity [78]. A detailed history should be taken with specific emphasis on the characteristic of the squeak, its reproducibility, its frequency, its association with pain, and its relation to specific hip movements. The most common form of squeaking is a benign squeak. This type of squeaking is commonly non-painful, occasionally reproducible, and occurs in deep hip flexion such as squatting or rising from a low chair [53]. Pathological squeaking usually is reproducible and occurs during normal gait cycle in each step. It can be associated with pain, and limited hip function, and is relatively rare. Generally, it is intolerable by the patient and often requires further surgical intervention. Pathological squeaking is commonly a result of anterior edge loading due to component malpositioning, while benign squeaking is a result of posterior edge loading with well-aligned components [53]. Often a single or episodic event of squeaking will be reported by the patients. However, these events are usually non-reproducible and their nature is not clearly defined. Furthermore, limited or painful hip range of motion can be coupled with other bearing pathologies such as impingement and ceramic fracture, which can further be associated with noise generation [20, 71].

The radiographic assessment should be composed of plain radiographs to evaluate gross component malpositioning, implant failure, or fracture. In the case of persistent squeaking, pain, limited range of motion, or a suspected ceramic fracture, further assessment with a CT scan should be performed. This has the potential to better appraise component position (anteversion and inclination) and detect ceramic fracture [19–21].

Treatment

Following patient assessment and evaluation, a better understanding on the nature of the squeak, associated pathology, and patient limitations can be assessed. When squeaking is benign and infrequent, patients should be closely followed up in clinic. In rare cases when pathological squeaking has been diagnosed with a significant effect on the patient's quality of life, further surgical intervention is advocated. In such cases, the bearing surfaces can be surgically repositioned to optimize implant location, with additional soft-tissue balancing and/or correction of bony impingement. In the case of well-aligned components, the position of the ceramic liner can be exchanged to a polyethylene liner in order to eliminate squeaking. The diagnosis and treatment algorithm are presented in Fig. 14.6.

Literature Review

There is wide variation in the reported rates of squeaking (between 1 and 20.7%) within the literature (as noted in Table 14.3). The large variation can be explained by diversity in patient and implant factors, ceramic generations, interpretation of what is defined as a squeak, and investigators' query.

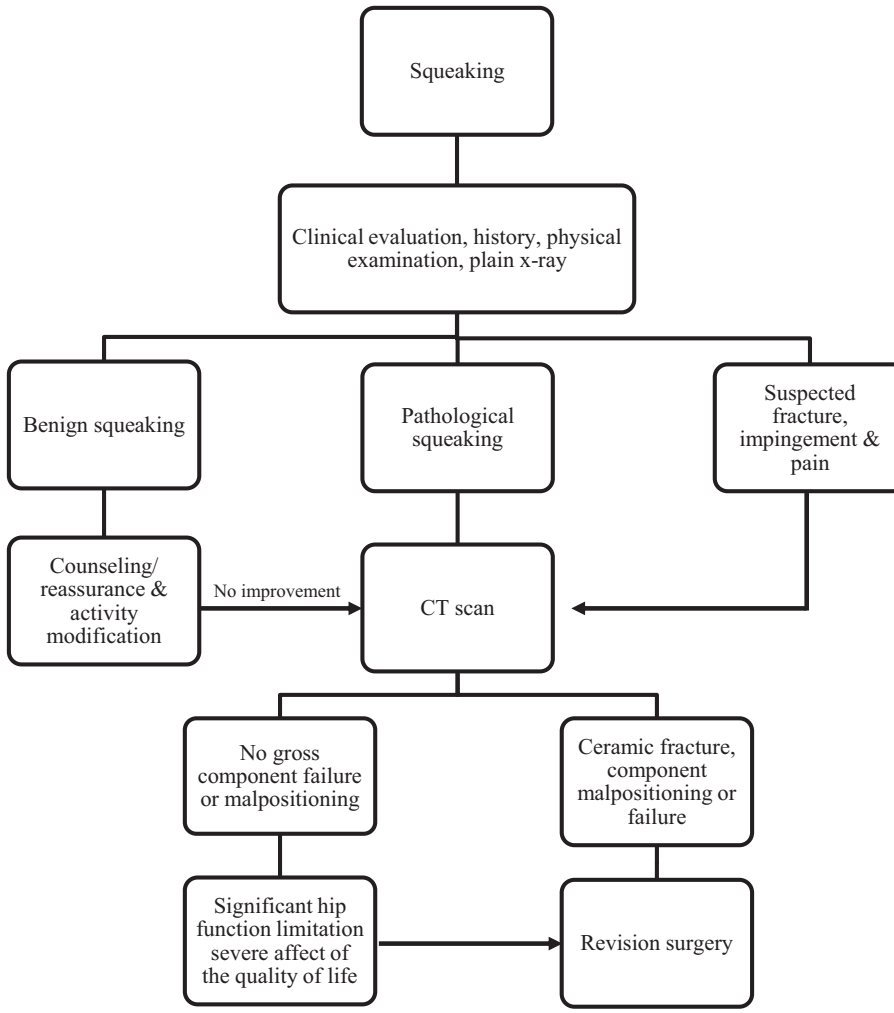

Fig. 14.6 Diagnosis and treatment algorithm for squeaking total hip arthroplasty

Table 14.3 The rate of squeaking for third- and fourth-generation ceramic bearings

Author	Number of hips	Squeaking (%)
Ceramic third generation		
Choi et al. [46]	173	5
Cogan et al. [60]	284	2.6
Jarrett et al. [73]	149	10.7
Park et al. [7]	577	1.4
Mai et al. [63]	336	10
Sexton et al. [69]	2406	3.1
Ceramic fourth generation		
Hamilton et al. [49]	345	7.5
Wang et al. [82]	177	1.1
McDonnell et al. [78][a]	208	20.7
Tai et al. [79][a]	206	7.3

[a]These two series represent large-diameter ceramic bearings (>36 mm, DeltaMotion, DePuy, Warsaw, IN)

Case Solution

Since the squeaking was intermitted and only during deep flexion, not associated with pain, and the patient had good hip ROM, combined with unremarkable radiograph (Fig. 14.5), the squeaking was considered benign and the patient was treated conservatively with clinical visits every 6 months.

Acknowledgment The authors would like to thank Selin Munir PhD, for her scientific input and help in preparation of this chapter.

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Complications of Metal-on-Metal Bearings

15

Keith A. Fehring, Thomas K. Fehring, and Edwin P. Su

Case Example

A 51-year-old male presents with activity-related groin pain 2 years after a primary right uncemented total hip arthroplasty (THA). The pain has been a constant dull ache for the past 6 months. He localizes the pain to the groin area and it is worse with activity. He has occasional popping and mechanical symptoms in his hip. He denies any fevers or chills. Initially he had complete pain relief and he had no issues in the immediate postoperative period. An anteroposterior (AP) radiograph of the right hip revealed a metal-on-metal THA with a DePuy ASR acetabular component, and a Corail stem (Fig. 15.1). A thorough evaluation revealed a serum cobalt level of 18 ng/mL (normal <3.0), serum chromium of 9.1 ng/mL (normal <3.0), erythrocyte sedimentation rate of 8 mm/h (normal <20), and C-reactive protein of <0.5 mg/L (normal <1.0). Magnetic resonance imaging with metal artifact suppression technology revealed a small amount of fluid in the area of the greater trochanter measuring 5 mm × 1.1 cm × 2 cm. However, no pseudotumor or mass was appreciated

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Epidemiology: The Nature of the Problem

Metal-on-metal THAs made a resurgence due to their improved wear characteristics, promise of longevity, and lower dislocation rates in the early 2000s [1, 2]. By 2006, 35% of primary THAs in the United States were MoM articulations. It was estimated that over 1,000,000 MoM articulations have been implanted worldwide since 1996 [3]. Recently, adverse local tissue reactions (ALTRs) associated with these bearings have curbed enthusiasm for their use identified, in addition to the traditional failure mechanisms.

The evaluation of a failed MoM THA must begin systematically, and should be similar to the evaluation of any problematic THA. Traditional modes of failures such as instability, infection, tendonitis, aseptic loosening, periprosthetic fracture, and referred pain must be thoroughly evaluated as potential causes of pain before attributing the source of the problem to the metal-on-metal bearing (Table 15.1) [2, 4, 5]. Once these issues have been ruled out, bearing-related problems such as tissue necrosis, modular junction corrosion,

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_15

skin hypersensitivity, and systematic cobaltism should also be considered.

Histologically, ALTRs appear as a lymphocytic inflammatory response that leads to vasculitis-induced necrosis of soft tissue and bone. The terms aseptic lymphocytic vasculitis-associated lesions (ALVAL), pseudotumor, and metallosis have all been used as umbrella terms in the literature to describe the soft-tissue destruction due to metal-metal junctions and articulations in THA [1, 2, 4–10]. The more commonly accepted term for these problems is adverse local tissue reaction. This chapter presents the evaluation and treatment of complications unique to THA with metal-on-metal articulations.

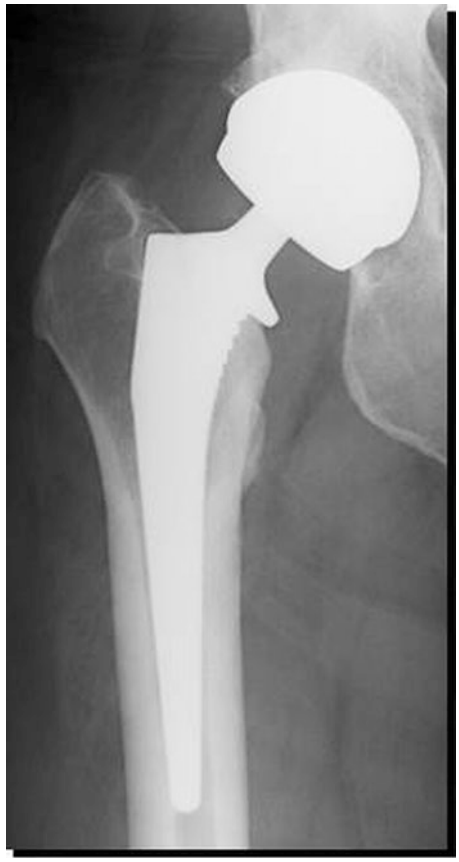

Fig. 15.1 An anteroposterior (AP) radiograph of the right hip revealed a metal-on-metal THA with a DePuy ASR acetabular component, and a Corail stem

Table 15.1 Traditional modes of failure for THA that must also be considered during the evaluation of a MoM THA

Modes of failure
Periprosthetic infection
Osteolysis
Aseptic loosening
Dislocation
Periprosthetic fracture
Iliopsoas tendonitis
Referred radicular pain
Trochanteric bursitis

Risk Stratification

Risk stratification is important in the diagnostic and treatment algorithms of painful MoM THAs. This process is multifactorial as differences in clinical presentation exist. Clinical, laboratory, and radiographic factors help the clinician stratify patients into low-, moderate-, and high-risk categories, which can impact surveillance and treatment (Tables 15.2 and 15.3). A patient who is asymptomatic with normal serum ion levels, appropriately positioned components, and an implant with a low failure rate must be evaluated differently than a patient who is symptomatic with elevated cobalt and chromium levels, a malpositioned cup, and an implant with a high

Table 15.2 The following factors can help surgeons risk stratify patients [5]

Factors to consider for risk stratification
Patient factors
Symptoms
Clinical exam
Implant type
Implant position
Radiographs
Infection workup
Metal ion level
Cross-sectional Imaging

Table 15.3 Guide to management

Risk stratification can help guide management
Who needs cobalt and chromium levels?
Who needs a MARS MRI?
What frequency of surveillance?
Who needs a revision THA?

rate of failure. This risk stratification algorithm has been described by Kwon et al. [5].

Prevention

At this point, the main prevention mode to complications associated with metal-on-metal articulations is to discontinue the use of this bearing surface in contemporary THAs.

Diagnosis

The evaluation of a painful MoM THA is multifaceted, focusing on history and physical examination, plain radiographic assessment, laboratory values, and cross-sectional imaging. A thorough review of systems must be performed as systemic cobaltism has been reported [11].

Patient History

A thorough patient history is essential in the evaluation of a patient with a painful MoM THA (Table 15.4).

- The location, duration, and severity of pain are essential to the evaluation.
- The patient should be asked about mechanical symptoms such as popping, clicking, or ratcheting.
- Exacerbating or alleviating factors should be noted.
- Signs or symptoms of infection must be delineated in the history, as this will change your diagnostic and treatment algorithm.
- The skin should be inspected for previous scars, dermal reaction, or signs of infection.
- A complete review of systems may also unveil systemic issues due to metallosis (Table 15.5).

Table 15.4 Questions to consider in the evaluation of a symptomatic MoM patient

Where is the pain?
How long has the pain occurred?
Was there a pain-free interval?
Is there start-up pain?
Is there thigh pain? (stem or socket pain)
Is there groin pain? (socket pain)
Do they have mechanical symptoms?
Exacerbating activities?
Alleviating activities?
Constitutional symptoms?
Instability events?

Physical Examination

Physical examination remains important in the evaluation of any painful total hip arthroplasty. Essential components include the following keys:

- The skin should be inspected for previous scars, dermal reactions, or signs of infection.
- Palpation should be performed to detect any areas of pain or a soft-tissue mass.
- Complete neurovascular examination.
- Range of motion of the hip joint and abductor muscle strength testing should be routinely performed.
- Any gait abnormalities, such as a Trendelenburg gait, should be noted.
- Is the pain reproduced by supine or reverse straight leg raising (radiculopathy)?
- Is the pain reproduced by trochanteric palpation (trochanteric bursitis)?
- Is the pain reproduced by resisted hip flexion (iliopsoas tendonitis)?

Radiographic Evaluation

After a complete history and physical, evaluation of a painful MoM THA should proceed with standard radiographs examining the implant type and component position, as well as signs of loosening

Table 15.5 Questions asked during a review of systems

Due to multiorgan toxicity of cobalt and chromium, consider the following questions:
Have you had any change in your vision?
Have you experienced any ringing in your ears, difficulty hearing, or dizziness?
Have you experienced recurrent rashes?
Do you have a tremor, difficulty remembering things, or numbness and tingling in your feet and hands?
Do you have shortness of breath?
Do you have mood swings, fatigue easily, or have gained weight lately?

or osteolysis. One must pay close attention to component malposition, as this has been shown to correlate with increased ion levels and wear [12]. A high-abduction angle or high levels of combined anteversion of the components lead to diminished bearing lubrication leading to increased ion release and soft-tissue reactions [12–16].

Radiographic Analysis

- Radiographic evaluation of the failed THA should include an anteroposterior (AP) view of the pelvis and a cross-table lateral view of the affected hip.
- Both the acetabular and femoral components should be examined closely for signs of loosening, osteolysis, or ingrowth.
- Judet views may be necessary to evaluate for osteolysis or loosening.

Laboratory Evaluation

Following the above evaluation, laboratory testing is important in the diagnostic algorithm of the painful MoM THAs (Table 15.6). Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) should be obtained to rule out periprosthetic joint infection. Unlike MoP THAs, ESR and CRP have been shown to be more nonspecific in the evaluation of MoM THA, as patients with adverse local tissue reactions (ALTR) without infection have also shown elevated markers [17]. Likewise, aspiration results of painful MoM THAs can be misleading and must be interpreted with caution. Traditional values of 3000 WBC/mL combined with >80% PMN indicating periprosthetic infection may not apply to those MoM THA with ALTR with a propensity for falsely positive results [18, 19]. It is therefore important to have a manual rather than an automated cell count performed as automated counts may misinterpret metallic debris leading to spuriously elevated counts. Unfortunately, alpha defensin testing may also be falsely positive in these patients. In general we have a low threshold to aspirate these patients preoperatively in an attempt to more definitely rule in or out infection prior to operative intervention as the intraoperative appearance can also be misleading with purulence commonly identified intraoperatively.

Table 15.6 Laboratory evaluation

Labs
• CRP
• ESR
• Aspiration
• Cobalt
• Chromium

The measurement of serum cobalt and chromium has been used for the evaluation of MoM THA [1, 8, 20]. These metal ions are not only released from the bearing surface during articulation, but also from modular junctions due to corrosion. In 2010, the British Medicine and Healthcare Products Regulatory Agency voiced concern over MoM hip implants issuing a safety alert recommending cross-sectional imaging in any MoM hip arthroplasty patient with cobalt or chromium ion levels greater than 7-ppb [10]. Although a useful adjunct, ion levels alone should not be used as a trigger for revision due to their inaccuracy in predicting soft-tissue damage in MoM THA. Metal ion levels and their correlation to MoM THA are poorly understood and have been unreliable predictors of soft-tissue destruction at the time of revision arthroplasty [4, 10, 16]. Unfortunately, no current test can predict periarticular necrosis; however biomarkers to detect adverse local tissue reactions are currently under investigation [4, 10].

The evaluation of a MoM patient is similar to the evaluation of a potential periprosthetic infection (Fig. 15.2). Where the clinician cannot rely solely on a single variable to determine the need

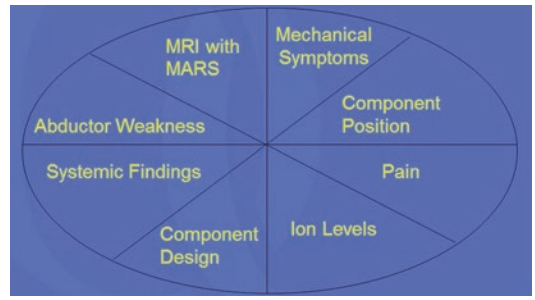

Fig. 15.2 Multiple variables that should be considered when evaluating a MoM THA patient

for intervention, multiple variables must be considered and taken into account as a group.

Advanced Imaging

Cross-sectional imaging in the form of an ultrasound or metal artifact reduction series (MARS) magnetic resonance imaging (MRI) has been used in the evaluation of adverse soft-tissue reactions (Figs. 15.3 and 15.4) [21, 22]. Ultrasound has been able to detect soft-tissue lesions, and may differentiate these lesions as solid or cystic. However, this imaging modality remains operator dependent limiting its consistent use in the detailed evaluation of soft-tissue lesions. It can be efficient and cost effective as an initial screening test with high sensitivity [21].

MARS MRI has become the workhorse imaging modality for the evaluation of ALTRs associated with MoM THAs [21, 22]. MARS MRI allows for early detection of soft-tissue lesions and the ability to follow MoM THA patients longitudinally with serial evaluations.

Clinical Presentation

The clinical presentation of a patient with an adverse local tissue reaction remains variable with each patient having an individualized response to metal debris. The initial presenting symptoms may be pain, mechanical symptoms, abductor weakness, instability, or rash (Fig. 15.5) [4, 5].

In addition to symptomatic patients, ALTRs have been identified in asymptomatic patients. A recent investigation has shown a 31% prevalence of cystic ALTRs in asymptomatic MoM patients on MARS MRIs [7]. The natural history of these lesions remains undefined but calls into question the reliability of pain as an indicator of bearing malfunction.

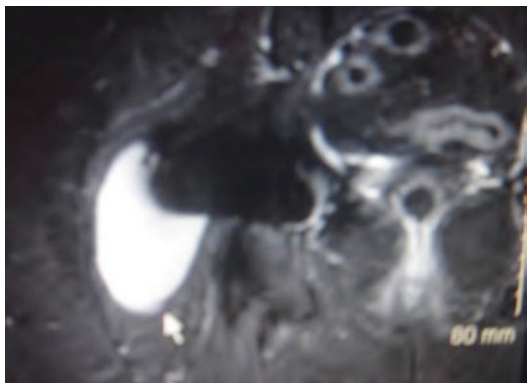

Fig. 15.3 Cross-sectional MRI of a cystic ALTR lesion in a MoM THA

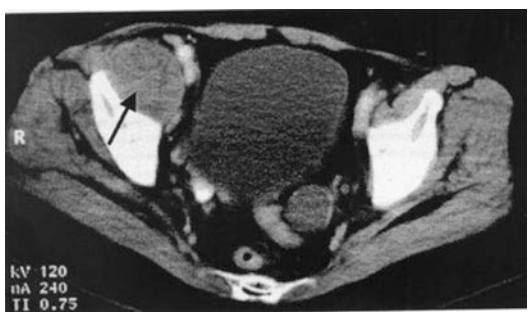

Fig. 15.4 Cross-sectional MRI of pseudotumor in a MoM THA

Treatment

Treatment centers on debridement of metal debris and removing the MoM articulation from the system. Treatment may also be altered by soft-tissue or bony destruction from metal debris (Figs. 15.6, 15.7, and 15.8). Synovectomy with debridement of diseased tissue is indicated in all revision THAs for metallosis. In modular metal-on-metal THAs, a straightforward treatment approach is possible with a head-liner exchange where the MoM bearing is changed to a ceramic-on-

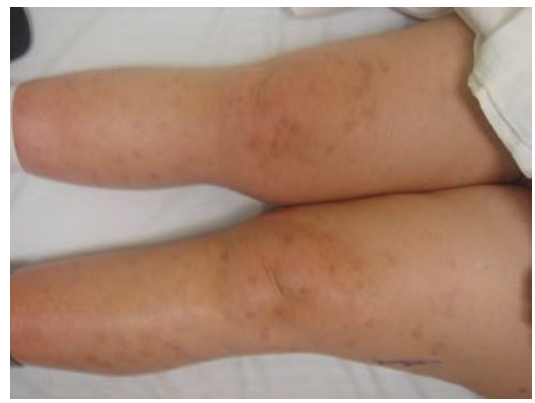

Fig. 15.5 Rash that can be seen due to metal toxicity

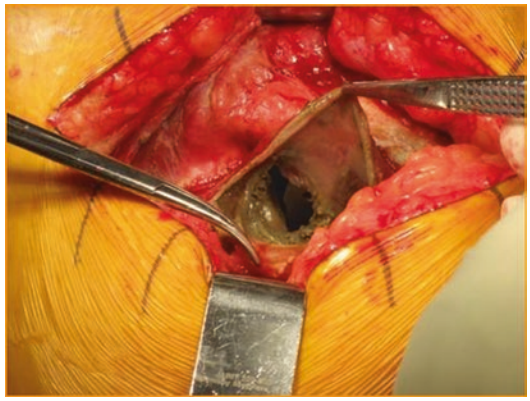

Fig. 15.6 Metallosis seen intraoperatively

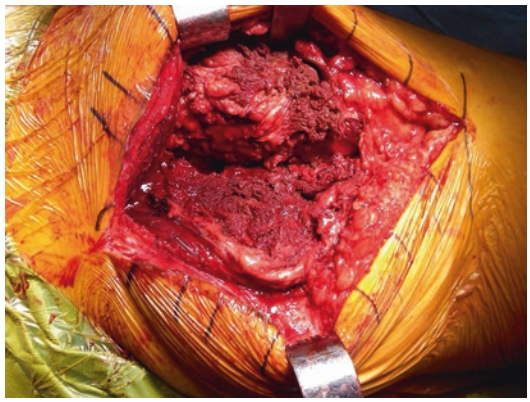

Fig. 15.7 ALTR seen intraoperatively with necrotic tissue

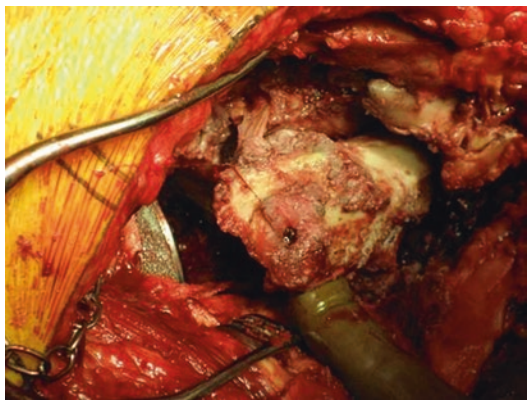

Fig. 15.8 Abductor deficiency and bone necrosis from ALTR

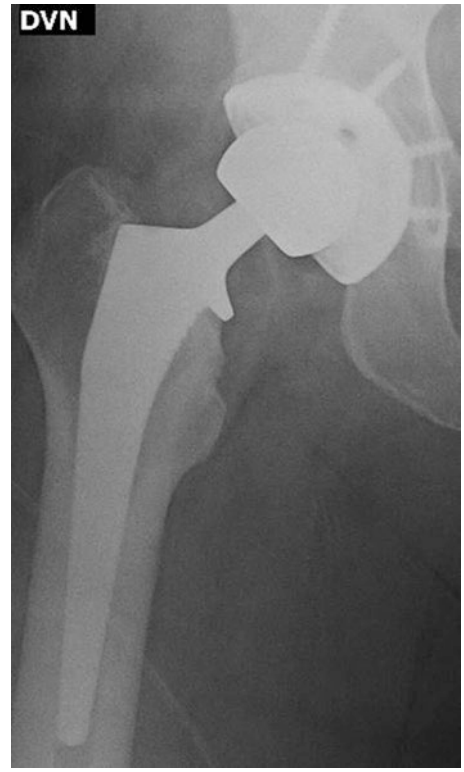

Fig. 15.9 Revision of acetabular component in MoM THA case

polyethylene bearing; this is preferred to a metal-on-polyethylene bearing as removal of all cobalt from the system makes postoperative serum metal-level interpretation easier and in some cases corrosion at the modular junction may be contributing to ALTR. When a ceramic head is utilized, the use of a titanium taper sleeve is suggested to decrease the potential increased risk of ceramic head fracture when placed onto a used trunnion.

Acetabular revision is indicated when revising a MoM THA with a monoblock acetabular component, if the implant is in poor position, or if the implant has sharp edges on its interior surface (Fig. 15.9). Results of formal acetabular revision have been challenging with a 20% complication rate in a large series of monoblock MOM revisions with loosening and instability being major causes of complications [23]. This has led to the consideration of using a polyethylene dual-mobility con-

struct within the existing retained monoblock cup provided that it has no sharp internal features and is in good position [24]. The use of dual-mobility constructs or constraining acetabular components may also be necessary in these revision situations due to abductor deficiency caused by metallosis. Revision of the femoral component is usually not necessary in revision THA for metallosis.

Results of Treatment

The outcomes of revision surgery for metallosis in MoM THA are suboptimal. Early results of revising monoblock MoM THAs have shown an unfortunately high complication rate ranging from 20 to 38% [23–30]. The most common complications include instability and aseptic loosening of the revised acetabular component, both which are thought to be secondary to soft-tissue and bony necrosis (Fig. 15.10) [23–30]. An alarming 8.1% rate of infection following revision of failed MoM THAs has also been reported [17].

Fig. 15.10 Retrieval of fibrous ingrown ASR cup at the time of revision

Literature Review

Biologic Mechanism of Failure in MoM THAs

The biologic response to metal particle debris can be both systemic and local. Much of the concern in THA has been due to the adverse local tissue reactions caused by the inflammatory response to metal debris. These local responses can result in tissue necrosis and adverse soft-tissue reactions. The biologic response to metal particles is not fully understood. It is likely a type IV hypersensitivity response initiating T-lymphocytes and macrophages to create a cytotoxic inflammatory response [1, 2, 23]. Each individualized patient may have a unique response to metal debris. The delayed hypersensitivity reaction driven by T lymphocytes was originally described as aseptic lymphocyte-dominated vasculitis-associated lesion (ALVAL) [24]. Histologically these lesions have an abundance of perivascular lymphocytic reaction leading to vessel constriction and necrosis.

ALVAL/ALTR

The terms ALVAL, ALTR, pseudotumor, and metallosis have all been used as umbrella terms in the literature to describe adverse local soft-tissue destruction due to metal debris from metal-on-metal articulations and junctions in THA. ALVAL is a histologic term denoting an aseptic lymphocytic vasculitis-associated lesion. ALTR on the other hand is the more accepted term for any adverse local tissue reaction around a MoM THA.

ALTR can be the result of bearing debris or various types of corrosion produced at different metal-on-metal articulations within the total hip system. Such corrosion occurs not only at a MoM articulation, but can also be seen due to mechanically assisted crevice corrosion at metal-metal modular junctions such as the head-neck and neck-stem junctions.

Skin Hypersensitivity

Metal-induced hypersensitivity reactions have been reported at an incidence of 1% [1]. Hypersensitivity following MoM THA appears to be low, but surgeons should be aware of the possibility of this delayed-type lymphocytic response to metal particles when evaluating the symptomatic MoM THA [24].

Articulation Modes of Failure

The unique wear characteristics of MoM implants have created problems relating to metal ion release and metallosis. The particles produced by wear of the articulation are more numerous, but smaller in size than the particles produced in metal-on-polyethylene bearings. Metal-on-metal THAs traditionally have had larger head sizes creating a larger surface area. These designs lead to dissolution of soluble ions such as cobalt and chromium increasing their levels in the joint and later the blood. These elevated metal ion levels can initiate an inflammatory cascade leading to tissue and bone necrosis. Complications such as aseptic loosening and lack of cup ingrowth have been attributed to equatorial seizing between the cup and large head.

Metal-on-metal implants perform best if well lubricated. A high-abduction angle or high degress of combined anteversion leads to diminished bearing lubrication leading to increased ion release and soft-tissue reactions [12–17]. A relatively horizontal cup position may increase lubrication leading to improved wear characteristics. Unfortunately, the clinical problems seen with metal-on-metal articulations were not predicted by simulator tests. These tests did not account for edge loading that is seen in vivo and thought to be one of the contributing factors to increased wear [25].

Systemic Cobaltism

Systemic cobaltism has been reported to occur due to periprosthetic metallosis from metal-on-metal hip arthroplasty. Systemic symptoms of cobaltism include tinnitus, fatigue, vision disturbances, anxiety, hearing loss, neuropathy, and cardiomyopathy [11]. One author noted extremely high cobalt levels in those patients with impaired renal function [11]. Surgeons should be aware of this rare but serious condition when evaluating a symptomatic MoM THA as serum cobaltism is often the result of cobalt levels greater than 200 mcg/L [11]. The majority of symptoms resulting from cobaltism resolve after revision surgery, as well as normalization of cobalt and chromium levels.

Case Solution

A revision THA was performed with removal of the monoblock ASR acetabular component and placement of another acetabular component. A complete synovectomy and debridement of the metallosis were performed, along with placement of a ceramic femoral head (with a taper adaptor) and a highly cross-linked polyethylene liner. The patient's cobalt and chromium levels were followed postoperatively and were found to normalize 3 months following revision surgery.

Conclusion

The evaluation of a symptomatic patient following MoM THA remains challenging. It is important to consider all common modes of failure associated with a conventional THA, in addition to those modes of failure unique to MoM articulations. A thorough clinical evaluation, in addition to specialized testing and imaging, is important to make the proper diagnosis. The early recognition of ALTR is essential for the successful management of the MoM patient. A systematic approach involving a careful history, physical, and radiographic examination should be undertaken in each MoM patient. Ion levels and cross-sectional imaging are useful adjuncts in determining the need for revision. As in evaluating a patient for periprosthetic infection, isolated variables should not trigger the need for surgical intervention; rather multiple clinical and diagnostic variables should be utilized in making such a decision.

Conflict of Interest

Dr. Keith Fehring—none

Dr. Thomas Fehring—DePuy-Johnson and Johnson, Board of Directors-Knee Society, AAHKS—research support, consultant, and royalties

Dr. Edwin Su—Smith and Nephew—consultant and research support

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Complications of Modular Neck-Stems

16

Ming Han Lincoln Liow and Young-Min Kwon

Case Presentation

A 67-year-old gentleman underwent a left total hip arthroplasty (THA) with the use of a dual-modular femoral neck-stem 24 months ago. At 20 months postoperatively, he developed persistent pain in the left hip and groin area after a minor injury. He was concerned about his increasing symptoms and was subsequently informed by his surgeon that he had a recalled femoral stem.

On physical examination, the patient walked with an antalgic gait. Examination of his hip revealed a well-healed incision with no signs of infection. Hip range of motion was limited and painful. Weakness of hip abduction was observed. No neurovascular deficits were noted on examination of his left lower limb. Anteroposterior (AP) pelvic and AP and lateral radiographs of the left hip revealed a well-fixed dual-modular femoral neck-stem THA (Fig. 16.1). Both erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were within normal limits. The patient had elevated serum cobalt (17 μg/L) and chromium (2 μg/L) levels (laboratory reference range was Co <0.3 μg/L, Cr <0.3 μg/L). Metal artifact reduction sequence (MARS) magnetic resonance imaging (MRI) of the hip showed a complex fluid collection suggestive of adverse local tissue reaction (ALTR) (Fig. 16.2).

Rationale for Modular Taper

Modularity in total hip arthroplasty (THA) allows surgeons to optimize implant reconstruction to patient anatomy intraoperatively [1]. Modular femoral neck-stem THA implants possess interchangeable necks, providing additional modularity at the neck-stem interface [2, 3]. Modular taper designs have the potential to allow precise reconstruction of center of rotation of the hip by facilitating adjustments in limb length, femoral neck version, and hip offset in order to optimize hip biomechanical parameters [4]. Other purported benefits include facilitation of surgical procedures, such as revision arthroplasty [5] and minimally invasive surgical techniques [6], as well as economic benefit of enhanced implant inventory control [7]. Four modularity-related failure modes have been described, namely taper corrosion-associated adverse local tissue reaction (ALTR), modular neck fracture, dissociation of the taper junction, and mismatch of the femoral head and taper connection dissociation [8–13]. Recently, there is increasing concern regarding

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_16

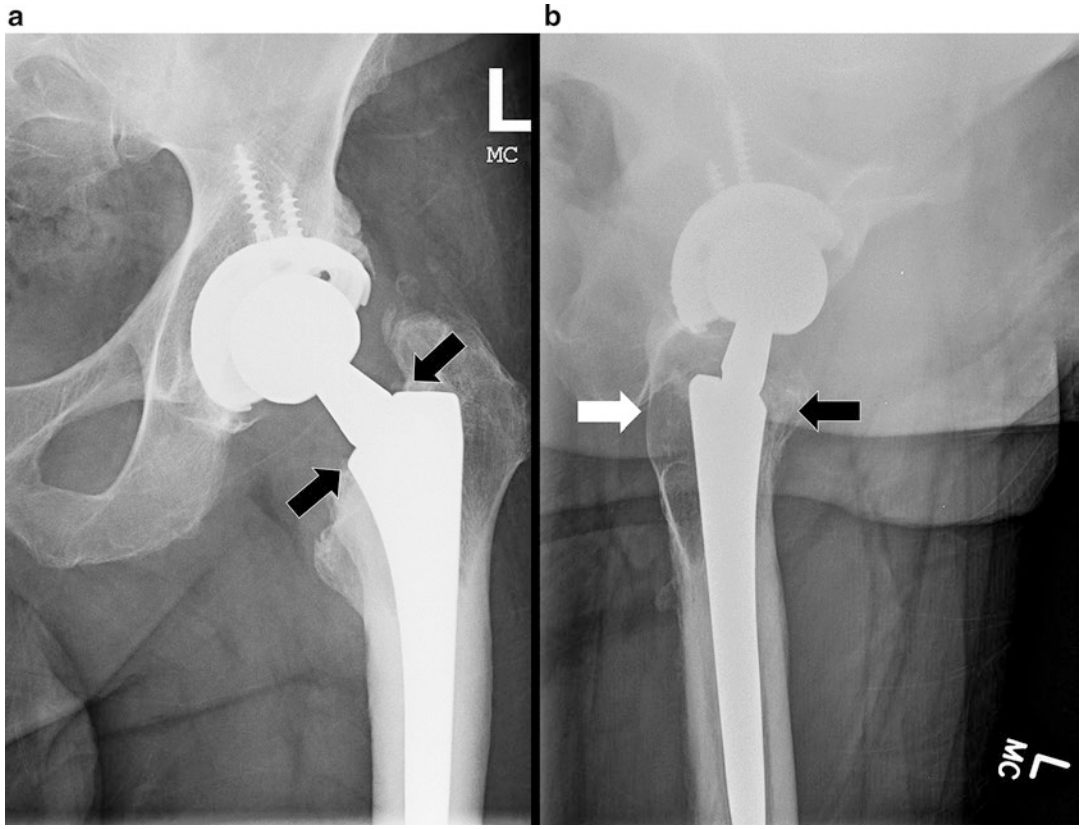

Fig. 16.1 Anteroposterior (**a**) and lateral (**b**) radiographs of a patient with recalled dual-modular femoral neck-stem with trochanteric osteolysis (*white arrow*) juxtaposed to neck-stem modularity junction (*black arrow*)

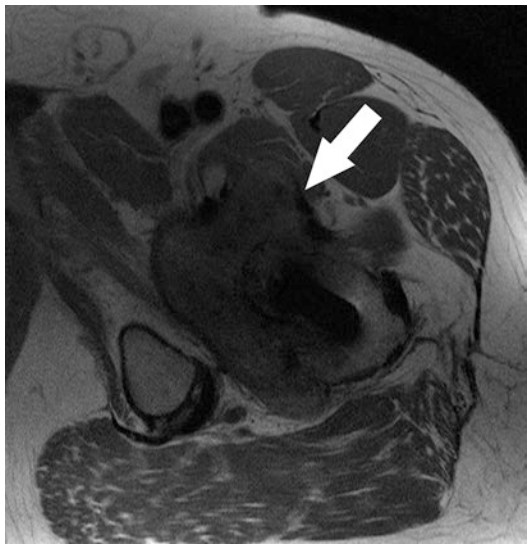

Fig. 16.2 Axial T1 MARS MRI image showing adverse local tissue reaction (pseudotumor) (*white arrow*)

this stem design as a result of the growing numbers of clinical failures due to fretting and corrosion at neck-stem taper junction, in a process that has been described as mechanically assisted crevice corrosion (MACC) [14].

History of Modular Taper Corrosion

The first modular neck-stem (ANCA-Fit) was designed by Cremascoli (Milan, Italy) and possessed an elliptical taper for rotational resistance [15]. Subsequently, a myriad of dual-taper neck-stems were introduced [4]. Several of these dual-taper neck-stem designs have since resulted in taper corrosion issues at the proximal neck-stem and distal head-neck junctions [16–21]. However, it must be noted that taper corrosion is not a new phenomenon. Head-neck taper corrosion has

been described in 1991 by Mathiesen et al. [22] between monoblock titanium (Ti) stems and cobalt-chromium (CoCr) heads [22]. Subsequently, MACC was recognized as a process which was dependent on multiple contributing factors, including taper geometry and metallurgical, mechanical, and solution chemistry between metal alloys [23]. In fact, several studies in the 1970s and 1980s cautioned against the use of dissimilar metals in orthopedic implants and described varying resistance to corrosion between different galvanic combinations of Ti and CoCr alloys [24, 25].

Modular femoral neck-stem THA implants have been manufactured with both titanium and cobalt chromium alloy modular necks; given the preference for titanium alloy femoral components, almost all of the "bodies" have been manufactured from titanium. While a titanium neck prevents the risk of corrosion from the use of mixed metals, titanium alloy necks would be more susceptible to fracture. Alternatively, cobalt-chromium alloy modular necks are stronger and reduce risks of facture; however, being a different metallic alloy from the stem, modular junction corrosion can occur, leading to early failure secondary to adverse local tissue reactions (ALTR) [26]. These junctions are subjected to axial and cantilever-type bending stresses, leading to metal-on-metal micromotion. This has been known to generate metal ion debris with subsequent elevation of serum Co and Cr ion levels [14, 26]. When evaluating a painful modular neck-stem, an understanding of the metals utilized to manufacture the modular neck is important. To further confuse the matter, some manufacturers have made necks of both titanium and cobalt chromium alloys at different times.

Epidemiology of Modular Taper Corrosion

The 2015 Australian Orthopaedic Association National Joint Replacement Registry Annual Report states that 9289 modular femoral neck-stems were used in primary total hip arthroplasties from September 1999 to December 2014 [27]. A significantly higher 10-year revision rate of 9.7% (95% CI: 8.8, 10.7) was reported for modular femoral neck-stems as compared to 5.1% (95% CI: 4.9, 5.2) for fixed femoral neck-stems. The main reasons for early revisions in the modular femoral neck-stems were due to loosening/osteolysis, dislocation, and modular neck fractures. In 2012, a manufacturer initiated a voluntary product recall of two modular femoral neck-stems. At that point of time, it was estimated that more than 30,000 patients received the recalled modular neck-stem implants worldwide [28].

Implant Factors Associated with Modular Neck Taper Corrosion

Implant, surgical, and patient factors have been identified as likely contributing factors responsible for taper corrosion in dual-modular neck-stem THA. Implant factors including taper cone angle, taper surface roughness, neck-stem taper metallurgy, taper geometry, and femoral head size play important roles in influencing extent of taper corrosion. Narrow cone-angled tapers have greater potential for micromotion and may explain higher fretting scores reported at the taper base of 11/13 taper designs compared to 12/14 and 14/16 tapers [29]. Rough-surface tapers were initially developed for use in ceramic heads and surface roughness has been linked to increased fretting in modular MoM head-neck taper combinations [30].

In vivo corrosion and MACC are more commonly seen in dissimilar alloy pairings (e.g., Ti alloy stem and CoCr head), and affect both head-neck and neck-stem [31]. Conversely, ceramic femoral heads have been reported to decrease taper tribocorrosion [32]. Taper geometric parameters such as length, taper contact area, and resultant lever arm contribute to taper corrosion at both the head-neck and neck-stem junctions. Femoral stems with longer modular neck lengths had significantly higher corrosion scores [33]. This corresponds with higher fretting scores noted with increased taper contact area [34]. However, there have been reports that describe increased edge

loading at the base of short taper trunnions [35]. Additionally, "long varus" necks demonstrate 32.7% greater bending moments when compared to "short varus" necks [11] which potentiates cantilever bending in vivo and resultant micromotion, fretting, and corrosion [33]. In relation to this, beta titanium alloy (Ti12Mo6Zr2Fe, TMZF) has shown decreased flexural stiffness and has been associated with increased fretting and corrosion [36]. These effects may be aggravated with the use of larger head sizes (>32 mm), which increase torsional forces at the taper trunnion [37]. Larger head sizes may increase offset and varus neck shaft angle, leading to increased lever arm [35], and has been recognized as a contributing factor in the increased failure rates of modular MoM THA [38].

Surgical Assembly Associated with Modular Neck Taper Corrosion

Intraoperative surgical assembly may play an important role. In vitro tests have demonstrated greatly reduced (>50%) load to failure with a contaminated assembly compared to a well-cleaned assembly [39] and has been shown to affect cantilever micromotion of dual-modular taper neck-stems [40]. Although impaction technique and force of impaction have been studied in head-neck taper corrosion, the effect of impaction at the modular neck-stem junction has not been examined to date. It is recognized that cleaning of interfaces before impaction, avoidance of angular mismatch between the neck and the stem, and use of similar alloys for the neck and the stem are essential in preventing modular neck taper corrosion.

Patient Factors Associated with Modular Neck Taper Corrosion

Potential patient factors associated with modular neck taper corrosion-related ALTR include metal hypersensitivity, body mass index, and activity level. Implant-related metal hypersensitivity has been reported since 1990s [22]. Although ALTR has been associated with taper corrosion secondary to MACC, ALTR has also been observed in the absence of high wear or metallosis [41–43]. Histological examination of periprosthetic tissues in dual-taper THA patients undergoing revision surgery has demonstrated features suggestive of metal hypersensitivity [44, 45]. Although increased body mass index (BMI) and increased activity levels would potentially increase the stresses borne by the modular trunnions, to date, no correlations have been reported between ALTR in dual-modular stem neck THA and BMI or increased activity levels [42, 46].

Systematic Evaluation

A painful dual-modular neck THA can present with a myriad of symptoms and may be attributable to various intrinsic and extrinsic causes. In general, the clinician should look to rule out common cause of pain or failure, including infection and implant loosening, prior to initiating an evaluation for modes of failure specific to a modular neck-stem. A systematic evaluation should include focused clinical history, detailed physical examination, laboratory tests, and cross-sectional imaging to identify potential differential diagnoses in a painful dual-modular neck THA [47, 48]. A consensus systematic risk stratification algorithm is available to guide physicians based on currently available evidence [49] to initiate prompt and appropriate treatment.

Clinical Evaluation

The physician should obtain a complete history when evaluating patients with a dual-modular femoral neck-stem total hip arthroplasty. The characteristics, site, severity, duration, and onset of the pain provide important information [48, 49]. Joint sepsis must be suspected in patients with a history of delayed wound healing, or hip pain after recent gastrointestinal or dental procedures. The physician should also ask about any discomfort caused by fullness or swelling around the hip as this may suggest a fluid collection secondary to an ALTR. Physical examination should begin with inspection of the skin for signs of

infection and previous scars. Palpation around the hip may reveal the presence of soft-tissue masses which again might suggest ALTR. Range of motion of the affected hip should be tested as reproduction of pain on passive extension and active flexion may indicate iliopsoas tendinopathy. Strength of hip abduction should also be examined. A comprehensive spine and neurovascular examination is essential to exclude potential confounding neurogenic and vascular causes of pain [48].

Implant Modularity

It is important to recognize that different types of material options exist at the neck-stem junction of a dual-modular femoral neck THA [49]. Different combinations of neck and stem materials may be used at the neck-stem modular junction of dual-taper stem THAs, and include:

(a) Titanium modular neck on titanium stem (Ti/Ti)
(b) Cobalt-chromium modular neck on titanium stem (CoCr/Ti)
(c) Cobalt-chromium modular neck on cobalt-chromium stem (CoCr/CoCr)

To date, the majority of taper corrosion-related adverse tissue reactions have been reported in dual-modular neck femoral THAs with cobalt-chromium modular necks on titanium stem modular junctions (CoCr/Ti).

Inflammatory Markers and Hip Joint Aspiration

Serum inflammatory markers (ESR and CRP) are frequently elevated in a setting of taper corrosion and this can occur in isolation, or may suggest presence of concurrent or isolated periprosthetic infection (PJI) [50, 51]. Taper corrosion may also mimic the diagnosis of PJI and this warrants hip aspiration for culture and differential counts [52]. However, synovial fluid counts are also affected by the presence of metallic debris which requires manual counting to reduce errors from metallic debris contamination or the erroneous measurement of dead white blood cells [53]. Although ESR and CRP have limited value in the diagnosis of PJI in dual-modular neck implants with corrosion, these inflammatory markers may be useful in excluding PJI. In addition, there should be a low threshold to perform synovial fluid hip aspiration in the setting of elevated inflammatory markers as the intraoperative appearance can be deceiving with purulent material frequently seen. Hence, a preoperative aspiration with a cell count and culture can be very useful to perform preoperatively to avoid confusion at the time of surgery. Newer methods to determine the presence of infection such as leukocyte esterase strip tests, alpha defensin, and PCR methods may be potentially useful to detect PJI in the presence of taper corrosion in dual-modular neck-stem THA patients although some reports have suggested false-positive alpha defensin testing in patients with corrosion reactions [54].

Serum Metal Ion Levels

Cobalt and chromium ion levels are influenced by the implant type, metallurgy, design of neck and stem taper interface, head size, and positioning of the implant [49]. Elevated metal ion levels have been documented in dual-modular neck-stem THA patients with taper corrosion-related adverse tissue reactions [4, 14, 55]. In general, the magnitude of elevation, however, has been lower in dual-modular neck-stem THA patients when compared to MoM bearing THA patients [49]. In addition, a preferential elevation of cobalt relative to chromium, resulting in an increase in Co/Cr ratio, is also commonly observed in patients with symptomatic corrosion [56]. A management algorithm based on the consensus systematic risk stratification statement of the American Association of Hip and Knee Surgeons, the American Academy of Orthopaedic Surgeons, and the Hip Society stated that although metal ion levels alone should not be relied on as the sole parameter to determine revision surgery, threshold of cobalt level >5 μg/L and Co/Cr ratio >5 are useful clinical diagnostic adjuncts in the systematic clinical evaluation for taper corrosion-related adverse tissue reactions in patients with dual-modular taper THA [49].

The mechanism that leads to differential elevation of cobalt relative to chromium remains poorly understood [26]. It has been hypothesized that, in contrast to MoM bearing surface wear,

the predominant ion release at modular taper junction may be chemical corrosion process that involves chromium precipitating as chromium orthophosphate and more soluble cobalt dissipating as free ions [57]. Metal ion levels have been reported to decline to near-normal levels within 3 months following revision surgery and removal of a dual-taper modular neck-stem THA [58]. In addition, metal ion levels can be difficult to interpret in patients with systemic renal disease, additional MoM bearings in conjunction with dual-modular neck-stem THAs, and bilateral dual-modular neck-stem THAs. Therefore, while metal ions are useful as an adjunct investigation, it must be noted that metal ion levels should not be used in isolation to determine clinical recommendation for surgery.

Radiographic and Cross-Sectional Imaging

Focused review of serial plain radiographs to identify loosening, osteolysis, trochanteric, and/or calcar erosion must be noted as they may be associated with taper corrosion (Fig. 16.1). Currently, ultrasound (US) or metal artifact reduction sequence (MARS) magnetic resonance imaging (MRI) is the preferred cross-sectional imaging modality of choice. Common MARS MRI abnormalities include the presence of a thickened capsule in association with an effusion (Fig. 16.2). Other typical findings include iliopsoas and abductor tendinopathy, peri-tendinous collections, and presence of metallic debris.

Both ultrasound and MARS MRI have been reported to be highly sensitive (92–100%) and specific for the detection of MoM THA-related pseudotumors (96–100%) [59]. Ultrasound is not affected by soft-tissue artifacts, and can discriminate solid from cystic lesions. Ultrasound assessment is operator dependent and does not allow the surgeon to perform preoperative planning nor longitudinal comparisons [60]. In addition, its inconsistency in evaluating the deep structures, especially in obese patients, is a potential disadvantage [61]. MARS MRI is a highly sensitive modality for detection of solid and cystic ALTR (pseudotumors); however, the potential disadvantages include an increased scanning duration, the obscuration of periprosthetic tissues by metal artifacts, and the costs [62].

Surgical Management

Management of a patient with a painful dual-modular neck-stem THA presenting with elevated metal ion levels and evidence of pseudotumor with bone or muscle damage warrants revision surgery. Revision surgery for dual-modular neck-stem THA necessitates a thoughtful approach to reduce intraoperative complications. Meticulous and careful debridement must be performed to remove the pseudotumor while protecting neurovascular structures. Removal of the well-fixed stem is technically challenging, requiring availability of instruments such as high-speed burrs, flexible thin osteotomes, and customized neck-stem extractors. Techniques such as simple and extended trochanteric osteotomies, high-speed needle-point burrs, and stack pin techniques have been described for stem removal [63, 64]. Stem removal may affect remnant proximal bone stock and fixation of the revision prosthesis stem.

Following removal of dual-modular femoral stem, acetabular component assessed to be loose intraoperatively is revised with a highly porous tantalum acetabular cup with multiple screws and highly cross-linked polyethylene liner. In the presence of reactive tissue necrosis, the area of necrosis is extensively debrided except in the close proximity of neurovascular structures. The use of modularity at the time of revision such as titanium modular tapered femoral stems is frequently required to optimize intraoperative stability in the setting of significant tissue necrosis. The largest diameter ceramic femoral head compatible with the acetabular component is used to maximize head-neck ratio in order to further optimize intraoperative stability.

The revision surgery may result in an increased complication rates and re-revision rates due to dislocations and recurrence of ALTR in the setting of well-fixed femoral stem requiring removal and adverse tissue reaction. The precise etiology of

ALTR recurrence after revision for symptomatic ALTR remains largely unknown. The potential contributing factors for ALTR recurrence is likely to be multifactorial related to surgical, patient, or implant factors. Incomplete surgical debridement and inadequate removal of pseudotumor during the first revision may contribute to ALTR recurrence. However, extensive debridement needs to be performed safely juxtaposed to neurovascular structures. Inherent patient metal hypersensitivity may be a contributing factor. ALTR recurrence has also been suggested to be secondary to taper corrosion at head-neck taper junction of metal-on-poly bearings or at modular taper junction of revision femoral stem used at initial revision surgery.

Patients with dual-taper THA are often concerned about the systemic elevation of metal ion levels and inquire about the time required to return to normal. In the vast majority of patients with elevated cobalt and chromium ion levels, metal ion levels decline to very low or undetectable levels following revision surgery with the serum cobalt and chromium levels declining on average by 32 and 21% at 6 weeks post-revision surgery. Further data is needed to determine the long-term outcomes and surgical complication of dual-taper modular neck-stem THA patients who have undergone revision surgery.

Histopathology Analysis

Recent studies have reported corrosion-related ALTR (pseudotumors) or aseptic lymphocyte dominated vasculitis-associated lesions (ALVAL) occurring in dual-modular neck THAs, which were initially described as complications of metal-on-metal (MoM) bearings [14, 16–18, 20, 33, 65, 66]. Although ALTR has been linked to modular junction mechanically assisted crevice corrosion (MACC) and elevated metal ion levels, ALTR has also been observed in the absence of high wear or metallosis [41–43]. Current evidence has indicated that the process is complex and multifactorial, with a spectrum of histological features being noted in periprosthetic tissues of dual-taper modular neck-stem THA patients undergoing revision. The histological features indicate tissue reactions consistent with metallic wear and metal hypersensitivity [44, 45]. Despite a correlation that exists between elevated metal ion levels and patients with pseudotumors, no dose-dependent relationship has been observed between metal ion levels and histological responses.

Implant Retrieval Analysis

Retrieval analysis allows close examination of failed implants and study of damage patterns at the neck-stem junction of dual-taper modular THAs. Cyclic cantilever motion and bending of the neck at the head-neck and neck-stem interfaces have been described [33]. Higher contact area, increased taper surface roughness, narrow cone-angle tapers, decreased flexural rigidity of beta titanium, longer neck lengths, and increased head sizes have been reported to contribute to higher fretting and corrosion scores in the retrieval analysis of dual-taper modular femoral stems [29, 30, 33–35, 37, 40, 67].

Case Solution

The patient was counseled on the risks and benefits of revision surgery and elected to proceed with revision surgery. A revision THA of the left hip was performed through a posterior approach. Upon entering the joint capsule, a large rush of metallic sludge was extruded from the joint. Extensive debridement was necessary for the large pseudotumor lesion and significant abductor necrosis. A “top-out” technique was performed for femoral stem extraction utilizing high-speed burrs, without the need for extended trochanteric osteotomy (ETO). The use of a titanium revision modular stem was necessary due to the proximal metaphyseal bone deficiency and to optimize intraoperative stability secondary to extensive abductor necrosis (Fig. 16.3). The acetabular cup was retained as it was assessed to be well positioned and stable intraoperatively. A ceramic femoral head and highly cross-linked polyethylene liner was utilized. The patient tolerated the surgical procedure and had no neurovascular deficits postoperatively.

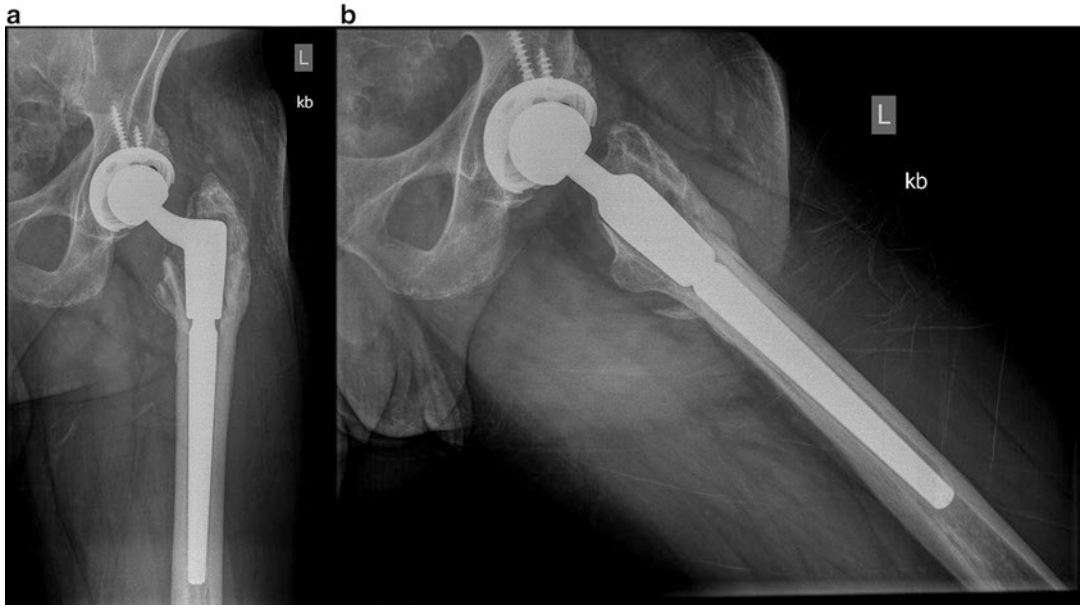

Fig. 16.3 Post-revision (**a**) anteroposterior (AP) and (**b**) lateral radiographs with a revision modular fluted tapered stem

Outcome

The patient returned to playing golf. At 6 months postoperatively, cobalt and chromium metal ion levels declined to 0.4 μg/L and 0.4 μg/L, respectively, from initially elevated serum metal ion levels of cobalt 17 μg/L and chromium 2 μg/L pre-revision surgery.

Summary

There should be a low threshold to conduct a systematic clinical evaluation of patients with dual-modular neck-stem THAs as early recognition and diagnosis will ensure prompt and appropriate treatment. As painful dual-modular neck-stem total hip arthroplasties have various intrinsic and extrinsic causes, patients should be evaluated utilizing systematic risk stratification algorithms. Although specialized tests such as metal ion analysis and cross-sectional imaging modalities such as MARS MRI and ultrasound should be used to optimize clinical decision making, overreliance on any single investigative tool in the clinical decision-making process should be avoided. Further research is required to gain understanding of implant, surgical, and patient risk factors associated with taper corrosion in dual-modular neck-stem THA.

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Corrosion at the Modular Head–Neck Junction

17

Michael B. Cross, Myra Trivellas, and Joshua J. Jacobs

Case Presentation

The patient is an 80-year-old female who presented with 9 months of pain in the groin following a primary total hip arthroplasty (THA), done through a posterior approach 3 years earlier. Implanted components included a cementless acetabular component 50 mm in diameter with a highly cross-linked polyethylene liner, a cementless titanium stem, and a 36 mm cobalt chromium alloy femoral head with a standard neck length. Preoperative evaluation included plain X-rays (Fig. 17.1) that showed well-fixed, acceptably sized, and positioned components. An erythrocyte sedimentation rate (ESR) was 30 mm/h and a serum C-reactive protein (CRP) was <5.0 mg/L. As there was no evidence of loosening and the evaluation for infection was negative, serum metal levels were obtained that showed a serum cobalt of 9.54 parts per billion (ppb) and a serum chromium of 0.72 ppb.

The patient's serum metal levels are highly consistent with an adverse local tissue reaction (ALTR) caused by corrosion at the modular head–neck junction following a metal-on-polyethylene bearing THA, with a serum cobalt level that is both greater than the serum chromium level and more than 1 ppb. A more careful evaluation of the plain X-rays (Fig. 17.1) shows a small lytic lesion just inferior to the tear drop and possibly small lytic areas at the lateral aspect of the acetabulum and in the calcar area. The patient subsequently had an MRI that was consistent with an ALTR and the patient was indicated for revision surgery. At the time of surgery, purulent-appearing fluid was identified within the joint (Fig. 17.2) and gross corrosive material was identified at the modular head–neck junction (Fig. 17.3). Local damage to the soft tissues was seen, consistent with an adverse local tissue reaction, but the abductors were intact. A manual synovial fluid white blood cell count showed 30 white blood cells (wbc)/μL; however a differential could not be calculated given the high number of dead cells in the sample. After careful trialing to ensure adequate stability, the modular liner was exchanged, and after manual cleaning the femoral taper with a lap sponge, a 36 mm +4 BIOLOX® (CeramTec, Plochingen, Germany) *delta* ceramic head with a titanium taper sleeve, was impacted onto the stem (Fig. 17.4).

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_17

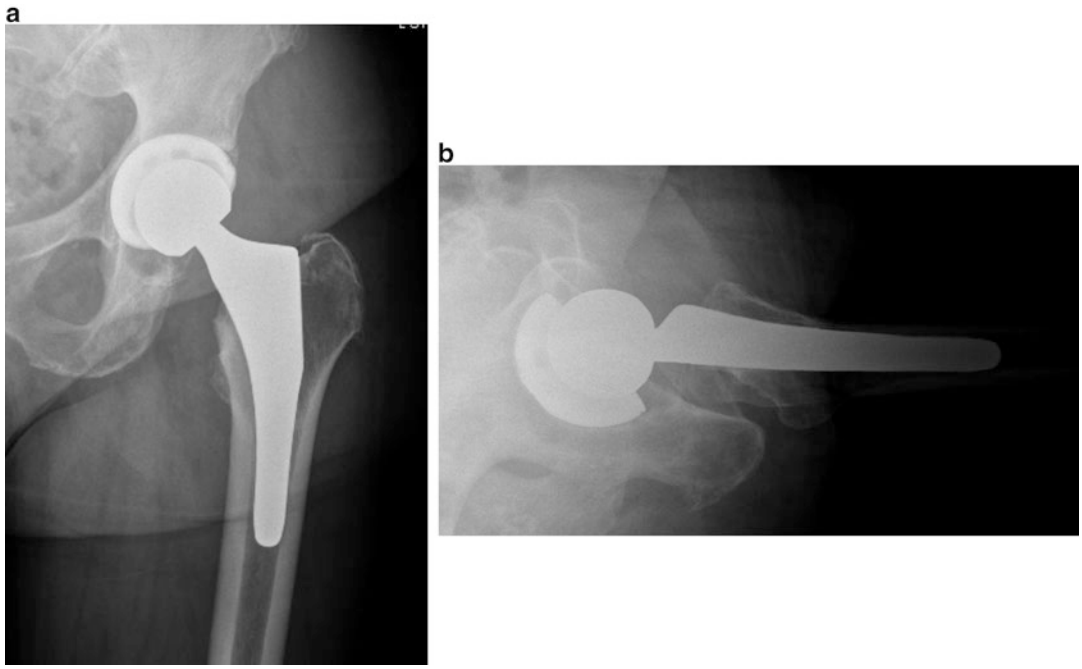

Fig. 17.1 Preoperative AP (**a**) and shoot through lateral (**b**) images show well-fixed, appropriately sized, and positioned components

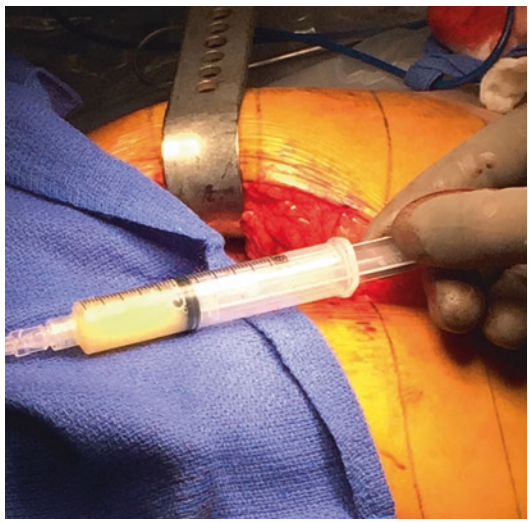

Fig. 17.2 Purulent material obtained at the time of surgery

Introduction

Modular heads were first introduced in the 1980s and became the standard of care by the early 1990s [1]. One advantage of modularity at the head–neck junction is the ability to make small adjustments to a head size, offset, and length to optimize soft-tissue tension, joint stability, leg lengths, and overall hip biomechanics. Additionally, modularity allows surgeons to choose from a variety of bearing materials, ranging from cobalt–chromium (CoCr) to ceramic, individualized for each patient. Furthermore, revision surgeries may be simplified if the revision only requires a head and liner exchange allowing a well-fixed, properly positioned stem to be retained (e.g., in managing an acute periprosthetic joint infection [PJI]). However, while advantages remain, this chapter discusses the potential disadvantages of modularity at the head–neck junction, and offers potential solutions to the recently seen problems of corrosion at the head–neck junction.

Corrosion: Definitions

Corrosion refers to the environmental degradation of a material that occurs on its surface due to a series of electrochemical reactions (reduction–

Fig. 17.3 Corrosive debris seen at the head–neck junction

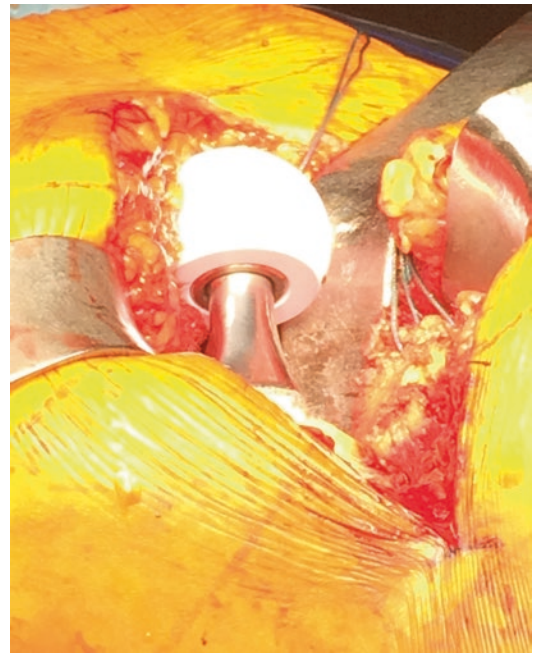

Fig. 17.4 BIOLOX® *delta* ceramic head with a titanium taper sleeve after impaction onto the taper

oxidation reactions); for metallic materials the degradation products are in the form of metal ions, metal salts, and/or adducts of metal ions such as metalloproteins. *Passivation* is a process that limits corrosion in which a thin layer, typically tens of nanometers in thickness, forms on the metal surface. In the case of surgical implant alloys, this layer consists of an oxide of one or more of the alloying elements. For titanium alloy implants, the passivating layer is composed of titanium oxides, whereas for CoCr alloys and stainless steel, the passivating layer is composed primarily of chromium oxide. Normally, with no external forces acting on the system to disrupt this passive layer, the transport of ions and/or electrons is impeded limiting the redox reactions involved in corrosion.

Eight different modes of corrosion have been described: uniform, galvanic, fretting, crevice, pitting, intergranular, selective, and stress [2].

- *Uniform* corrosion is the inevitable oxidation and reduction reactions all metal surfaces undergo when immersed in electrolyte solutions which involves the entire metal surface; however, uniform corrosion is virtually undetectable with metals used for total hip arthroplasty due to the highly resistant alloys that are used for the prosthetic components.
- *Galvanic* corrosion occurs between two different metals and requires physical contact in an electrolyte to enable the ion transfer. This contact between two different metals in a conducting solution is associated with an electrochemical potential difference in which one metal acts as a cathode and the other as an anode, facilitating the redox reactions involved in corrosion. For the spontaneously passivating metals used in orthopedic implant alloys, galvanic corrosion is impeded by the passivation layers.
- *Fretting* corrosion is due to mechanical forces that disrupt the passive layer and allows for unimpeded redox reactions of the metal surface.
- *Crevice* corrosion refers to corrosion within an area shielded from the surrounding environment, such as in cracks and crevices.

The local solution chemistry within the crevice, characterized by low pH and low oxygen tension, destabilizes the passive film leading again to unimpeded redox reactions.

- *Pitting* corrosion is similar to crevice corrosion. However, the localization is symmetric, with a downward propagation of pits and holes created at sites on the metal surface adjacent to high-energy features of the underlying metal.
- *Intergranular* corrosion occurs at the grain boundaries where impurities tend to segregate and where the mismatch in crystalline orientation leads to higher local reactivity. Intergranular corrosion is seen in cast alloys more commonly than wrought alloys.
- *Selective leaching* is preferential corrosion of specific structures within the alloy. Selective leaching is seen especially in multiphase alloys, since certain elements are more susceptible to corrosion. These susceptible elements dissolve out first and leave behind more stable elements. Although this corrosion results in loss of material on the surface, this process also aids in passivation due to the inherent higher corrosion resistance of the remaining elements.
- *Stress* corrosion describes redox reactions accelerated by mechanical stress leading to amplification of the material loss. Also termed corrosion-enhanced fatigue, cracks can grow along grain boundaries and other high-energy structures due to the applied stress in conjunction with redox reactions and the formation of solid corrosion products.

These eight different modes of corrosion can occur simultaneously and can be synergistic such that the actual corrosion process occurs synergistically (e.g., at modular junctions of a total hip arthroplasty). The manufacturing method, implant design, material selection, metallurgical history, and surface finish, in addition to the chemical and mechanical environment (i.e., pH, oxygen tension, presence of micromotion, and stresses on the implant), all affect the magnitude of corrosion.

In addition to defining and understanding the definition of corrosion, another important category of material degradation is wear. *Wear* is defined as material loss from the surface of a material due to contact and relative motion with a second body. Fretting is a specific type of wear relevant to total hip implants as it describes material loss due to micromotion (typically less than 100 μm) between two materials under a sustained load [2]. All modular head–neck junctions are subject to fretting [3, 4]. As mentioned above, fretting disrupts the outer passive oxide layer and allows for unimpeded redox reactions (corrosion) in the contact zone between the head and the neck. This is exacerbated by the crevice geometry of the contact zone. Since fretting initiates and potentiates this corrosion process, it has been described as "mechanically assisted crevice corrosion" (MACC) [5]. Many aspects of the geometry, assembly, and material properties of the trunnion and head can influence MACC, highlighting the complexity of this process.

Tribocorrosion is a term that is increasingly being used to describe the combined and synergistic mechanical and electrochemical (redox) processes that occur at metal contact zones. Tribocorrosion includes both wear and corrosion and is relevant when describing material degradation at metal bearing surfaces and metal contact zones in modular junctions.

Corrosion at the Head–Neck Junction: Incidence and Overview

Although the use of metal-on-metal (MoM) THAs has been almost entirely abandoned, the catastrophic consequences seen as a result of metal bearing wear in MoM THAs have led to increased scrutiny and caution at other metal–metal junctions, most notably the head–neck junction. History has shown that with an increase in modularity, where metal contacts metal, complications due to fretting, corrosion, and wear debris may become clinically relevant over time and thus must be studied and followed clinically. While protocols and clinical algorithms exist for the workup and management of MoM THAs, the ideal management of a "tribocorroded" THA remains unclear. Part of what makes taper corrosion so difficult as a clinical problem is that no

threshold has been established to predict what amount of tribocorrosion products at the trunnion produce clinically significant complications, specifically an adverse local tissue reaction (ALTR).

While the incidence of clinically significant corrosion at the modular head–neck taper has not been quantified, McGrory et al. reported an incidence of 1.1% in a population of patients having undergone a primary total hip replacement of one particular design [6]. In a consecutive series of 569 revision THAs, 1.8% of the revision surgeries were performed due to ALTR associated with MACC at the head–neck junction in patients with a metal-on-polyethylene bearing THAs [7]. Another center reported that of 519 revision THA cases between November 2011 and December 2013, 3.3% were to treat ALTR (i.e., pseudotumors) due to trunnion corrosion in metal-on-polyethylene THAs [8]. However, one of the challenges to determining the incidence of ALTR in association with MACC is that the presence of MACC at the head–neck junction does not always lead to a clinically significant ALTR that will require revision surgery. In a study of a recalled dual-modular stems, even some patients with abnormal imaging or lab values, such as elevated metal ion levels, were asymptomatic. In all asymptomatic cases in which the implants were removed because of the recall, there was macroscopic evidence of corrosion [9]. What is concerning about patients with "silent" corrosion is that in a retrieval study, when presenting clinical symptoms were correlated to assessed corrosion and wear damage found in retrieved implants, more severe abductor destruction and bone loss were seen when there was a preponderance of corrosion, whereas those cases with a preponderance of wear and less corrosive damage had more moderate soft-tissue involvement [10].

The presence and amount of tribocorrosion debris at the head–neck junction are determined by many factors. Material properties, including the inherent elastic modulus, flexural rigidity, and reactivity of the comprising elements, are believed to play a large role. Furthermore, the taper geometry, size, design, and lateral offset also play a role. Patient-specific factors have also been shown to affect fretting at the modular head–neck junction—male gender, younger age, and longer implantation time have all been shown to lead to increased fretting; however, body mass index (BMI) did not show a correlation [11]. Surgeon-controlled factors such as maintenance of clean and dry conditions during intraoperative engagement of the head–taper junction, and the application of impaction forces sufficient to engage the head–neck taper, have also been shown to affect tribocorrosion at this location [12, 13].

Component Material

The femoral head material is likely the most significant factor leading to ALTRs associated with MACC. In simple terms, femoral heads are either made out of metal or ceramic. With improvements in metallurgy and manufacturing, implant materials have had enhanced longevity and resistance to tribocorrosion. However, they still harbor the potential for tribocorrosion corrosive damage. The metal used for the femoral stem in contemporary implants is usually a titanium alloy (Ti–6Al–4V or Ti–Mo–Zr–Fe), and less commonly a cobalt–chromium–molybdenum alloy. Titanium (Ti) is inherently more inert than CoCr, but has inferior wear properties, a lower elastic modulus (i.e., is less stiff), and poor abrasion resistance (is more susceptible to surface deformation and wear as it slides along another metal).

Cobalt–chromium alloys have a higher abrasion resistance than titanium alloys making them more suitable for metal–metal head–neck junctions. Cobalt–chromium and its outer oxide layer are also harder than titanium, making it more resistant to fretting. Nevertheless, studies comparing Ti–Ti, CoCr–CoCr, and CoCr–Ti head–neck junctions have shown the least tribocorrosion in Ti–Ti components, owing to the superior corrosion resistance of Ti alloys. Not only is titanium more inert, but it has been hypothesized that titanium's superior ability to "cold-weld" once the head has been engaged with the trunnion prevails over the expectedly inferior properties, such as less resistance to fretting and lower stiffness [11]. Nitriding, which hardens metal surfaces by heat treating to diffuse nitrogen into the surface,

has also been described to reduce the amount of fretting and corrosion [14].

Ceramic heads or ceramicized metal heads (such as Oxinium® [Smith and Nephew; Memphis, TN]) have desirable wear properties, have high resistance to abrasion or scratching, are chemically inert in bulk form, have increased strength compared to metal counterparts, and have lower coefficients of friction against highly cross-linked polyethylene (HXLPE). Oxinium® is a zirconium alloy metal substrate whose surface is transformed by oxidation into zirconium oxide, so that the outer surface has the properties of a ceramic material. This allows for the head to have the superior wear properties of a ceramic articulating surface while at the same time maintaining the toughness (strength and ductility) of metal, therefore reducing the susceptibility to fracture. Overall, the surface hardness of Oxinium® is reported as two times greater than CoCr. In addition, Oxinium® is much less brittle than alumina ceramic, and is also 20% lighter than CoCr [15, 16].

Studies have shown that metal heads are associated with greater tribocorrosion damage than ceramic heads [17–19]. The low levels of corrosion products in ceramic-metal modular head–neck junctions are likely the reason that ALTRs associated with this combination have been rarely, if ever, reported.

In regard to the stem, either Ti alloy or CoCr stems are commonly used. Stainless steel (SS) stems are now rarely used in North America due to their inferior corrosion resistance. The corrosion seen between SS and CoCr at the head–neck junction was even greater than that seen with CoCr–CoCr pairings [20]. Since titanium is less stiff compared to cobalt chrome, with an elastic modulus of approximately half, a titanium taper would be expected to bend more and therefore have a greater potential for fretting and corrosion due to the elastic incompatibility between the neck and head. While the lower elastic modulus of Ti more closely matches the surrounding bone and is generally considered a beneficial characteristic of Ti femoral stems due to reduced stress shielding, the lower flexural rigidity of a titanium trunnion compared to a CoCr trunnion predisposes such couplings to MACC. When considering these pros and cons with the previously discussed comparison between metal and metal modular head–neck junctions that demonstrated that Ti–Ti combinations had the least amount of corrosion compared to CoCr–CoCr and CoCr–Ti interfaces [11], there seems to be a theoretical advantage for Ti–Ti components if choosing metal-on-metal head–neck junction. Titanium alloy heads, however, have inferior wear performance coupled with polyethylene bearing surfaces than CoCr alloy. Nonetheless, the superior tribocorrosion performance of Ti–Ti modular junctions provides the rationale for current treatment recommendations for treatment of trunnions with tribocorrosion damage in the setting of well-fixed femoral stem. In this situation, the use of a ceramic femoral head with a titanium taper sleeve is recommended to minimize further potential for ongoing corrosion at the head–neck junction while avoiding the potential occurrence of a ceramic burst fracture from stress concentrations on a damaged trunnion.

Taper Design and Size

The size of the taper has also been shown to have an impact on MACC at the head–neck junction. The smaller "11/13" taper showed evidence of greater susceptibility to micromotion and fretting compared to the larger, stiffer "12/14" taper [11]. Smaller tapers give the advantage of greater range of motion by maximizing the head–neck ratio, thereby protecting against dislocations. However, with less surface area for an interference fit and decreased flexural rigidity, smaller tapers can have increased micromotion leading to MACC. Furthermore, the shorter, narrower trunnion decreases the skirt and allows for greater range of motion without impingement. However, this can increase edge loading at the trunnion base as the base is brought closer to the taper [21, 22].

Head Size

It is believed that the adoption of larger head sizes was a major factor leading to the complications seen with MoM THAs. Thus, various studies have looked at head size in relation to the

incidence of tribocorrosion at the head–neck junction. One proposed theory is that larger heads increase the frictional torque seen at the articular bearing surface, which is then transferred to the modular junction as torsional forces, leading to increased tribocorrosion. Based on finite element modeling, heads larger than 40 mm are predicted to have increased tribocorrosion [23], but studies looking at heads less than 40 mm show varying results. Some retrieval studies show that increasing head size *does* have an impact on the amount of corrosion of the head–neck junction [23, 24], whereas other retrieval studies show that there is no statistically significant effect of head size on the amount of corrosion [12, 25]. Thus, currently, the impact of head size on corrosion on the head–neck junction is unresolved.

Local and Systemic Effects of Corrosion Products

When complications after a THA are suspected to be due to tribocorrosion, standard practice includes ordering tests to rule out other causes of the symptoms. The workup should include standard radiographs, metal-artifact reduction sequence (MARS) magnetic resonance imaging (MRI), serum metal levels (such as cobalt, chromium, and titanium levels), and inflammatory markers including ESR and CRP to rule out infection. Infection has been associated with metallosis, and therefore should be considered concomitantly in the diagnostic workup. If infection is suspected, an aspiration can be helpful. Advanced three-dimensional (3-D) imaging such as MARS MRI is useful in assessing the soft tissues surrounding the implant to look for evidence of muscle/tendon damage, pseudotumors, synovitis, osteolysis, and fluid collections. No current cutoffs exist for metal levels that suggest destructive ALTRs, so clinical judgment should be used to assess the patient's clinical signs and symptoms, imaging, and overall function. If the patient feels comfortable with monitoring progression, blood metal levels can be followed to ensure that there are no drastic changes that would suggest implant failure or imminent complications. If the choice is made to proceed with a revision surgery, metal levels have been shown to decrease dramatically by 6–12 weeks and generally return to normal within 6–12 months [26].

Cobalt–chromium is a commonly used metal in joint replacement devices, and therefore blood tests to measure cobalt and chromium metal are available. With corrosion reactions, cobalt is often found at higher concentrations than chromium in the serum, in part because Co is inherently more soluble. Conversely, chromium has the tendency to precipitate and is found in greater concentrations as deposits on the retrieved implant components and in periprosthetic tissues. While serum titanium levels can also be drawn and followed over time, the usefulness clinically is far less than Co and Cr.

Cobalt, chromium, and titanium can be involved in redox reactions and can therefore release reactive oxygen species that can have cytotoxic effects from oxidative damage to proteins, lipids, and nucleus of cells [27]. Titanium wear products found in surrounding tissues are usually of the same composition as the original implant unlike CoCr debris that may not have the same composition of Co and Cr as the base alloy [28]. Titanium is far less soluble than either Co or Cr, and may explain, at least in part, why titanium debris is better tolerated than CoCr debris.

As a consequence of the widespread failure of large head metal-on-metal implants, the surgeon has become aware of the local complications that can arise when excessive metal is released from an artificial joint into the surrounding tissues. Pain, instability, stiffness, ALTR (which includes local tissue necrosis, aseptic lymphocyte-dominated vasculitis-associated lesion [ALVAL] pseudotumors, and osteolysis), implant loosening, and predisposition to infection have all been shown to occur as a result of metal wear debris [29, 30]. Systemic effects and systemically elevated metal levels have also been reported in association with tribocorrosion. However, the lack of specificity of the symptoms makes it difficult to prove that the systemic manifestations were a direct result from the metal levels. On the other hand, what is nearly universally regarded as a direct result of excessive metal release from tribocorrosion is ALTR in all its forms including pseudotumors, ALVAL, periprosthetic tissue

necrosis, and osteolysis. A higher risk for ALTR has been reported in females likely resulting from differences in metabolism of metal, storage ability (both cellular/extracellular and fat stores), as well as differences in renal excretion [31, 32].

Surgical Treatment

When revising a patient for ALTR due to MACC at the head–neck junction, or when tribocorrosion is visibly seen when revising a THA for another unrelated reason, the overall goal of treatment is to remove the debris generator(s), clean the trunnion as much as possible, and debride any inflammatory or necrotic soft tissues and bone. Thorough debridement of the affected tissues should be performed to allow remaining healthy tissues and bone to heal successfully. However, caution should be used not to remove so much tissue that the joint becomes unstable. With ALTRs, turbid, brown, or gray joint fluid can be extensive and this may be confused with infection. An intraoperative frozen section and joint fluid for a manual cell count and differential can be sent if any doubt exists whether an infection is present. If the original femoral component is well fixed and well aligned, and consists of a Co–Cr femoral head, the head should be removed and replaced with a ceramic head, ideally with a titanium sleeve, to minimize the chance of future tribocorrosion at this interface. Prior to impacting the ceramic head with the titanium sleeve on to the trunnion, every attempt should be made to clean the corrosion products off of the trunnion while not further damaging the trunnion. If the surgeon deems the trunnion damage to be severe placing the neck at risk for fracture, the femoral stem should be removed instead of using the technique described above. In the majority of revision surgeries for taper corrosion, resolution of pain and symptoms and normalization of metal levels have been reported [33].

Conclusion

Tribocorrosion at the modular head–neck junction can vary greatly from limited to severe damage, and consequently the clinical ramifications can vary. Patients may be asymptomatic or have clinical signs and symptoms of an ALTR requiring revision. Further studies are required to attempt to delineate metal-level thresholds and to optimize clinical algorithms for the management of these difficult patients.

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Aseptic Implant Loosening

18

Nicholas M. Desy and Matthew P. Abdel

Case Presentation

An 83-year-old female patient presented with significant pain in her left hip. She had undergone a left total hip arthroplasty (THA) 4 years ago for osteoarthritis at an outside hospital. She did well until 4 months prior to presentation when she started to complain of pain. One month prior to her presentation she was found to have a dislocated hip and a migrated acetabular cup and was then referred to our institution. She denied any constitutional symptoms such as fever, chills, or night sweats. Outside operative records and implant stickers revealed that she had a 52 mm porous, spiked acetabular component and a flat wedge taper femoral component with a 36 mm femoral head. Her radiographs demonstrated an uncemented THA that was dislocated, as well as an acetabular component that had migrated and was grossly loose (Fig. 18.1). The patient's erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were 30 mm/h and 24.5 mg/L, respectively. A hip aspiration demonstrated 912 cells with 57% neutrophils, and no bacterial growth at 14 days.

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Epidemiology

Aseptic loosening of acetabular and/or femoral components is one of the main complications following THA. An investigation of all revision total hip arthroplasties (THAs) recorded in the Healthcare Cost and Utilization Project Nationwide Inpatient Sample Database found that mechanical loosening was the second most common cause for revision surgery at 19.7% among revision THAs performed between October 1, 2005, and December 31, 2006 [1]. In a separate study that involved two centers over a 6-year period, Ulrich et al. [2] found that aseptic loosening was the most common reason for failure at 51.9%, with the majority developing after 5 years of follow-up.

For cemented THAs, the 25-year survivorship free of revision or removal for aseptic loosening for the primary Charnley THA was found to be 86.5% in one study of 2000 hips [3]. The original Exeter cemented femoral stem (Stryker Howmedica, Kalamazoo, MI) was found to have a survivorship of 93.5% free for aseptic loosening at 33 years of follow-up in a study of 33 hips [4], while the Exeter Universal cemented femoral

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_18

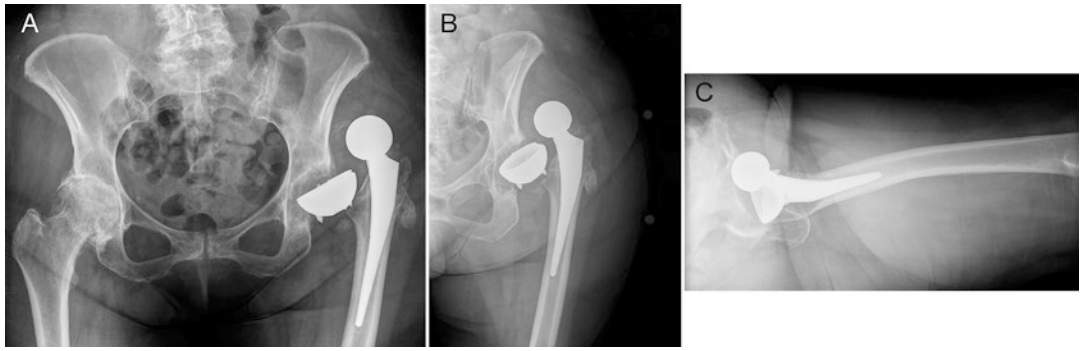

Fig. 18.1 Anteroposterior (AP) view of the pelvis (**a**) as well as AP view of the left hip (**b**) and cross-table lateral X-ray of the left hip (**c**) demonstrate a dislocated left THA with uncemented components. The acetabular component has flipped and migrated. The femoral stem appears to be well fixed

component (Stryker Howmedica) had a survivorship of 100% free for aseptic loosening at 17 years of follow-up in another series of 325 hips [5]. Hybrid THAs (i.e., those with an uncemented acetabular component and a cemented femoral stem) have also demonstrated satisfactory survivorships [6]. Furthermore, cementation has been associated with an increased survivorship of the femoral stem in patients ≥80 years of age [7].

The use of uncemented components for primary THAs has seen worldwide increase over the last 5–10 years [8]. Several studies have reported excellent long-term survivorship of various uncemented acetabular and femoral components [9–15]. A long-term follow-up of a randomized controlled trial between cemented and uncemented primary THAs revealed that uncemented components demonstrated increased survivorships for all causes as the end point [14]. An analysis of the Nordic Arthroplasty Register Association identified that uncemented implants had a reduced risk of revision for aseptic loosening [16]. However, a review of various worldwide registries found that cemented fixation offered a lower risk of revision in patients older than 75 years [8].

Risk Factors

Several risk factors have been postulated to be associated with aseptic loosening after THA. These can be subcategorized into (1) patient factors, (2) component factors, and (3) surgical technique factors.

Patient Factors

The patient factors that have been determined to date to be potential risk factors for THA aseptic loosening include

- Obesity
- Bone quality
- Activity level
- Patient genetics

Obesity has become identified as a risk factor for several THA complications such as infection (superficial and deep) and dislocation [17–19]. The effect of obesity on aseptic loosening is currently controversial. A recent study found that obesity (body mass index [BMI] >30 kg/m^2) was associated with early total hip revision for aseptic loosening [20]. The authors found a 4.7 relative risk of THA early revision for aseptic loosening/osteolysis of obese patients compared to nonobese patients. However, a separate recent study that looked at the effects of BMI on the risk of complications and reoperations found that increasing BMI was not a risk factor for mechanical failure or aseptic loosening [17].

Patients with poor bone quality, such as in osteoporosis, have been found to be associated with aseptic loosening of cemented THAs [21]. A study that matched 78 patients with loose cemented THAs to a group of 49 patients with stable implants found that patients with a loose component had significantly lower periprosthetic and lumbar spine bone mineral density [21].

However, male patients have been found to have increased rates of aseptic loosening with the Charnley cemented THA [3, 22–24]. This finding may be secondary to harder bone that leads to a poor cement mantle.

It is currently not clear if activity level is a risk factor for aseptic loosening in THA. However, it is possible that increasing the load or stress on an implant may increase the risk of failure due to loosening. Two relatively recent studies identified increased patient activity level as a risk factor for component loosening [25, 26]. Flugsrud et al. [25] found that men with higher recreational activity levels were at increased risk of acetabular component loosening in a group of cemented and cementless acetabular cups, while Lübbuke et al. [26] identified an increased rate of revision of the femoral component for aseptic loosening in patients with high levels of activity. This association between increased activity and higher aseptic loosening rates could be explained by bearing surface wear.

Lastly, the impact of our genetic makeup has become of interest as a potential cause for early THA failure due to aseptic loosening. The study of single-nucleotide polymorphisms (SNPs) has increased to identify genetic variability that can increase the risk of component aseptic loosening in both cemented and uncemented THAs. Several papers in the literature have identified variation within specific genes that are associated with osteolysis [27, 28]. Furthermore, some studies have found specific polymorphisms that are associated with THA aseptic loosening [29–32].

Component Factors

Advances in THA implant material and design have been devised to promote THA longevity. Both cemented and uncemented components have undergone various modifications over the years to minimize THA failure. There are currently various acetabular cup and femoral stem options from several companies, including cemented and uncemented options, with excellent early to long-term survivorship [5, 10–13]. The main THA component material factor that potentially has played the largest role in improving THA longevity is the conversion of conventional polyethylene to highly cross-linked polyethylene (HXLPE) acetabular liners. One recent study identified significantly more osteolysis in patients that received a THA with conventional polyethylene liners compared to those that received a HXLPE liner at 10 years of follow-up [33]. One of the longest studies to date also found that THA with conventional polyethylene liners had significantly more osteolysis and were considerably more likely to be revised than those with a HXLPE liner at 13 years of follow-up [34].

While the use of metal-on-polyethylene (HXLPE) bearings has been the most widely used articulation, alternate bearing surfaces have also been utilized with the goal of reducing wear rates and improving THA longevity, especially in younger, more active patients. Such bearing surfaces include metal-on-metal, ceramic-on-ceramic, and ceramic-on-polyethylene. These bearings have shown reduced wear rates compared to metal-on-polyethylene; however some may be at a cost, considering the evolving understanding of the effects of metal-on-metal bearings, both locally and systemically [35–38]. Furthermore, the observation of corrosion at the modular head–neck junction leading to "trunnionosis" has prompted some surgeons to utilize a ceramic-on-HXLPE articulation although it is unclear if this will lead to a clinically relevant reduction in wear or failure rates [39–42]. Additionally, one study that compared metal-on-polyethylene (conventional) with ceramic-on-ceramic and metal-on-metal bearing surfaces at 10 years of follow-up found that metal-on-metal articulations had higher aseptic loosening rates than ceramic-on-ceramic bearings [43].

Surgical Technique Factors

Proper surgical technique and component positioning are critical to the early and long-term success of a THA. It is becoming increasingly evident that revision rates are increased with surgeons that have a reduced volume practice [44, 45] or lower surgical skill [46]. A recent study

found that patients who received a THA by a surgeon who performed ≤35 primary THAs the year prior were more likely to experience instability or early revision [45]. Component malposition may increase contact stresses and edge loading and in turn may increase wear rates, which can lead to aseptic loosening. For example, a recent long-term study found that the position of a cemented acetabular component at the anatomic hip center for Crowe type-II dysplastic hips resulted in less aseptic loosening rates compared to cups placed at a nonanatomic hip center [47].

For cemented implants, improper cementing technique, particularly of the femoral component, can lead to early loosening and THA failure. First-generation cementing techniques lead to approximately a 30% loosening rate at 10 years [48]. However, the rate of aseptic loosening in cemented femoral stems has significantly decreased with the introduction of enhanced cementing techniques [49].

For uncemented THA components, initial stability is vital to allow for bone ingrowth or ongrowth. Selecting the appropriate implant size is critical to achieve an adequate press fit and initial stability. Therefore, undersizing an uncemented acetabular or femoral component is a risk factor for aseptic loosening.

Prevention

Given that THAs are mechanical devices, complete prevention of aseptic loosening may not be achievable. A certain amount of component wear may be inevitable. However, early loosening can be minimized and the longevity of the implants can be optimized. Aseptic loosening prevention relies on exacting surgical technique combined with optimal patient and implant selection.

Patient weight reduction is becoming an increasingly important part to preoperative patient optimization [50, 51]. Not only does it benefit their overall general health, but it can also decrease complications associated with THA including infection, instability, and early aseptic loosening. Counseling patients on appropriate activities that are compatible with implant longevity may also be helpful. While it is encouraged that patients remain physically active following surgery, they can alter the types of activities, such as avoiding high-impact sports that involve significant running or jumping.

The choice of THA implants can also help to reduce the risk of aseptic loosening. If a polyethylene liner is selected as part of the articulation, then choosing HXLPE will likely improve the THA longevity for younger, more active patients. As previously noted, however, longer term studies are still required to confirm the long-term superiority of HXLPE over conventional polyethylene past 10 years. One recent study found a 100% survivorship for aseptic loosening in young, active patients (≤65 years old) at a minimum of 10 years of follow-up [52]. Alternate bearings may also reduce the risk of wear and loosening. However, they may cause other complications such as adverse local soft-tissue reactions and systemic manifestations from metal ions seen with metal-on-metal bearings or squeaking and ceramic fractures that are associated with ceramic-on-ceramic bearings.

Proper surgical technique can also minimize early implant loosening and increase the durability of the components. Appropriate component positioning of the acetabular cup (version, inclination, and medialization) and femoral stem (version, coronal alignment, and sagittal alignment) is critical to the success of the reconstruction. For cemented components, particularly a cemented femoral stem, proper third- or fourth-generation cement techniques have been shown to improve THA longevity [5, 49]. Contemporary cementing technique relies on appropriate femoral canal preparation with pulsed lavage and drying, placement of a femoral canal restrictor, use of a cement gun, vacuum cement mixing, retrograde canal filling, use of femoral stem centralizers, and most importantly application and maintenance of pressurization during the cementing process and femoral stem placement [53]. Finally, for uncemented components, it is important to obtain implant initial stability by choosing the correct implant size. Acetabular cups may be augmented with screws to further increase stability depending on the surgeon's preference [54].

Diagnosis

Patient Symptoms and Signs

Aseptic loosening can be a challenging diagnosis to make in some cases or it can be fairly evident as in the case example presented. Evaluation begins with a thorough patient history and physical examination. Patients will typically present with pain in their affected hip. The pain is usually worsened by joint loading with either standing or weight bearing. Patients can also complain of "start-up" pain whereby they report significant pain by changing from a seated to a standing position and taking the first few steps of walking. For aseptic loosening of the acetabular component, pain is typically located deep in the groin area, while femoral component loosening is usually associated with thigh pain. Patients should also be queried for any history of constitutional symptoms that are suggestive of infection, such as fever, chills, or night sweats.

Radiographic Analysis

Radiographic analysis for implant loosening begins with obtaining the appropriate radiographs. These include an anteroposterior (AP) view of the pelvis, and AP view of the affected hip, and a cross-table lateral view of the same hip. It is also helpful to review previous radiographs (if available) to identify any change in radiolucent lines, osteolysis, or component position. It is then important to specifically look at each component in detail on all views to look for evidence of loosening. The radiographic signs of loosening can be quite subtle and may require image magnification to identify a radiolucent line or a comparison between sequential radiographs of specific measurements from the implant and anatomic landmarks such as the greater trochanter.

A radiographic review of the acetabular component requires knowledge of the three DeLee and Charnley zones, which were initially described to demarcate the circumference of cemented cups as seen on the AP hip view [55]. These zones are separated by a vertical line that extends superiorly and a horizontal line that extends medially, both from the center of rotation of the femoral head. Zone 1 corresponds to the superolateral portion of the acetabulum, zone 2 is the medial portion of the acetabulum, and zone 3 is the inferior part. Each zone is assessed for radiolucent lines or areas of osteolysis that can be indicative of loosening. Gross component migration is diagnostic for acetabular cup loosening (Fig. 18.2). While these zones were initially described to assess for loosening of cemented acetabular components, they are also used for uncemented acetabular cups (Fig. 18.3).

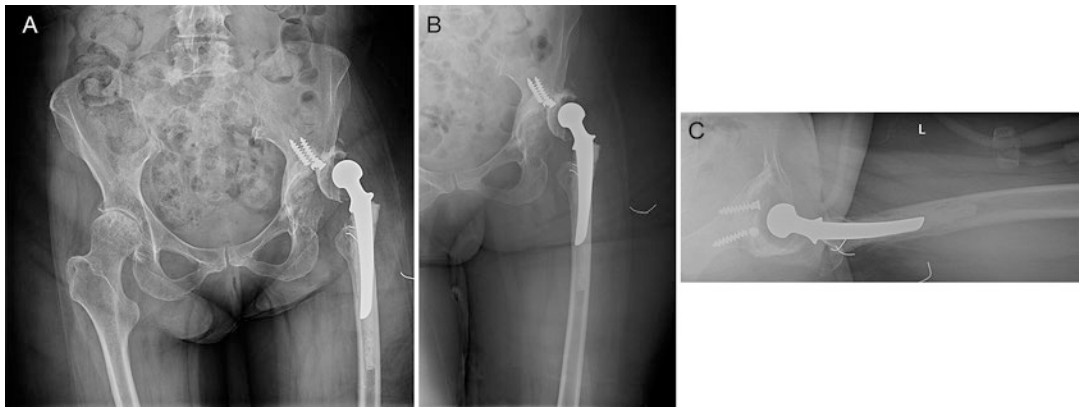

Fig. 18.2 Preoperative radiographs of a 64-year-old female with severe rheumatoid arthritis who presented with a failed left THA that was dislocated. Anteroposterior views of the pelvis (**a**) and left hip (**b**) along with a cross-table lateral X-ray of the left hip (**c**) show a cemented acetabular component and a cemented monoblock femoral stem. Her cemented acetabular cup had loosened and migrated superiorly with two broken screws in the ilium

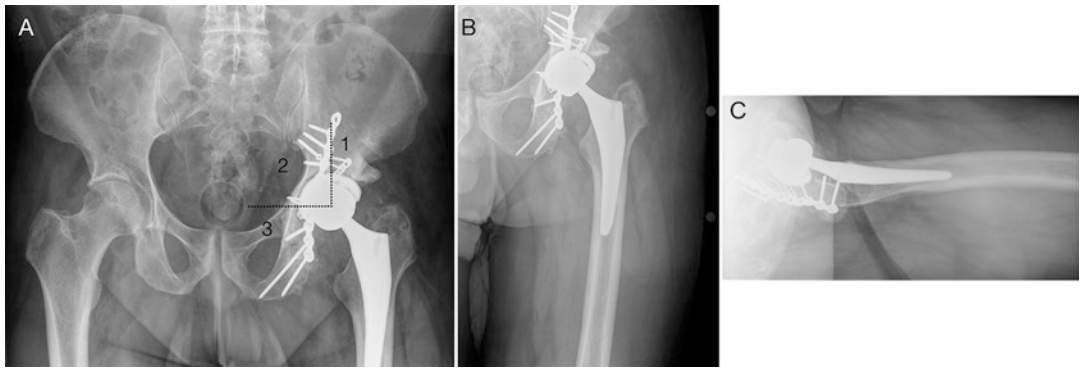

Fig. 18.3 Presenting radiographs of a 56-year-old male patient who presented with left hip pain following a THA that was performed for post-traumatic arthritis at an outside institution. Anteroposterior (AP) view of the pelvis (**a**), AP radiograph of the left hip (**b**), and cross-table lateral view of the left hip (**c**) demonstrate a radiolucent line surrounding the entire circumference of the cup in all three zones suggestive of a loose acetabular component. Note the plates and screws along the posterior column and wall of the acetabulum used for fixation of his original acetabular fracture. The three zones by DeLee and Charnley (**a**) are depicted by a *vertical dotted line* and *horizontal dotted line* that meet at the center of rotation of the femoral head

Radiographic assessment for femoral stem loosening requires a thorough review of the femoral component on all views. Seven zones that surround the femoral component as seen on the AP hip radiograph have been described by Gruen et al. [56] to analyze stem loosening (Fig. 18.4b). These zones were originally described for cemented stems. However, they have been applied to uncemented stems as well. Each zone is reviewed for evidence of radiolucent lines or osteolysis.

Certain criteria have been described to determine the likelihood for a cemented stem to be loose. These criteria, described by Harris et al. [57], have been used to determine if a cemented stem is definitely loose (Fig. 18.4), probably loose, or possibly loose (Table 18.1). While these criteria have been used for cemented stem loosening, stem subsidence is an expected evolution of polished, tapered, collarless cemented femoral stems and contributes to force transmission to the femur [58–60]. Therefore, stem subsidence with these stems, which is observed with a radiolucent line at the stem-cement interface in Gruen zone 1 at the superolateral portion of the shoulder of the stem, does not indicate loosening. However, radiolucencies or migration at the cement–bone interface can infer a loose stem.

Loosening of uncemented femoral stems (Fig. 18.5) has been predicted using criteria described by Engh et al. [61]. An unstable implant is determined by continued migration or stem subsidence within the femoral canal. Increased cortical density can also be seen at the calcar and at the tip of the stem. Fibrous ingrowth is seen by radio-opaque lines that completely surround the stem without progressive subsidence and stable bone ingrowth defined as the lack of subsidence and lack of radio-opaque lines around the stem.

Radiographic analysis of the articulation is also important when assessing for component loosening. Conventional polyethylene has been shown to wear and is determined by the eccentric location of the femoral head within the acetabular cup. This finding is particularly important because the wear particles from conventional polyethylene wear have been shown to cause osteolysis, which can lead to component loosening. It is important to closely follow patients with eccentric wear to recognize progressive or symptomatic osteolysis, which is an indication for surgery to prevent further progression and bone loss. Replacement of the polyethylene liner with a HXLPE liner is usually performed along with changing the femoral head. Bone grafting of the osteolytic lesions can also be performed depending on their size and location.

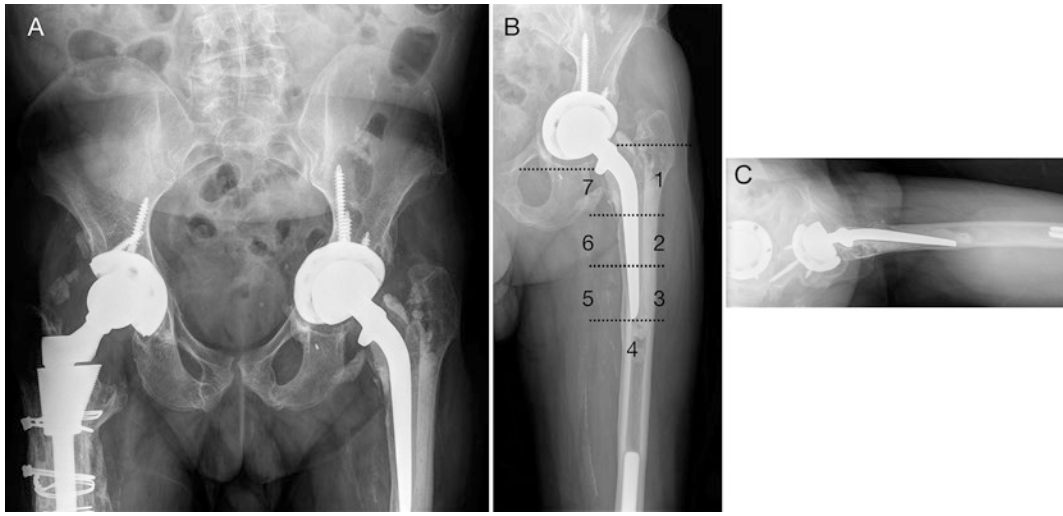

Fig. 18.4 Anteroposterior (AP) radiograph of the pelvis (**a**), AP view of the left hip (**b**), and cross-table lateral X-ray of the left hip (**c**) of a 54-year-old male patient who is known for juvenile idiopathic arthritis and underwent bilateral THAs approximately 30 years ago along with a left acetabular component revision in 2012. His radiographs demonstrate a radiolucent line surrounding the entire femoral stem at the implant–cement interface, migration of the femoral component into a varus alignment, and evidence of cement–bone loosening in Gruen zone 1 (**b**). The patient is also known for bilateral revision total knee arthroplasties, which explains the distal femoral stem in (**b**) and (**c**). The seven Gruen zones are also demonstrated around the femoral stem (**b**)

Table 18.1 Harris et al. [57] criteria for cemented femoral stem loosening

Probability of stem loosening	Criteria/description
Definite loosening[a]	1. Migration of the femoral stem
	2. Migration of the cement mantle
	3. Fracture of the femoral stem
	4. Fracture of the cement mantle
Probable loosening	A continuous radiolucent line that surrounds the stem at the cement–bone interface
Possible loosening	A radiolucent line at the cement–bone interface that surrounds more than 50% of the femoral stem but less than 100% of the stem

[a]Presence of one of the four criteria meant that the stem was definitely loose

Infection Analysis

Once loosening of one or both THA component(s) is diagnosed, it is important to rule out infection as the cause of implant loosening (particularly early loosening within 2 years of the index THA). The infection workup begins with an erythrocyte sedimentation rate (ESR) and a C-reactive protein (CRP). If those blood tests are elevated, or if the clinical suspicion for infection is high, then a hip aspiration is indicated to obtain a synovial fluid white blood cell count, differential, and culture. Given that one study identified 4% of periprosthetic joint infections that occurred with a normal ESR and CRP [62], a joint aspiration may be warranted with any suspicion based on the history and physical examination, especially if surgical intervention is planned. Once infection has been preoperatively evaluated and ruled out, a diagnosis of aseptic loosening can be made. However, intraoperative pathology and cultures should still be considered.

Treatment

Once aseptic loosening of the acetabular and/or femoral components has been diagnosed, the patient can be treated either nonoperatively or operatively. Aseptic loosening of the acetabular and/or femoral components can be treated nonoperatively depending on the patient's symptoms and comorbidities. A discussion can be had with the mildly symptomatic patient, particularly if they

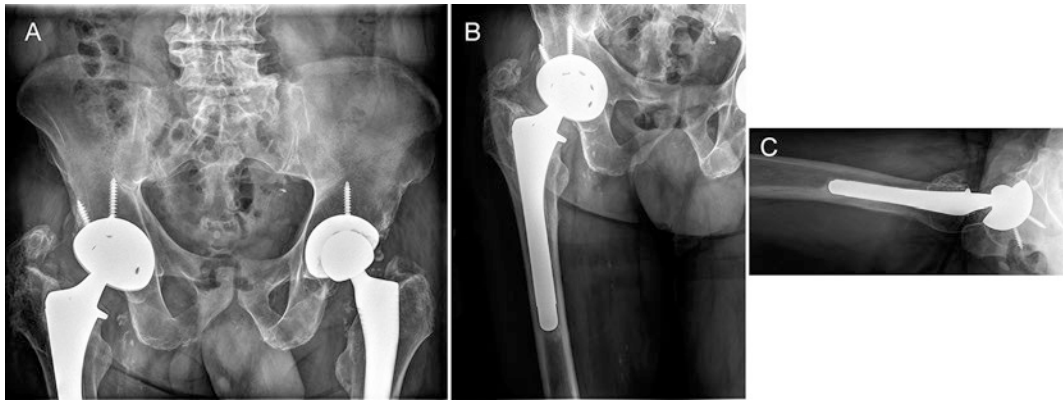

Fig. 18.5 Anteroposterior (AP) radiographs of the pelvis (**a**), AP view of the right hip (**b**), and cross-table lateral view of the right hip (**c**) of a 69-year-old male patient who presented with right hip and thigh pain following a primary THA approximately 8 years earlier along with a revision procedure performed 1 month postoperatively for instability at an outside institution. A 1 mm thick radiolucent line can be seen around the entire femoral stem suggestive of fibrous ingrowth or loosening

are medically infirmed and/or minimally active who are not greatly limited on a plan of nonoperative treatment with close follow-up. If progression of symptoms or radiographic evidence of further bone loss from osteolysis or component migration is documented, then surgical intervention becomes increasingly warranted.

Once surgical management becomes required, it is important to confirm that periprosthetic joint infection has been ruled out as described above. Proper preoperative planning is then initiated to plan for the desired surgical instruments and revision components. Foremost, prior operative records and implant stickers should be obtained, particularly if one of the components is to be retained to ensure that appropriate trials and replacement parts are available. Even if both components are to be removed, definitive identification will oftentimes assist with implant removal as specific devices may be required or helpful to easily remove them.

Templating is also paramount to achieving a successful outcome. It is important to plan and template for the loose component as well as for an implant that appears stable, which may prove to be loose when tested intraoperatively or require removal for exposure, component malposition, component recall, or implant mismatch. The lack of infection is further confirmed intraoperatively by sending specimen(s) to pathology to rule out acute inflammation and an odd number of tissue cultures to rule out bacterial growth.

Literature Review

The majority of papers that analyze outcomes of a specific implant type, implant size, bearing surface, age group, or THA for a particular hip pathology also report survivorship free from aseptic loosening. Several national and institutional registries have also been created to further analyze THA complications and survivorship of both cemented and uncemented components as well as various bearing surfaces. It is therefore difficult to completely summarize the literature on aseptic loosening given the numerous reports on its association with various clinical scenarios. With the identification of specific patient risk factors, improvements in component materials, and surgical technique, the long-term survivorship of cemented and uncemented THAs is improving. However, with the increasing placement of THAs in younger patients, it is critical to continue to study the long-term results of these implants to be able to ensure longevity of these mechanical devices.

The use of uncemented components has seen a worldwide increase over the last several years and remains the most popular method of fixation in North America [8]. Furthermore, uncemented

implants coupled with HXLPE liners have demonstrated encouraging results over mid- to long-term follow-up with little osteolysis and no cases of aseptic loosening [33, 34, 52].

Little is currently known as to why some patients develop early aseptic loosening and some do not. The identification of a particularly genetic susceptibility has become of interest. As mentioned previously, mutations in specific genes and gene pathways have been discovered as potential explanations for implant loosening. However, this knowledge is still in its infancy and requires further study and understanding [63].

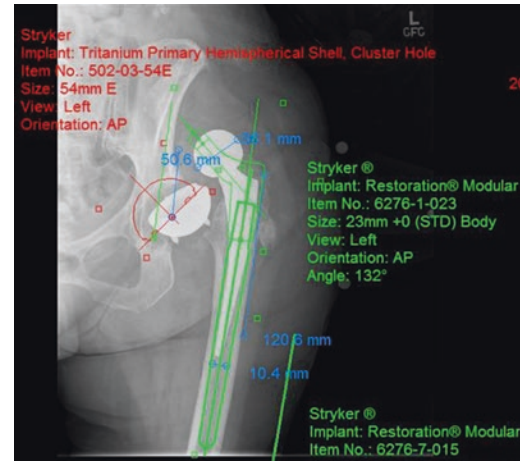

Fig. 18.6 Anteroposterior radiograph of the left hip that was templated for a highly porous-coated revision acetabular shell. A modular fluted tapered stem was also templated in case the femoral component was loose or required removal for exposure or trunnion damage. The length of a potential extended trochanteric osteotomy was also mea-

Case Solution

The preoperative plan consisted of acetabular component revision using a cementless acetabular component with multiple screws for fixation and a dual-mobility articulation for enhanced stability via an anterolateral exposure given that was her previous approach (Fig. 18.6). A template was also created for the femoral component in the event it was found to be loose, malpositioned, or otherwise required revision. Intraoperatively, the cup was easily removed and had no evidence of any bone ingrowth or ongrowth (Fig. 18.7). Intraoperative pathology was negative for acute inflammation and multiple specimens were sent for culture, which were all negative. The femoral stem was well fixed and appropriately positioned and was therefore retained; a fourth-generation ceramic head was utilized with a titanium (revision) adaptor sleeve. At 2 years from surgery, the patient is functioning well (Fig. 18.8).

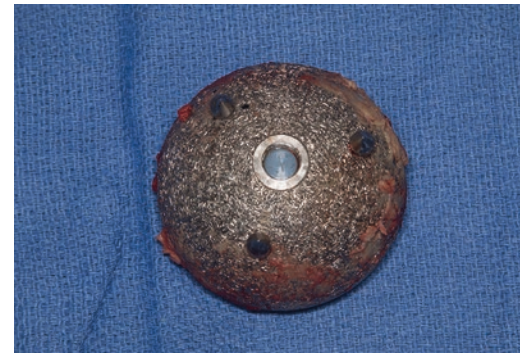

Fig. 18.7 Intraoperative photograph of the extracted loose acetabular component which demonstrates a lack of

Summary

Aseptic loosening is one of the most common complications following primary THA, but seems to be less common with contemporary implants and techniques. Several potential risk factors exist that may increase the probability to develop aseptic loosening; however several remain controversial. Genetics and SNPs are becoming increasingly understood as key players in aseptic loosening. Some risk factors are modifiable such as obesity, activity level, implant material, and surgical technique which can decrease the chance of component aseptic loosening. The diagnosis is achieved with patient history, physical examination, and radiographic assessment. Infection must be ruled out with appropriate blood work and potentially a hip aspiration, especially if surgical treatment is planned. Patients can be managed either nonoperatively or operatively depending on the clinical presentation, medical comorbidities, and goals of the patient.

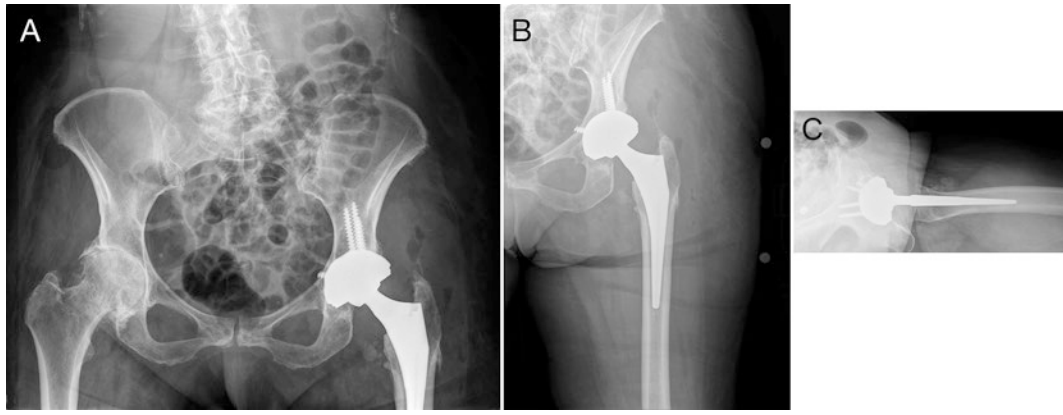

Fig. 18.8 Postoperative anteroposterior (AP) radiograph of the pelvis (**a**), AP view of the left hip (**b**), and cross-table lateral view of the left hip (**c**) that demonstrate the revised loose acetabular component to a highly porous-coated revision shell via an anterolateral approach. The cup was further stabilized with multiple screws in various trajectories for enhanced rotational stability. A dual-mobility articulation was utilized and the femoral stem was retained

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Iliopsoas Impingement After Primary Total Hip Arthroplasty

19

Peter K. Sculco, Rafael J. Sierra,
and Robert T. Trousdale

Case Presentation

A 54-year-old female with a diagnosis of right-hip osteoarthritis underwent a primary uncemented total hip arthroplasty through the posterolateral approach with a highly cross-linked polyethylene liner and a 36 mm ceramic femoral head. Postoperative radiographs demonstrated accurate restoration of femoral offset and leg length. Five months postoperatively the patient complained of an insidious onset of right groin pain that was exacerbated by stair climbing and driving. Physical examination demonstrated pain in the right groin with resisted hip flexion and with passive hip extension. Laboratory values, including C-reactive protein and erythrocyte sedimentation rate, were within normal limits. An anteroposterior pelvic radiograph (Fig. 19.1a) demonstrated a well-fixed 52 mm uncemented acetabular shell and uncemented femoral stem. On the cross-table radiograph (Fig. 19.1b), however, the acetabular component was noted to have low anteversion and 13 mm of anterior component overhang. The patient underwent an ultrasound-guided local anesthetic injection and corticosteroid into the psoas bursa that provided a transient relief of symptoms. At 6-month follow-up, the patient continues to complain of activity-related groin pain.

Epidemiology

The evaluation of a patient with persistent pain (>3 months) after total hip arthroplasty (THA) can be a diagnostic challenge. Pain after THA may present in the lateral hip, groin, buttock, flank, or thigh. The two most common intra-articular causes for persistent groin pain include aseptic loosening and periprosthetic joint infection (PJI). There are several extra-articular sources of periarticular pain including heterotopic ossification, vascular lesions, referred pain from the spine or abdomen, lateral femoral cutaneous nerve injury, and soft-tissue inflammation. Soft-tissue inflammation originates from either trochanteric bursitis or iliopsoas tendonitis [1]. Anterior iliopsoas tendonitis, or impingement, has been reported in up to 4% of patients after total hip arthroplasty [1–5]. Symptoms can occur within months of THA or present several years later.

Anatomically, the iliopsoas tendon is the distal confluence of the psoas and iliacus muscles which passes anterior to the acetabular rim to insert onto the lesser trochanter. The iliopsoas is a powerful

Investigation performed at the Mayo Clinic, Rochester, MN.

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_19

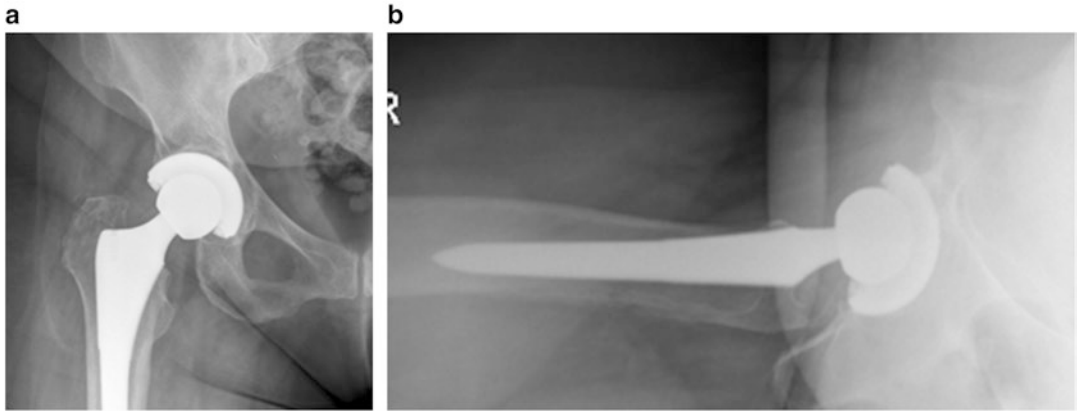

Fig. 19.1 Anteroposterior (**a**) and cross-table lateral (**b**) radiographs demonstrating well-fixed acetabular and femoral components with reduced acetabular component anteversion and 13 mm of anterior component overhang

hip flexor and weak external rotator [6]. The tendon is bordered posteriorly by a bursa which may become intracapsular after anterior capsulectomy during THA. Iliopsoas impingement or tendinitis most often occurs at the level of the acetabular psoas recess but can occur anywhere along its musculotendinous course. A proud acetabular screw may irritate the iliacus muscle along the inner table of the ilium, a protruding anterior acetabular component can injure the iliopsoas tendon at the level of the acetabulum, and a prominent femoral collar can rub the mostly tendinous insertion at the level of the lesser trochanter. The anterior border of the acetabulum, the convex surface of the femoral head, and the overlying anterior capsule act like a pulley around which the iliopsoas tendon runs and anything that increases the likelihood of direct contact of the iliopsoas tendon with the acetabular or femoral components can potentially cause iliopsoas inflammation and subsequent tendonitis and groin pain.

Risk Factors

Anything that results in the mechanical irritation of the iliopsoas muscle or tendon is a risk factor for iliopsoas impingement. This most commonly originates from an acetabular component that projects past the anterior wall resulting in abrasion of the iliopsoas tendon at the level of the psoas recess. Insufficient acetabular anteversion produces a prominent and sharp acetabular component projecting past the anterior rim [7]. Cyteval et al. [8] reported on eight cases of iliopsoas impingement and found that acetabular overhang >12 mm was a significant risk factor for groin pain. Oversized acetabular components (>6 mm compared to the native femoral head size) have also been associated with an increased risk of postoperative groin pain [9]. Excessive lateralization of the acetabular component will also increase the amount of bony uncoverage and anterior component prominence. Patients with anterior wall deficiency may also be at increased risk due to insufficient anterior bony coverage of the acetabular component. An oversized, lateralized, acetabular component with decreased anteversion or frank retroversion has the highest risk for anterior acetabular component prominence and iliopsoas impingement. Less common causes for iliopsoas tendonitis that have been reported in the literature include retained cement, excessively long screws projecting into the iliacus muscle [10], and a prominent acetabular cage [11].

On the femoral side, tendon impingement can also occur as the tendon wraps around the femoral neck to insert in the lesser trochanter, which is a posteromedial structure. For this reason osteophytes along the anterior aspect of the femoral neck may lead to tendon impingement [7]. In one report a prominent femoral collar produced iliopsoas tendonitis and was treated with revision to a collarless prosthesis with resolution of symtpoms [13]. The authors advised the use of a collarless cemented component when a low neck cut is planned as a

collared prosthesis may rub against the tendon insertion on the lesser trochanter. Large femoral head metal on metal and hip resurfacing had a 15% reported rate of groin pain [14]. And while adverse reaction to meta debris must first be excluded, authors have hypothesized that the increased in groin pain was secondary to abrasion of the iliopsoas tendon as it articulated with the large femoral head and the sharp transition point at the inferior margin. This led to the development of an anatomically contoured large-diameter femoral head with the peripheral region contoured to stay within the articular margin [15]. There are also circumstances in which iliopsoas tendonitis may occur without identfication of an underlying risk factor [16].

Prevention

The risk of iliopsoas tendonitis can be minimized with careful attention to cup position and its relationship to the anterior wall of the acetabulum. The posterior, anterolateral, and direct anterior surgical approaches all allow for palpation of the anterior acetabular wall and the acetabular component should be flush, or slightly recessed with the native anterior acetabular rim. The acetabulum should not be reamed more than 6 mm of the native femoral head diameter in order to reduce the risk of peripheral rim prominence which has been correlated with increased rates of groin pain after THA [17]. In patients with a deficient anterior wall, increased anteversion and greater cup medializaiton may be necessary to avoid anterior overhang. Prevention of iliopsoas impingement on the femoral side includes removal of all osteophytes from the anterior aspect of the femoral neck, avoiding complete resection of the anterior capsule, and avoiding the use of a large-collared femoral component, especially when combined with a low femoral neck resection.

Diagnosis

Iliopsoas impingement presents with anterior groin pain that is exacerbated with hip flexion activities. The workup for a patient who presents with pain after a total hip arthroplasty should include a clinical history, physical exam, laboratory tests to rule out PJI, and radiographic imaging. A systemic approach to the evaluation of a painful total hip arthroplasty reliably excludes other causes of pain after THA since iliopsoas tendonitis, or iliopsoas impingement, is a diagnosis of exclusion.

A comprehensive history and physical are essential to determine the underlying cause of pain. Symptom onset from time of surgery, location, duration, intensity, inciting activities, rest pain, and pain quality are all important features in the history. A history of postoperative wound drainage raises concerns for underlying PJI and must be ruled out. Periarticular pain within the first 6 weeks after surgery should be treated conservatively with activity modification, use of an assistive walking device, focused physical therapy, and nonsteroidal anti-inflammatories. Pain that persists after 6 weeks should be investigated further with imaging and possibly laboratory values depending on the clinical presentation. The characteristic clinical history for iliopsoas tendonitis is groin pain with activity and that resolves with rest. Activity-related groin pain is worse with hip flexion maneuvers such as climbing stairs or getting into or out of a car. Getting in and out of a car is particularly painful, and the majority of patients if not all complain of this, and commonly have to lift the affected leg when entering a low vehicle. Driving is particularly painful for patients with a right THA as alternating between the brake and gas pedal requires repeated hip flexion. Rising from a deep-seated position with hips flexed past 90° can also exacerbate groin pain symptoms.

On physical examination, gait should be assessed for evidence of start-up pain that could indicate component loosening. An antalgic or Trendelenburg gait may suggest other sources of THA dysfunction as walking on level ground is usually not painful in patients with iliopsoas impingement. On supine examination, hip range of motion should be assessed for hip positions that trigger pain. A positive Stinchfield's test due to psoas activation and irritation with straight leg raise against gravity is common, but is less painful than when the hip is externally rotated. The

most provocative test is positive groin pain with resisted hip flexion and pain with passive hip extension. As with any complete physical exam, the hip area should be assessed for other areas of tenderness, presence of any swelling or masses, appearance of the incision, nerve root tension signs, and a distal neurovascular exam.

Every patient with a persistently painful THA should be assessed for PJI with laboratory studies including erythrocyte sedimentation rate and C-reactive protein. If elevated, a fluoroscopic- or ultrasound-guided hip aspiration is recommended. Any patient with persistent groin pain and a metal-on-metal articulation should be evaluated with serum cobalt and chromium serum metal ion levels and cross-sectional imaging, whether that be an ultrasound or magnetic resonance imaging. Recently, adverse reaction to metal debris, pseudotumor formation, and soft-tissue necrosis has been reported in articulations with cobalt–chrome femoral heads on highly cross-linked polyethylenes [18]. Mechanically assisted crevice corrosion at the head–neck junction between the cobalt–chrome head and titanium stem, known as trunnionosis, produces metallic debris that can trigger this adverse tissue response. For this reason, serum metal ion testing should be included in the complete laboratory profile for patients with groin pain and a cobalt–chrome femoral head and titanium alloy stem. Iliopsoas impingement could be the first symptom associated with adverse soft-tissue reactions and should prompt further investigation.

Every patient with persistent pain after THA should have anteroposterior (AP) and lateral imaging of the pelvis and femur. The AP pelvis radiograph should be evaluated closely for any signs of prosthetic loosening of the acetabular or femoral component. The AP pelvis radiograph can also be evaluated for leg length and offset restoration. Serial radiographs should be reviewed if available for the presence of progressive radiolucencies or component migration. The cross-table lateral radiograph provides important information on the position of the acetabular component in relation to the anterior wall and allows for objective measurement of component overhang. The amount of overhang is measured from the anterior bony rim of the acetabulum to the anterior rim of the acetabular component on the cross-table radiograph. Computer tomography (CT) also provides information on component version and anterior overhang of the acetabular component. A CT scan can also provide a more detailed assessment when body habitus obscures component visualization on plain radiographs. Moreover, a CT scan can visualize prominent screws within the inner pelvic table, and their position in regard to the psoas muscle.

Ultrasound is another excellent imaging modality to assess for fluid collections and tendon quality. Fluid collections will appear as hypoechoic areas located anterior to the femoral neck. The iliopsoas muscle may appear swollen and inhomogeneous and closely juxtaposed over a prominent cup. Dynamic US evaluation can also be performed during resisted hip flexion. In sagittal sonograms, the iliopsoas tendon may overlie and impinge on the protruding acetabular component [19]. A contralateral ultrasound examination can be performed for comparison and may be particularly useful if the patient has a contralateral asymptomatic THA. The benefits of ultrasound are that it is inexpensive, and noninvasive, and does not expose the patient to radiation but it is highly technician dependent to obtain accurate studies.

A diagnostic injection of local anesthetic and possibly corticosteroid into the psoas sheath is helpful to confirm a diagnosis of iliopsoas tendonitis. Ultrasound or CT can be used to guide the needle, and once confirmed to be in the psoas sheath, local anesthetic with or without corticosteroid can then be injected. This injection is both diagnostic and potentially therapeutic and groin pain resolution suggests the iliopsoas tendon as the underlying cause of pain. In addition, when the diagnostic injection is performed using ultrasound, fluid within the psoas bursa and mucoid degeneration of the tendon can be directly observed.

Treatment

Initial treatment of acute or chronic iliopsoas tendonitis should always be nonsurgical. Nonsurgical treatment includes rest and activity modifications including limiting stair climbing and driving. In

additional, nonsteroidal anti-inflammatory medications and possibly physical therapy can reduce symptom intensity and duration. If symptoms do not improve, an injection or local anesthetic and corticosteroid into the iliopsoas tendon sheath may provide lasting relief. The literature is varied on the outcome of local injection on pain resolution. Nunley et al. [20], in a group of 27 patients with presumed iliopsoas tendonitis, found that 21 (78%) were treated satisfactorily with fluoroscopically guided steroid injections. Radiological analysis of those who responded to an injection compared to those who went on to require surgery did not reveal any differences between the groups. In addition, the authors found that several patients responded positively to a second injection and were able to avoid surgery. Jasani et al. [21] found that all 9 patients in their series benefited from a CT-guided injection, but the resolution of pain was temporary with 8 patients having a recurrence of pain 3.6 months after the injection on average. A recent review by Lachiewicz [25] examined the results of several studies and estimated the success of nonsurgical treatment for iliopsoas tendonitis to be 39%.

If nonoperative management fails, surgical treatment is recommended. The surgical options include arthroscopic or open tendon release or more commonly, an isolated acetabular revision with or without concurrent iliopsoas tendon debridement or release. Release of the iliopsoas tendon can be performed either arthroscopically or open and is a surgical option when radiographs do not show significant acetabular component overhang. Tenotomy provides satisfactory results without significant loss of hip flexion force at final follow-up [22]. Tenotomy consists of sectioning only the tendon fibers at the insertion site on the lesser trochanter. The iliopsoas tendon at the level of the anterior rim of the acetabulum is 44% tendon and 55% muscle belly and release of the entire tendinous portion is all that is necessary [23]. Van Riet et al. [23] reviewed 9 patients undergoing an arthroscopic iliopsoas tendon release and reported no complications with satisfactory relief of symptoms in all patients [24]. The degree of acetabular component overhang was not recorded in this study.

In the United States, Trousdale et al. [2] first reported on two patients with anterior groin pain after primary THA and diagnosed iliopsoas impingement. Both patients had significant acetabular component overhang and both were treated successfully with acetabular component revision [2]. Acetabular revision is usually recommended when the cross-table radiographs or CT scan shows significant protrusion in front of the anterior bony acetabular rim. The iliopsoas tendon and bursa, if inflamed and enlarged, can also be debrided. The component is then removed and a new hemispherical cup is inserted with medicalization and/or additional anteversion to ensure that the acetabular component is below the bony acetabular rim. The results of surgical management are generally favorable and a recent literature review [25] found an overall success rate of 92% (65 of 71 hips) at a mean of 23 months postoperatively. Dora et al. [5] reported on 22 cases of iliopsoas impingement treated with either tenotomy or cup revision. Acetabular overhang was not recorded and they found equivalent outcomes between the two groups with a much lower complication rate in the tenotomy group. This is the only paper in the literature to report a high complication rate with cup revision and may be related to the number of threaded cups revised and the use of reinforcement rings at the time of revision. Standard hemispherical cups revised to hemispherical cups with screws, as reported in other studies, have demonstrated a lower rate of surgical complications [3, 7, 12, 25].

The Mayo Clinic experience includes 49 patients treated for a diagnosis of iliopsoas impingement after THA [26]. Twenty patients were treated nonoperatively and 29 patients were treated with surgery (21 with acetabular revision and 8 with iliopsoas tenotomy). Fifty percent of patients treated with iliopsoas injections had complete resolution of symptoms. The other ten patients treated nonoperatively continued to have symptoms but had not undergone surgical treatment. The majority (12/20) of patients underwent more than one injection. The remaining 29 patients who failed conservative management went on to cup revision or iliopsoas tenotomy. Overall the rate of symptom resolution after

operative management was 76%, lower than the overall 92% success rate reported in a recent systematic literature review [25]. In a subgroup analysis, acetabular revision was highly successful in patients with at least 8 mm of preoperative acetabular component prominence with groin pain resolution in 12 of 13 patients (92%). Iliopsoas tenotomy improved groin pain in all patients when there was less than 8 mm of overhang. In contrast, only 33% patients with a cup prominence >8 mm experienced improvement of groin pain with tenotomy alone. For the 29 patients in the operative group, there were no medical or surgical complications. The surgical management of iliopsoas impingement is relatively uncommon, so this retrospective review is not powered to make definitive conclusions on surgical management but the results support the protocol of cup revision rather than tenotomy in cases of significant acetabular overhang [25].

Case Resolution

Due to the failure of 6 months of conservative management and >8 mm anterior component overhang, the patient was indicated for acetabular component revision. The acetabular component was noted intraoperatively to be uncovered anteriorly and inferiorly, and fraying was noted in the iliopsoas tendon. A new 54 mm acetabular component was medialized and anteverted and the tendon was debrided but not released (Fig. 19.2a,b). At 6 months postoperatively, the Harris Hip score improved to 96 with complete resolution of groin pain and restoration of desired activity.

Summary

The diagnosis of anterior iliopsoas impingement and tendinitis should be considered in patients with groin pain and functional disability after THA. Patient history and physical examination findings usually suggest the iliopsoas tendon and bursa as the site of pathology. In addition to standard imaging, evaluation should include a cross-table lateral radiograph and, if necessary for visualization of the anterior acetabulum, a CT scan. An image-guided diagnostic injection of the iliopsoas sheath is strongly recommended to confirm the diagnosis. Although a trial of nonsurgical management is warranted, 50% of patients will have persistent groin pain and will require repeat injections or surgery. Iliopsoas tenotomy or resection alone is recommended in patients with minimal acetabular overhang. Acetabular revision is appropriate when there is significant acetabular overhang on the cross-table lateral radiograph or CT scan and patients can expect a 75–90% chance of groin pain resolution after surgical treatment.

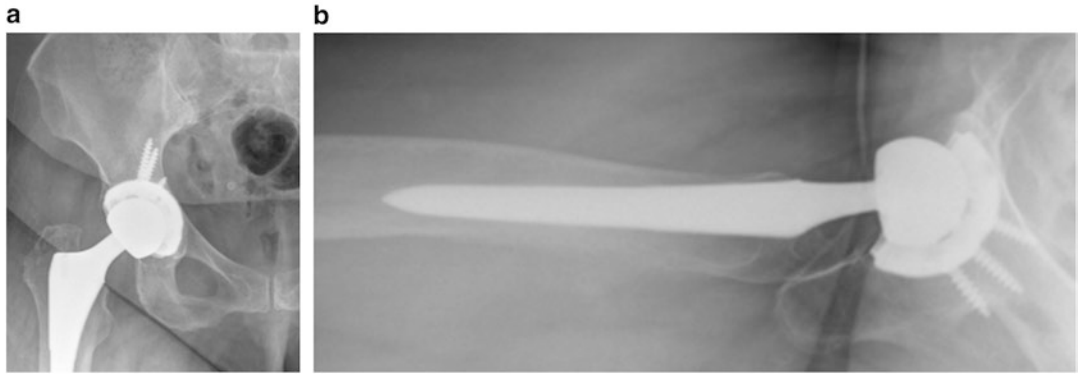

Fig. 19.2 The above patient underwent revision of the acetabular component with increased anteversion as noted on the anteroposterior hip (**a**) and cross-table lateral (**b**) radiographs. Patient had groin pain resolution without postoperative complication

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Implant Breakage

20

Gwo-Chin Lee

Introduction

Case Presentation

This patient is a 75-year-old male who presented for evaluation of right hip and thigh pain with inability to ambulate. The patient had undergone primary and revision total hip arthroplasties (THAs) at an outside hospital 10 and 5 years ago, respectively. There was no history of recent trauma or history of wound healing complications surrounding both of his surgeries. The patient did not endorse or exhibit any signs or symptoms of infection.

Radiographs upon initial presentation revealed a failed metal-on-metal THA with a fractured right modular femoral stem (Fig. 20.1). Additionally, the patient had elevation of both blood cobalt (35.3 μg/L (normal <1.0 μg/L)) and chromium levels (13.3 μg/L (normal <5.0 μg/L)) as well as erythrocyte sedimentation rate (39 mm/h (range 0–15)) and C-reactive protein (1.4 mg/dL (normal <0.8)). Hip aspiration with a manual cell count confirmed leukocytosis (WBC = 5400) with a neutrophil differential of 73%. Based on these findings, the patient was recommended to undergo a two-stage procedure to treat both his broken right femoral component and deep prosthetic joint infection. Intraoperative cultures were positive for *Staphylococcus aureus*.

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Epidemiology

Total hip arthroplasty (THA) has been shown to be durable, reproducible, and reliable in relieving pain and improving function in patients with hip arthritis [2]. Implant fracture fortunately occurs very infrequently following THA. The Australian Orthopaedic Association National Joint Replacement Registry reported a cumulative revision rate for implant breakage of 2.8% as the principal cause for all revision THAs. The prevalence for each individual component was as follows: (1) implant breakage stem (0.9%); (2) implant breakage acetabular (0.8%); implant breakage acetabular insert (0.8%); and implant breakage head (0.3%) [3]. Other authors have also reported similar rates of failure [4].

Risk Factors

Failures of THA implants are multifactorial and can be due to (1) implant design; (2) implant materials; (3) surgical technique; and (4) patient factors. While no amount of in vitro material

M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_20

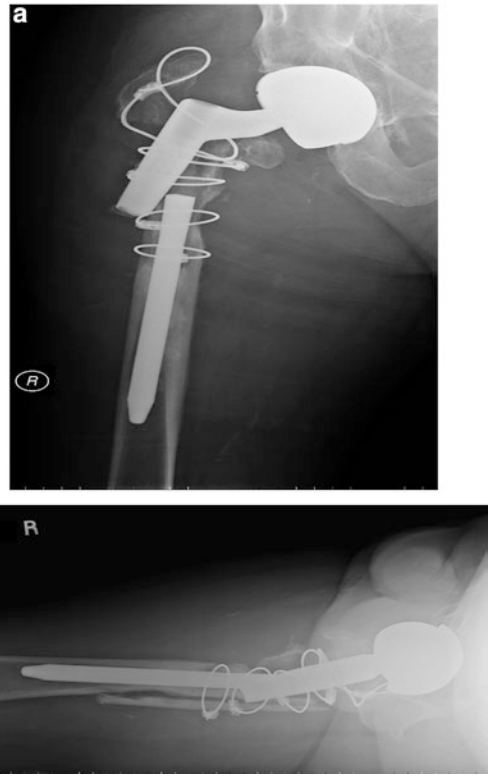

Fig. 20.1 AP and lateral radiographs of the right hip and femur demonstrating a fractured modular, bi-body stem with associated periprosthetic femur fracture. Note the severe proximal femoral bone loss

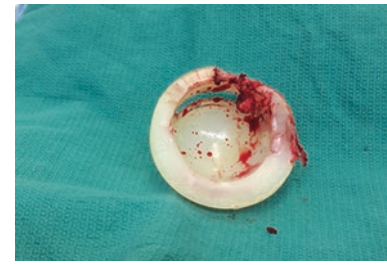

Fig. 20.2 Fractured polyethylene liner. The outer rims of the liner are most susceptible to repetitive impingement and fatigue fractures

testing can predict behaviors of the eventual implant in vivo, certain mechanisms of failures for the various components of the hip prosthesis have been identified.

1. Acetabular component breakage

   Breakage of the acetabular component is rare. In the literature, acetabular implant fracture is usually described in cemented all-polyethylene cups with severe wear and osteolysis [5]. Metal acetabular component breakage has also been described in cases with catastrophic wear of the bearing surface and metallosis [6, 7]. Improvements in metallurgy, prosthesis design, and understanding of the importance of polyethylene thickness to long-term survivorship of hip implants have decreased the incidence of acetabular component fractures.

2. Acetabular liner failures

   Liner breakage is also relatively rare. Polyethylene liners can fracture or dissociate from the acetabular component [8]. Wear characteristics and acetabular component position can significantly affect reliability and durability of acetabular liners [9]. Suboptimal acetabular component position, thin polyethylene, and large heads can lead to increased edge loading, rapid wear, impingement, and hip instability. Rimmed and lipped liners are particularly susceptible to impingement and fatigue failure [10] (Fig. 20.2).

   Liner dissociations are either due to failures of the acetabular locking mechanism or failure of the surgeon to fully engage the liner at the time of surgery. While improvements in design have significantly improved the strength and reliability of acetabular component locking mechanisms, incomplete liner seating, impingement, and fatigue failure of the polyethylene liner tabs can still lead to dissociation of the liner from the acetabular component [11, 12] (Fig. 20.3).

3. Femoral component fractures—Non-modular

   Non-modular femoral implant fractures occur in general due to lack of proximal femoral support or impingement. Cemented or uncemented stem breakages were traditionally attributed to lack of proximal implant support in the setting of distal fixation resulting in

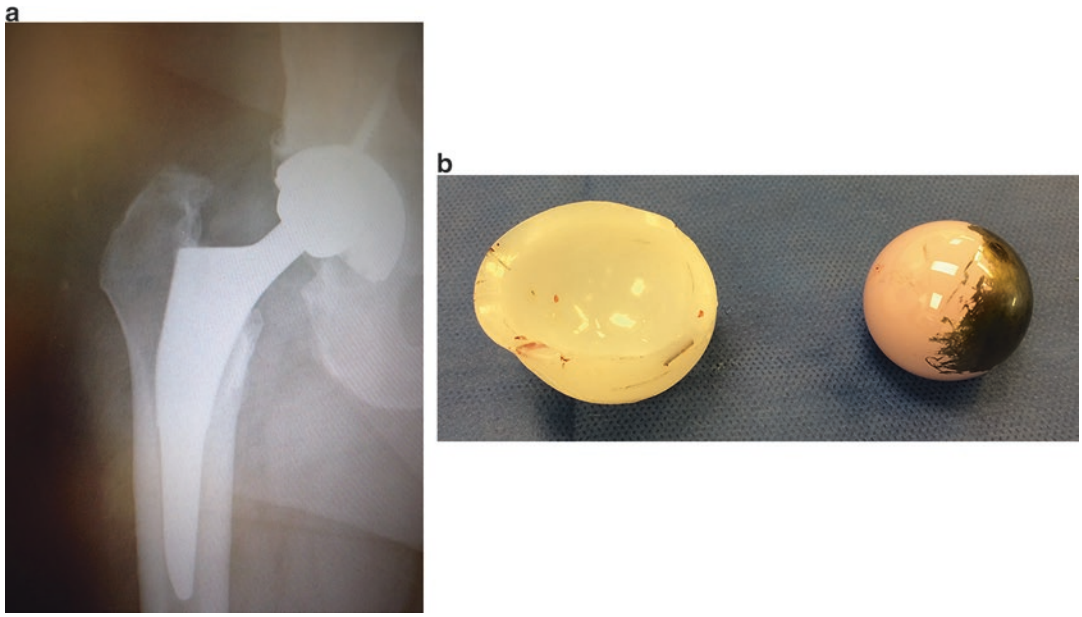

Fig. 20.3 (**a**) AP and lateral radiographs of the left hip demonstrating a dissociated polyethylene liner. (**b**) Retrieved liner and ceramic ball head. Note the deformation of the liner rim and the metallosis on the femoral head associated with articulation with the underlying acetabular shell

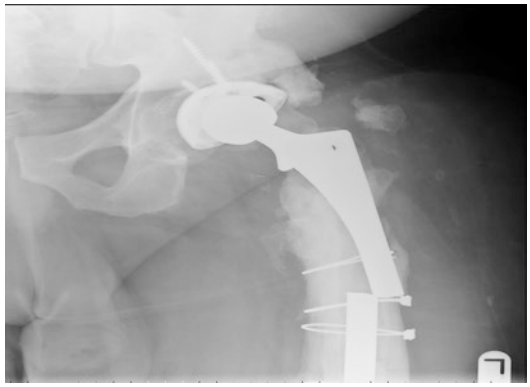

Fig. 20.4 AP and lateral radiographs of the left hip demonstrating a broken fully porous-coated femoral component. The mechanism of failure is due to lack of proximal femoral support leading to cantilever bending and fatigue fracture

cantilever bending eventually leading to fatigue failure of the implant [13] (Fig. 20.4). Usually described in extensively coated femoral components, the primary risk factor is the size of the femoral component with stems less than 13.5 mm in diameter being at greatest risk [14]. Other risk factors include nonunion of an extended trochanteric osteotomy and high patient weight [15]. Femoral components can also fail at the neck of the prosthesis due to implant impingement and notching and/or crevice corrosion leading to eventual fracture [16] (Fig. 20.5).

4. Femoral component fractures—Modular

   Femoral components that include a modular neck can break at the neck–body junction (Fig. 20.6) [17, 18]. Modular necks have been made of both titanium alloys and cobalt chromium alloys by various manufacturers. The advantage of a cobalt–chromium alloy neck is that they are stronger and less prone to break. however corrosion is a risk and this failure mechanism has been well described leading to the recall of several implants. Alternatively titanium alloys can be utilized that are not associated with corrosion if the stem is also made of titanium; however the neck is more prone to breakage. The precise mechanism of failure is unknown but there is evidence supporting a fretting fatigue mechanism with subsequent

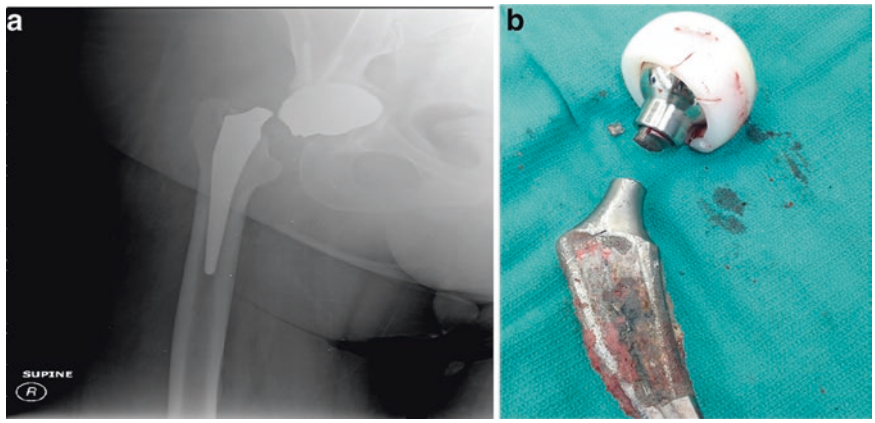

Fig. 20.5 (**a**) AP radiograph of the right hip demonstrating a fracture of the femoral component at the neck of the implant, secondary to impingement with resultant femoral stem notching. (**b**) Intraoperative image of the broken implant

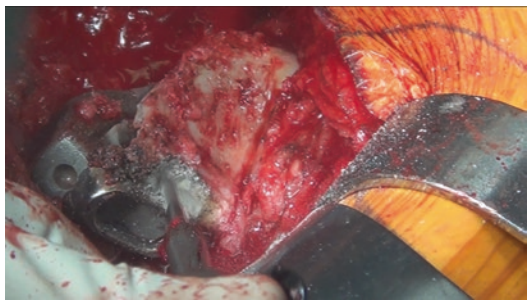

Fig. 20.6 Intraoperative image showing breakage of a modular neck femoral component. Specialized instruments or extensile approaches to the femur such as an extended trochanteric osteotomy are necessary for safe implant removal

propagation of a bending mechanism leading to failure [19]. The strength of the taper and proper taper engagement and impaction can also significantly affect implant reliability.

Stems that include modularity between the proximal and distal segments (so-called bi-body stems typically used for revision procedures) can also break at the modular junction (Fig. 20.1). Breakage at this junction leads to the redesign of several of the first-generation modular, bi-body revision stems that were introduced in the late 1990s and early 2000s. These breakages were similarly associated with excessive body weight and inadequate proximal bone support [20]. Modifications to the design have included enlargement of the taper junction, hardening of the modular taper junction, and improved instrumentation to ensure proper proximal and distal segment taper engagement that all have led to a dramatic decrease in the prevalence of this complication.

5. Ceramic ball head fractures

   Utilization of ceramic ball heads has increased due to their favorable wear properties and concerns with corrosion at the head–neck junction when cobalt–chromium alloy heads are utilized [21]. While material and manufacturing improvements have continually decreased the rate of ceramic ball head fractures over the past 15 years, occasionally failures can still occur. Most fractures occur within the first 5 years following implantation and alumina matrix composite ceramic heads are less likely to fracture compared to pure alumina ball heads. Additionally, a 28 mm ball head is more likely to fracture compared to larger ceramic ball head sizes. Finally, and most importantly, taper design, taper contamination, and proper impaction significantly affect the fracture risk for ceramic ball heads [22, 23].

6. Ceramic liner fractures

   Ceramic liner fractures have also decreased in frequency over the same time period but are

presently more common in contemporary practice when compared to ceramic femoral head fractures. Elimination of lipped liner and sandwich-type ceramic insert designs have led to the overall reduction in ceramic liner fractures [24]. Modern ceramic liner fractures most frequently occur within the first 24 months following implantation: pointing to surgeon and implant-related factors as the underlying causes for failure [25]. Risk factors for ceramic liner breakage include (1) poor component position, (2) incomplete seating of the ceramic implant, (3) liner chipping during insertion, and (4) hip instability [26].

Prevention

The causes of implant breakage following THA are multifactorial. Unanticipated consequences of design, materials, and modularity have contributed to the fractures of certain implant designs. However, proper planning, good surgical technique, and adherence to sound principles of hip reconstruction can minimize the risk of implant failure in hip arthroplasty.

The process begins with proper preoperative planning and careful implant selection. In most instances, the degree of bone loss or deformity will dictate the type of implant required for fixation and reconstruction. In cases where the native medullary canal is extremely narrow, avoidance of a long, small monoblock extensively coated femoral component may be prudent. Furthermore, if a smaller (less than 13.5 mm) fully porous-coated femoral component is used in conjunction with an extended trochanteric osteotomy, strut augmentation of the osteotomy site may impart additional proximal support and stability [15]. Modularity should be used only when necessary in order to eliminate another potential interface for failure. Finally, selection of implants with good track records can reduce risks for implant breakage following hip arthroplasty.

Good surgical technique and adherence to sound principles of hip reconstruction are critical to minimize postoperative complications. Proper acetabular component position can minimize wear, impingement, and instability. Additionally, adequate surgical exposure and circumferential engagement of the locking mechanism can minimize liner-related complications. This is particularly true for ceramic liners. Most modern liner fractures are due to incomplete seating and chipping of the ceramic liner during implantation [27]. Proper taper assembly and femoral head impaction can minimize the risk of ceramic head breakage.

Diagnosis

Diagnosis for the broken hip implant can range from the subtle to the obvious. Depending on the failed implant, a patient's complaint can range from noise and mild discomfort to severe pain and inability to walk. A detailed history and physical exam form the foundation of the workup for a painful THA. Characteristics of symptoms such as onset, timing, and events that exacerbate pain and symptoms can give clues to the type of failure. Additionally, any prior history of trauma, infection, and rest pain should be elucidated. While most implant breakages are easily visualized on plain X-rays, in some cases the findings can be quite subtle (Fig. 20.7a, b). Similarly, breakage of a ceramic liner can be difficult to visualize on plain X-rays and the surgeon should have a low threshold to get a CT scan to identify liner breakage if the patient presents with new onset of pain, crepitation, or noise from the hip.

All painful THAs should undergo a comprehensive workup for infection. Simply because an implant is broken does not necessarily preclude the possibility of concurrent infection. Failure to recognize an underlying infection will result in recurrent failure. Finally, serial radiographs should be reviewed and evaluated for subtle changes in implant and component position (Fig. 20.8).

Treatment

Successful management of the broken implant requires a systematic approach. From proper diagnosis and understanding why the first implant failed to removal of broken implants and eventually

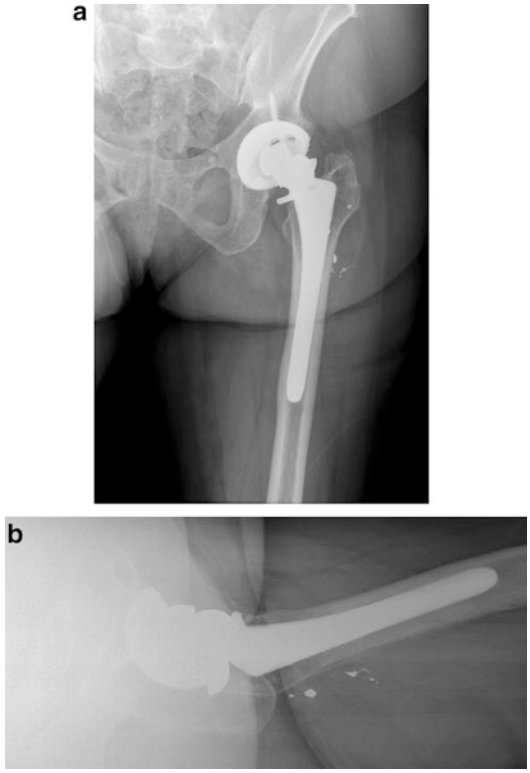

Fig. 20.7 (**a**) AP radiograph of a broken extensively coated femoral component. Note the subtle discontinuity of the lateral border of the implant. (**b**) Magnified view of the broken femoral implant. The resultant cantilever bending leads to fatigue fracture of the implant over time

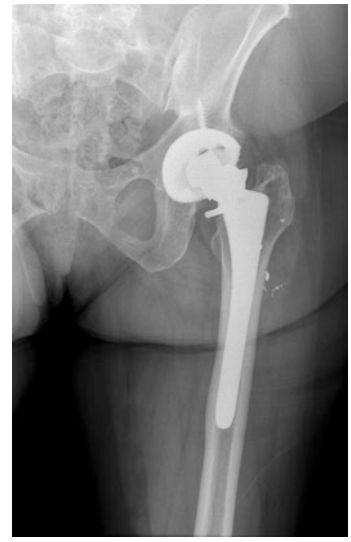

Fig. 20.8 AP and lateral radiographs of the left hip demonstrating a ceramic ball head fracture. Notice the loss of sphericity and fragmentation of the femoral head. These particles are extremely sharp and abrasive and must be removed to prevent subsequent third-body wear

to definitive reconstruction, each of these steps is critical to maximizing success and minimizing complications.

The first step in the surgical management of a patient with a broken hip implant is to carefully and safely remove the failed component; this is often challenging as removal features are oftentimes made nonfunctional secondary to the breakage of the implant. The principal goal is to minimize bone loss and not compromise subsequent reconstruction. An extensile approach to the hip including an extended trochanteric osteotomy is often required to visualize the interfaces for safe removal of the hip implants. In cases of a ceramic fracture, a complete synovectomy and thorough debridement are critical to removing sharp, fragmented ceramic particles that can compromise subsequent reconstruction due to third-body wear. Specialized instruments such as cup explant osteotomes, high-speed burrs, trephines, and implant-specific handles or extraction devices in cases of modular implants can simplify the procedure (Fig. 20.9).

Revision surgery must follow sound principles of hip reconstruction. In cases of acetabular component and liner fractures, emphasis on proper acetabular component position, engagement of the locking mechanism, and minimum polyethylene thickness can help decrease the risk for subsequent failures. On the femoral side, the revision femoral component must be sized appropriately in order to achieve axial and rotational stability. Frequently, bony pedestals or retained cement can be obstacles to proper implant sizing and therefore proper establishment of the true femoral canal prior to instrumentation is recommended. Finally, an intraoperative radiograph prior to definitive implantation can help confirm appropriate sizing of the femoral component.

The choice of bearing following revision for implant breakage depends on the situation and

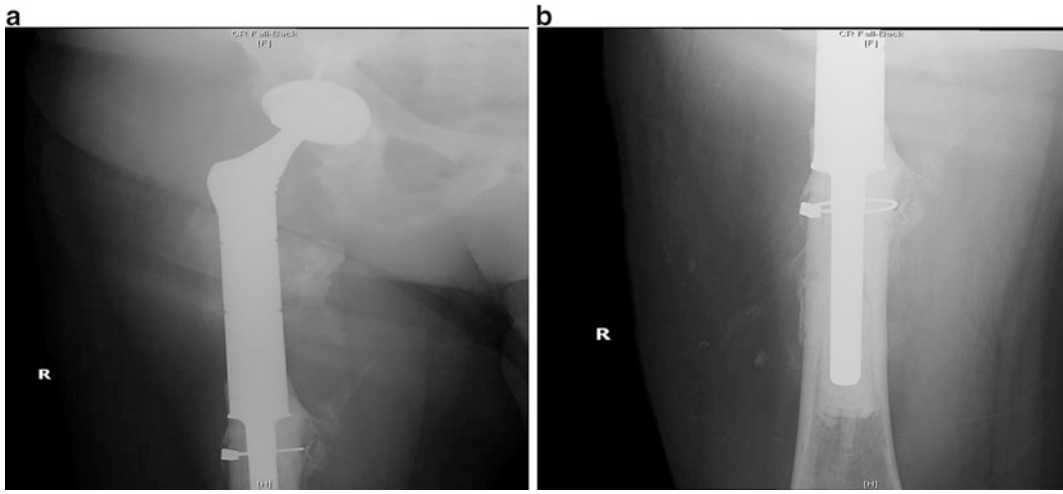

Fig. 20.9 Trephines utilized to remove distal segment of a diaphyseal engaging stem

mode of prior implant failure. In most cases, revision to a conventional bearing (metal or ceramic ball on polyethylene) is reasonable and satisfactory. An exception to this rule is when the revision THA is being performed for fractured ceramic implants. In this specific instance, a ceramic ball head should be used as they are harder and more scratch resistant compared to conventional metal ball heads. When the femoral component is retained during these cases, a ceramic ball head with a titanium inner sleeve should be used for reconstruction [28].

Literature Review

Due to the rarity of implant fractures, there are mostly case reports and a few small clinical series dealing with this complication. Sadoghi et al. [1] performed a systematic review of the literature looking at this specific problem. The authors analyzed 23 studies and found that the risk for implant breakage following THA was 304 per 100,000. Femoral stem and ball head fractures were more common than acetabular component failures.

Revisions for failed acetabular components are usually associated with catastrophic wear. Results for reconstruction are usually favorable using modern uncemented acetabular components [7, 29, 30]. Liner failures can occur as a result of wear, impingement, and dissociation from the acetabular component. Acetabular component orientation has been shown to affect the stress distribution of highly cross-linked polyethylene liners. Compared to conventional polyethylene, highly cross-linked polyethylene is more brittle and thus more susceptible to plastic deformation and fracture. Lam et al. [31] demonstrated that excessive inclination and extreme version were associated with increased peak stress magnitudes concentrated on the rim notch and locking groove regions of the acetabular components. Additionally, current trends of maximizing femoral head sizes for a given acetabular cup diameter have led to increasing utilization of relatively thinner polyethylene liners which further reduces the resistance to fatigue and failure. Consequently, revision for polyethylene liner complications often requires revision of the acetabular component orientation to improve wear properties and hip joint kinematics.

The results for revisions for broken femoral components have also been favorable provided that sound principles of reconstruction are followed. Callaghan et al. [32] reviewed a series of

53 revision THAs performed for fractured cemented femoral stems, and at 5.2 years follow-up, excellent clinical ratings were reported in 64% of patients with 6 mechanical failures. Furthermore, Steno et al. [33] reported on a case series of three broken extensively coated femoral components revised to larger fully porous-coated femoral components. The authors reported no refractures at short-term follow-up. Finally, Lakstein and colleagues [20] reported on a series of six tapered modular femoral component fractures undergoing revision THA. The authors found that a high body mass index was a risk factor for implant fracture. All patients underwent revision using taper modular stems with additional strut or allograft augmentation when required. At 1–6-year follow-up, five patients had successful reconstruction and one patient had early implant subsidence requiring reconstruction using an allograft prosthetic composite. Consequently, long-term survivorship of femoral components requires proximal bone support and both axial and rotational stability.

Revision surgery for fractured ceramic components has been shown to provide variable clinical results. Allain et al. [34] reported on a series of 105 revisions performed for ceramic head fractures and found that the survivorship at 5 years was 63%. The authors reported a high reoperation rate and also worse survivorship when the acetabular component was retained, a metal head was used for revisions, age was younger than 50 years, and a complete synovectomy was not performed at the time of revision. More recently, Sharma and colleagues [35] reported on a series of eight ceramic fractures revised to a metal-on-polyethylene articulation performed with a complete synovectomy. At 10-year follow-up, there were no increased failures; increased wear; or lesser function compared to six matched patients undergoing revision using similar implants for other diagnoses. Interestingly, the authors did not see any adverse effects of using metal heads at the time of revision surgery. However, others have reported catastrophic wear following ceramic fracture revision using conventional metal ball heads [36]. Therefore, a thorough debridement of fracture ceramic particles is key to minimize the risk for third-body wear.

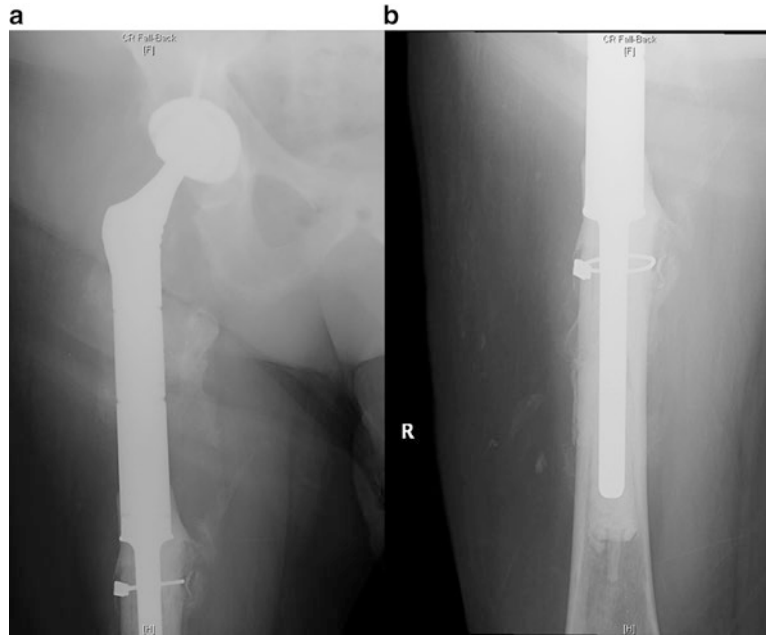

Fig. 20.10 AP and lateral radiographs of the right hip and femur demonstrating definitive reconstruction using a cemented, segmented, proximal femoral replacement megaprosthesis

Case Solution

Following successful infection control, the patient underwent reimplantation THA using a cemented, proximal femoral replacement due to bone loss and inadequate proximal bone support. At 5-year follow-up, there was no evidence of loosening or implant failure (Fig. 20.10).

Summary

Improvements in prosthesis design and manufacturing have significantly increased the reliability of THA implants used today. Implant breakage is fortunately a rare complication. The etiology is often multifactorial and an understanding of the various mechanisms of implant failure is necessary to prevent recurrence. Diagnosis and successful treatment of patients with broken hip implants require a systematic approach and adherence to the principles of good surgical technique and hip reconstruction.

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Heterotopic Ossification

21

Michael J. Taunton

Case Presentations

Case #1

A 70-year-old gentleman presented 1.5 years after a femoral neck fracture treated with a bipolar hemiarthroplasty through an anterolateral approach. The patient experienced pain in the right groin and buttock, and was utilizing narcotics for his pain. On exam, the patient was fixed in 20° of hip flexion and slight external rotation. The right leg is slightly short compared to the right. He was neurovascularly intact in the lower extremities. He had a history of diabetes, high blood pressure, and coronary bypass grafting with six stents. On radiographic examination, he had Brooker type IV heterotopic ossification of the right hip (Fig. 21.1a–c). A CT scan revealed that most of the bone was located anterolaterally (Fig. 21.2). His uncemented femoral component was well fixed. A bone scan revealed increased uptake around the right hip (Fig. 21.3).

Case #2

A 78-year-old gentleman presented 2.2 years after a left total hip arthroplasty performed for osteoarthritis through a posterior approach. At the time of surgery, the physician noted an acetabular defect and placed bone graft and BMP into the acetabulum. A deep venous thrombosis mandating 6 weeks of low-molecular-weight heparin complicated his postoperative course. The patient noted a progressive decrease in motion, as well as an increase in groin pain since surgery. On exam, the left hip was fixed at 25° of flexion with a 10° adduction contracture. It was difficult to examine hip muscular strength, but the abductors and flexors did fire with attempted range of motion. There were two large bony protrusions on the lateral aspect of his hip next to the greater trochanter. He was neurovascularly intact in the lower extremities. On radiographic examination, he had Brooker type IV heterotopic ossification of the left hip (Fig. 21.4a, b). His uncemented femoral and acetabular components were well fixed.

Epidemiology

Brooker's [1] original classification of heterotopic ossification (HO) found that 20% of 100 consecutive patients treated with THA developed some level of HO. Eighty-four percent of

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2_21

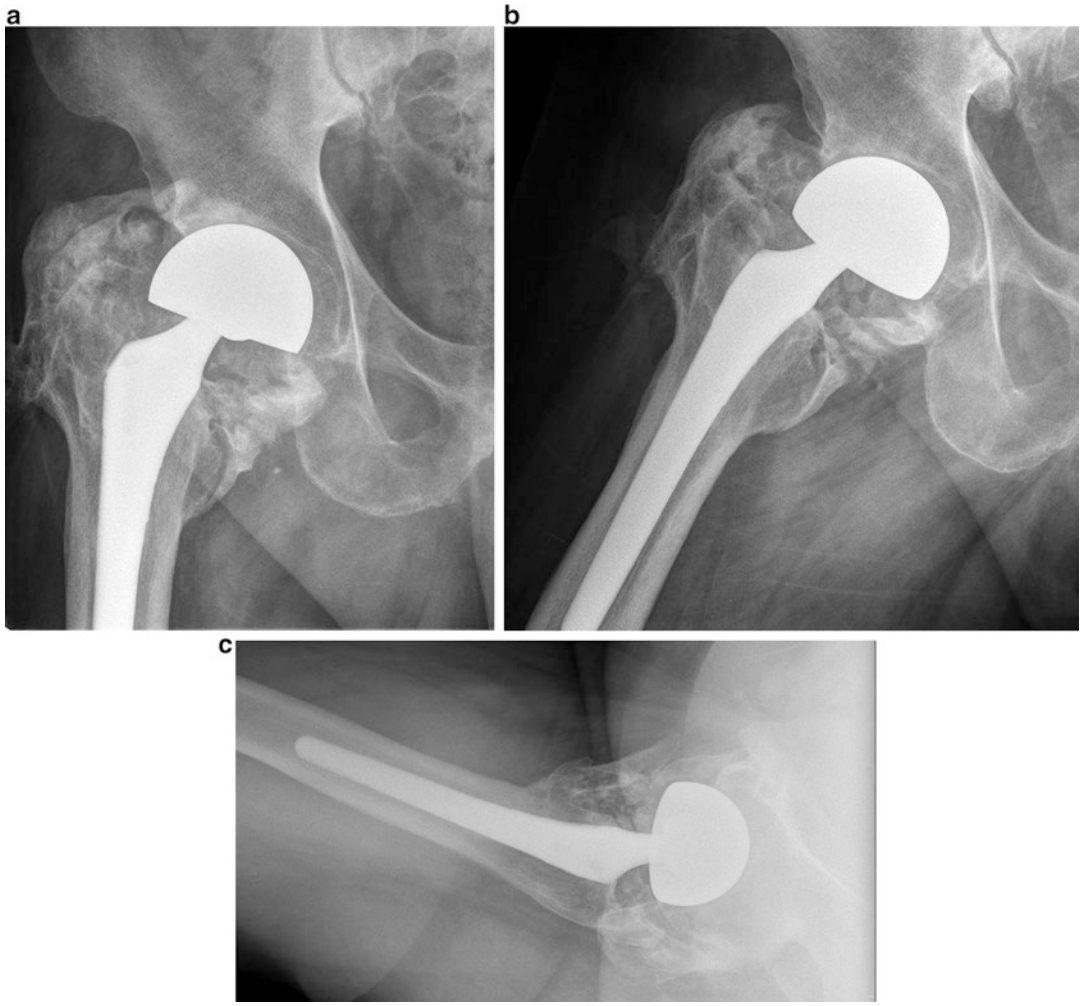

Fig. 21.1 (**a**) AP radiograph, (**b**) frog leg lateral radiograph, (**c**) cross-table lateral radiograph of right-hip bipolar arthroplasty with Brooker IV heterotopic ossification

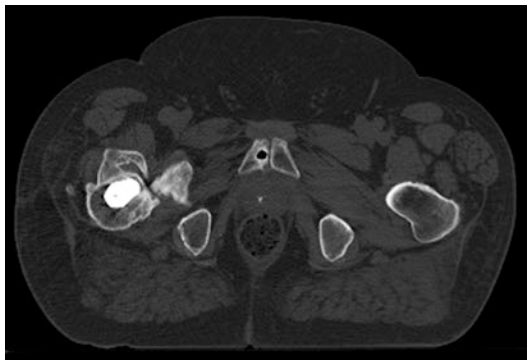

Fig. 21.2 Axial CT cut at the level of lesser trochanter revealing significant heterotopic ossification about the right hip

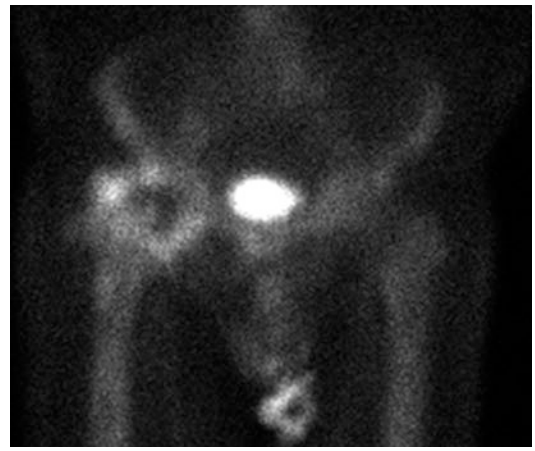

Fig. 21.3 Three-phase bone scan of the hip revealing significant uptake around the right hip

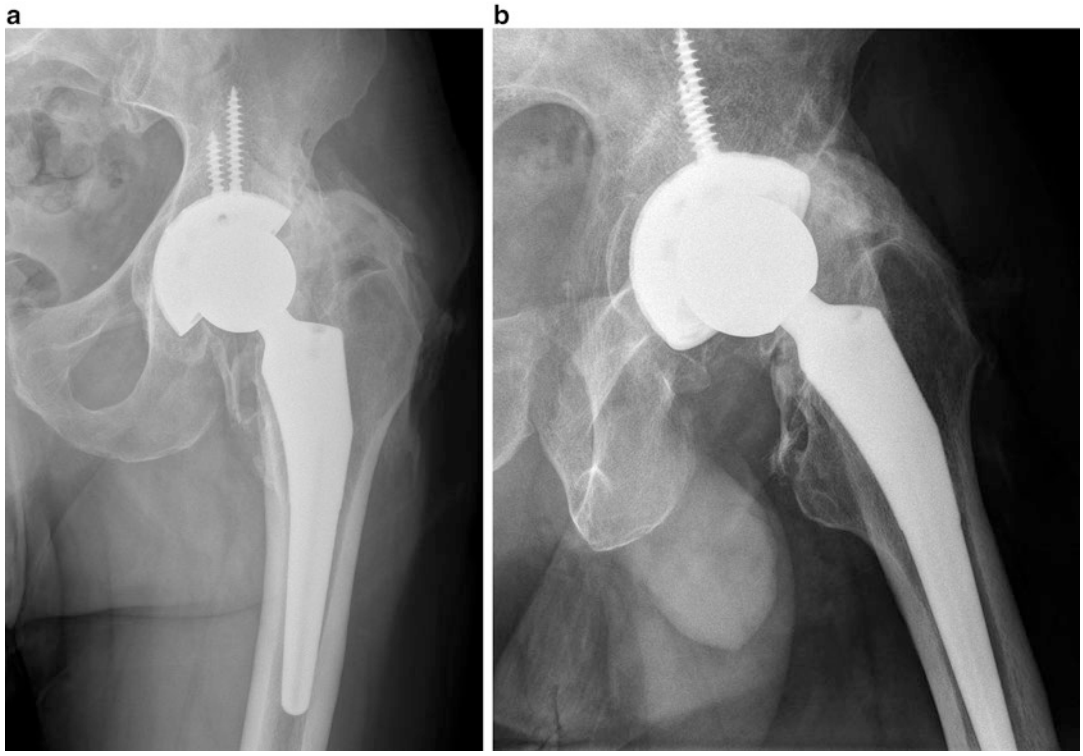

Fig. 21.4 (**a**) AP radiograph, (**b**) frog leg lateral radiographs of left total hip arthroplasty with Brooker IV heterotopic ossification

those THAs were performed through a lateral approach, and the rest through a trochanteric osteotomy. The HO was classified (Table 21.1) as Brooker I in 7%, II in 5%, III in 7%, and IV in 2% [1]. Recent reviews have found that the overall incidence of HO following primary THA is from 10 to 60% depending on the risk factors studied [2–13]. Differences in technique and approach have been identified in the epidemiology of HO with a rate of HO in direct anterior THA ranging from 19 to 41.5%, posterior THA from 10 to 27.5%, and anterolateral THA of 34% [10–13]. It is important to note that the severity of the HO by Brooker classification varies widely by article since HO that forms after THA is often minor and not clinically significant [14]. Brooker III or IV is more clinically relevant than Brooker I [15]. Brooker III HO has been reported to occur in 1.4–19% and Brooker IV in 0–5% [7, 10, 11, 13, 16].

Risk Factors

Heterotopic ossification after total hip arthroplasty can have a devastating impact on clinical function, and is often unpredictable. It is important, however, to inventory the risk factors for HO and to better understand the epidemiology of HO as reviewed above to better prevent its occurrence. Heterotopic ossification occurs when mesenchymal cells present in bone marrow, periosteum, muscle, and fascia differentiate into osteoprogenitor cells. This transformation occurs within 18 h after the index surgical procedure. An osteoid matrix is then calcified. HO consists of mature lamellar bone with trabeculae formation in soft tissue [17].

A previously ankylosed hip has been identified as perhaps the highest risk for HO, with an odds ratio of 9.85 in one study [18]. In general, patients

Table 21.1 Brooker classification [1] of heterotopic ossification

Class I: Islands of bone within the soft tissues about the hip
Class II: Bone spurs from the pelvis or proximal end of the femur, leaving at least 1 cm between opposing bone surfaces
Class III: Bone spurs from the pelvis or proximal end of the femur, reducing the space between opposing bone surfaces to less than 1 cm
Class IV: Apparent bone ankylosis of the hip

who have post-traumatic arthritis, spinal cord injuries, diffuse idiopathic skeletal hyperostosis, ankylosing spondylitis, or had multiple operations on the hip are at higher risk [19–22]. Male gender has been identified as twice the risk for HO than female gender, but female patients over the age of 65 with osteoarthritis approach the same risk as men [23]. Rheumatoid arthritis may be protective for the development of HO [18]. There is a higher incidence of HO with a trochanteric osteotomy, lateral or anterolateral approach, previous hip surgery, sub-trochanteric femoral osteotomy, and male gender or combination of any of these factors [2, 7, 10, 22, 24, 25]. Resurfacing hip arthroplasty may have a greater risk of grades III and IV HO than patients with THA [16]. Revision THA or those with excessive bleeding may also be at higher risk [26]. Additionally, patients with secondary arthritis because of congenital hip disease had a statistically significantly higher incidence of HO compared with those with osteoarthritis [27, 28]. Approach for THA and effect on incidence of HO have been widely studied and results are extremely variable form study to study. Unequivocally, more disruption of muscle tissue or release of progenitor cells into the musculature places patients at higher risk of HO.

Prevention

The complete pathogenesis of HO is unknown, but surgical trauma to soft tissue or bone appears to induce the process. Current prophylactic measures generally adhere to one or more of the following three principles: disrupting the relevant inductive signaling pathways, altering the relevant osteoprogenitor cells in the target tissue, or modifying the environment conducive to heterotopic osteogenesis [29].

There are a multitude of surgery-related factors that may modify the environment regarding heterotopic osteogenesis. Incision length, approach [6, 9, 11], localized tissue trauma and muscle damage [30] and ischemia [31], blood loss, anesthetic type, and length of surgery may all contribute to the local inflammatory response. Pulsed lavage may also spread osteoblast precursors, thereby creating an osteoconductive environment [11]. Smaller incisions may reduce the "zone of injury" to the skin and underlying soft tissues and subsequent risk of HO formation. However, if the smaller incision leads to a more difficult procedure, and more muscle damage, HO may be increased. Common intraoperative principles to avoid HO include the suctioning of marrow contents during femoral broaching, irrigating any bone dust on muscle tissue, and avoiding any muscular dissection that is not necessary. These principles again are based on limiting the spread of osteoblast precursors.

Several studies suggest that nonsteroidal anti-inflammatory drugs (NSAIDS) are efficacious in preventing HO after THA [32–39]. Indomethacin is one of the most commonly used agents and inhibits PGE2 via COX-1 downregulation and osteoprogenitor cell differentiations to osteoblasts. A typical treatment dose of 25 mg three times a day or 75 mg once a day has been shown to be efficacious if given directly after surgery [40]. More recently, naproxen 500 mg twice daily has been shown in a prospective double-blind placebo-controlled trial to lower rates of HO after hip arthroscopy from 46 to 4% [41].

A number of randomized trials have compared nonselective NSAIDS to selective NSAIDS. In a study by Saudan et al. [42], patients were allocated to receive either ibuprofen 400 mg three times daily or celecoxib 200 mg twice daily. There was an incidence of Brooker II and III HO in 13% in the ibuprofen group, and 5.1% in the celecoxib group [34]. However, in systematic reviews [37, 43], there have been no differences identified in the selective versus nonselective

NSAIDS in the prevention of HO. Yet selective NSAIDs have enhanced compliance due to gastrointestinal side effects compared with the nonselective NSAIDs [37]. The beneficial action of NSAIDS for prophylaxis against heterotopic ossification is attributed to the inhibition of cyclooxygenase 2 (COX-2) enzyme, an inducible enzyme in the osteoblasts. COX-2 is the enzyme that catalyzes the first reaction of arachidonic acid toward prostaglandin formation. The increased concentration of prostaglandins, especially PGE2, results in new bone matrix production and thus in heterotopic ossification formation [44].

Utilizing NSAIDS to prevent HO has been presented as an adjunctive medication for the sole purpose of prevention of HO. However, patients who received aspirin for DVT prophylaxis compared to warfarin experienced a decreased incidence and severity of HO [34, 39, 45]. Cohn et al. demonstrated a rate of 0% Grade III or IV HO in a cohort of 35 hips after THA treated with aspirin for DVT prophylaxis. The dosage that has been studied in multiple studies is aspirin 325 mg twice daily for 6 weeks [39].

Prevention with perioperative radiation treatment (RT) for prophylaxis of HO has been widely studied [20, 46–49]. RT is attractive as compliance is 100%, there is a low side effect profile, and it avoids the possible gastrointestinal complications of NSAIDs. Since the postoperative treatment may be uncomfortable for patients, our center prefers immediate preoperative treatment. Historically, treatment included 2000 cGy over 10 days. However, recent studies have demonstrated efficacy at a single dose of 500 cGy [48]. Ionizing radiation appears to interfere with the processing of nuclear DNA during cell division and inhibits transformation of pluripotential mesenchymal cells [48]. RT also influences the cellular responsiveness to BMP-2-signaled osteoblast differentiation [50]. Because treatment is directed at a local area, adverse reactions are limited to this region, mitigating systemic reactions [51, 52]. Cost is much higher than NSAID treatment, provided that there are no complications due to NSAID use. In an analysis of patients who were diagnosed with a malignancy after hip replacement, there was a 4% rate of malignancy in a cohort of 238 patients who had RT, compared with a 7% rate of malignancy in a control group of 476 patients who did not have RT. No patients in the radiation group had a malignancy in the field of radiation, demonstrating reasonable safety of RT for HO prophylaxis [52].

Diagnosis

The diagnosis of HO is made at postoperative visits both by physical exam and radiographic evaluation. Range of motion may be significantly reduced or eliminated altogether. Patients often complain of achy pain that has been progressive with concurrent decrease in motion. Decreased range of motion correlates with higher grades of HO [15]. Occasionally, contractures in flexion and adduction cause additional difficulties for activities of daily living. Primary classification is made by the system of Brooker [1]. Once the initial diagnosis of HO has been made, a CT scan may be obtained to provide the clinician a more detailed view of the locations and extent of the HO, and its relationship to anatomical structures including muscle and the sciatic nerve—especially if operative intervention is planned. If there is concern that the HO may still be in an immature state, a bone scan may help the clinician by showing little activity in the bone at a safe time to remove.

Treatment (Operative and Nonoperative)

Range-of-motion limitations due to HO itself will not respond to physical therapy. However, gentle stretching and strengthening may prevent further stiffness, and encourage improved gait, and optimal positioning and function of the limb. NSAIDS may be helpful on a more chronic basis to reduce inflammation associated with impingement due to the excessive bone. Generally, after 1 year [53] the bone is considered to be matured, and at that time if the decreased range of motion and pain are bad enough, excision may be contemplated. Pain as the only reason for excision may be a contraindication for operative management. Heterotopic

bone usually does not cause pain after maturation is complete [53]. However, the perception may continue and lead to a chronic pain syndrome that removal cannot fully resolve. In one study, patients who had HO excised for pain only, none had complete resolution of symptoms [54].

A careful preoperative plan is needed. Prior operative reports will help the surgeon know the prior surgical approach and any complications or issues noted in the initial procedure. The surgeon may have to perform an approach that they are not familiar to due to the prior approach, or location of HO. Implant design and manufacturer should be noted as in many cases implant exchange is necessary to gain access, or to enhance stability. Constraint or dual-mobility constructs may be considered as HO oftentimes includes much of the abductor muscle mass with a consequent high risk of postoperative instability.

Radiographs or CT scan should be reviewed to again determine the location of the bone relative to anatomical structures. Specifically, if the HO is near the sciatic nerve, preparation to isolate the sciatic nerve and perhaps perform a neurolysis should be made. Prior to revision for HO excision, perioperative radiation therapy, and postoperative NSAID treatment should be considered to give the best chance for non-recurrence of the HO.

Intraoperatively, painstaking care must be taken to identify the HO, and carefully remove it from native tissues. A good technical tip is to find the border of normal tissue and progress to the joint along the abnormal tissue, removing HO off of normal bone until the joint is reached. Often an osteotome or a Cobb elevator can aid in pushing the tissue off of the HO. Typically the HO has to be removed in piecemeal fashion to continue to gain access. Bleeding may be encountered if the HO invades normal tissue, and preparations should be made for increased blood loss. Autogenous blood recycling may be considered if available. As mentioned above, care should be taken around the neurovascular structures. The surgeon must be aware that these structures may be adjacent to, or perhaps in the middle of, the HO. Again, careful review of preoperative imaging will assist. Neurosurgical consultation could be made if the surgeon is not comfortable with neurolysis. If appropriate preparations are made, and careful and efficient surgical technique is employed, safe and effective removal of HO will be achieved.

Results of Treatment, Pitfalls, and Complications

In cases of significant HO formation after THA, where pain and limitation of function are significant, excision may be entertained as described above. Delaying excision for at least 1 year until the bone has matured and formed a stable fibrous capsule will improve results and allow the bone to be removed [53]. A bone scan revealing decreased activity may also aid in the timing of surgery [54]. Alkaline phosphatase levels are often elevated with immature HO, and return to normal that may indicate maturing of the HO [53]. Attempting removal before this time has been shown to have inferior results, and more difficult removal. However, there is significant debate that the bone may be removed earlier with perioperative radiation as soon as the HO is clinically important [55]. After excision of HO, patients may expect an average of an increase in flexion range of motion (ROM) of 30°–40°, abduction–adduction of 20°–30°, and internal–external rotation of 20°–30° [54, 56]. Although not well studied, it is important to note that pain is generally improved for most patients, but in modest amounts for many patients [54].

Complications of HO excision follow many of the normal complications of revision total hip arthroplasty. Extensive dissection may lead to sciatic nerve direct or stretch injury leading to long-standing neuropraxia. When removing HO from the undersurface of the abductor musculature there is a risk of damaging the superior gluteal neurovascular bundle which may lead to further defects in the abductors. In cases of significant ankyloses, osteotomy of the femur may be required to lift up the abductors and gain access to the joint.

Often large amounts of bone and tissue, up to 1 L, may be removed during excision of HO. This may lead to cases of instability due to a large

dead space, or dislocation due to impingement if bone is selectively removed in one range of motion. Component position and range of motion before impingement must be inspected closely. A low threshold for dual-mobility or constrained constructs may be entertained in those patients that do exhibit instability intraoperatively.

The results of radiation after HO excision are encouraging. RT should be given either right before or the day after excision, but may be effective out to 3 days after excision [57, 58]. Using 500–2000 cGy in one dose has been shown to be safe and effective in prevention of recurrence of HO after excision in the setting of THA [48, 54, 58–60]. Recurrence rates of HO after RT are 5–15% clinically significant HO [58, 59]. Concerns remain for fixation of newly implanted uncemented implants, and shielding of these implants may be indicated during RT to prevent lack of bony ingrowth [58].

Case Solutions

Case #1

It was discussed that the patient would need to wait until he was at least 2 years out from the prior procedure to allow for maturation of the heterotopic ossification. While a bone scan is not normally obtained, he did have one at the outside facility, which did underscore the activity in the bone at the less than 2-year point (Fig. 21.3). At 2.5 years after the index procedure and after discussion of further nonoperative care, the patient felt that he would like to proceed with surgical intervention. Approximately 2 h prior to the procedure, the patient underwent radiation treatment of the right hip area of 700 cGy without difficulty.

The revision was performed using a modified Hardinge approach to the hip joint, exposing the large anterior bar of heterotopic ossification. HO extending posterolateral up to the ilium was also identified and removed. The hip was then dislocated, and the femoral component was well fixed and well positioned. A hemispherical uncemented shell was placed with screws. Due to the concern of instability after massive heterotopic removal, a dual-mobility construct was selected. That provided good restoration of leg length and good stability to external rotation, hyperextension, position of sleep, 90° of flexion, and internal rotation at 90°–50° before soft tissues limited further internal rotation (Fig. 21.5). The wound was thoroughly debrided and irrigated. The range of motion at completion of the case was well past 95° of flexion and a 60° rotation arc. The abductors were repaired with nonabsorbable sutures. The patient was placed on indomethacin 75 mg daily for 2 weeks. The patient was allowed to weight bear as tolerated with dislocation precautions.

At latest follow-up of 2 years, the patient has 95° of flexion, external rotation of 45°, and internal rotation of 10° with near full extension and has minimal pain. Radiographic examination reveals no reformation of heterotopic ossification (Fig. 21.6a, b).

Case #2

After discussion of further non\operative care, the patient felt that he would like to proceed with surgical intervention. Approximately 2 h prior to the procedure, the patient underwent radiation treatment of the left hip area of 700 cGy. The prior incision was utilized and the hip approached via a posterior approach. The gluteus maximus insertion was localized to help identify the sciatic nerve and a vessel loop was placed around it distally. The nerve was then traced proximally and was found to be displaced around the acetabular region.

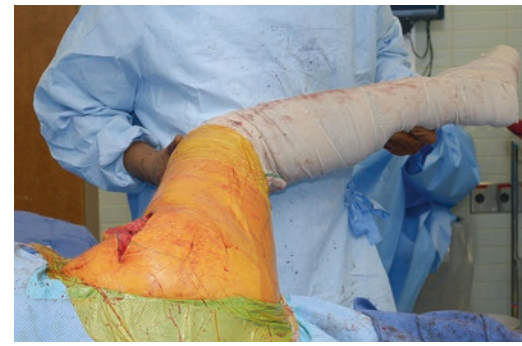

Fig. 21.5 Intraoperative photograph revealing severely limited internal rotation of the right-hip joint

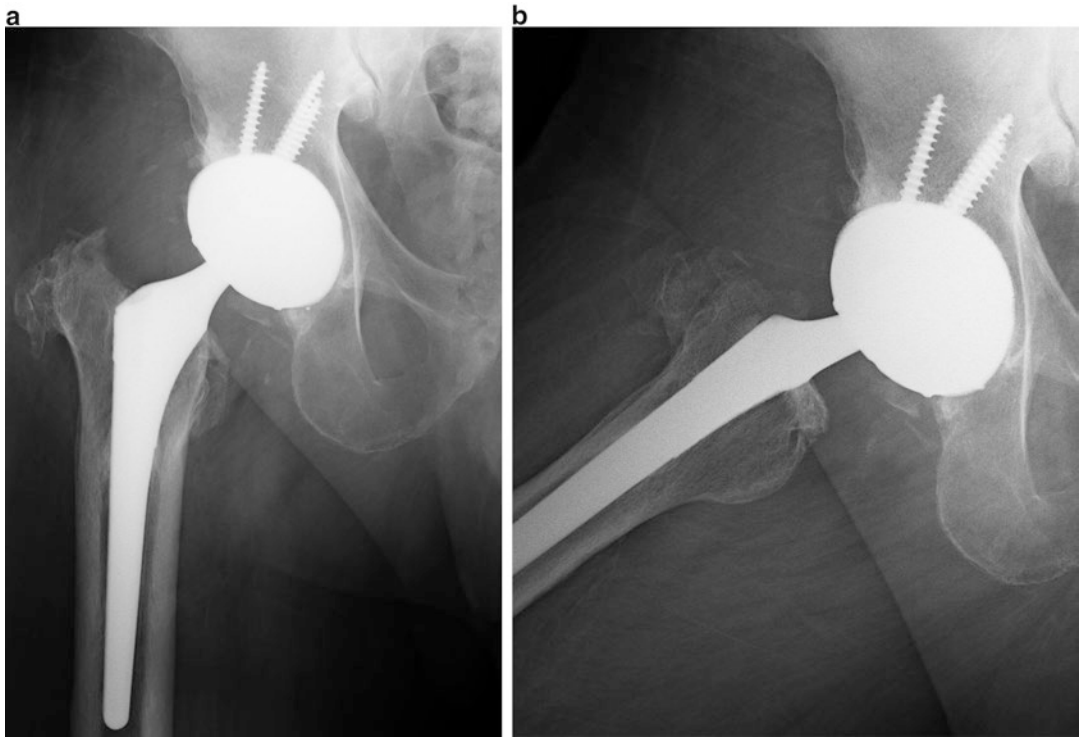

Fig. 21.6 (**a**) AP radiograph, (**b**) frog leg radiographs of right total hip arthroplasty after removal of heterotopic bone

The normal-appearing nerve distally flattened significantly as it passed toward the sciatic notch around the bony prominence of heterotopic ossification (Fig. 21.7). Neurolysis over a segment of about 15 cm was performed. Proximal control of the nerve was obtained above the bony lesion.

After mobilization of the nerve so that it could be retracted posteriorly, the hip was approached anteriorly to remove the heterotopic bone which was present there in massive amounts. This was accomplished through a modified Hardinge approach, dividing the gluteus medius and vastus lateralis and reflecting the anterior portion with a wafer of trochanteric bone anteriorly. This allowed identification of the heterotopic bone which was deep to the gluteus medius muscle, and beginning distally in the normal femur, work was continued proximally, identifying the heterotopic ossification that began well below the lesser trochanter, and progressively identifying the heterotopic bone and removing it with an osteotome, gradually working around the anterior portion and medial portion of the femur, freeing this up of soft-tissue attachment all the way up to the level of the joint. A large mass of bone anteriorly was removed. Gradually the acetabular component was identified by removing heterotopic bone and scar. There was HO along and superior to the trochanter, and this was removed from the anterior direction, identifying and taking care to retract the nerve posteriorly; this was well away from the course of any sharp instruments such as osteotomes. After removing the anterior heterotopic bone, the hip was still ankylosed due to additional bone that was posterior. Attention was then taken posteriorly and osteotomes were utilized to complete the heterotopic bone removal and finally free up the hip and restore motion (Fig. 21.8). Working progressively from both the anterior and posterior aspects of the hip, the vast bulk of the heterotopic ossification was removed, and the hip was dislocated anteriorly.

The modular head was disimpacted from the stem. The femoral component was found to be

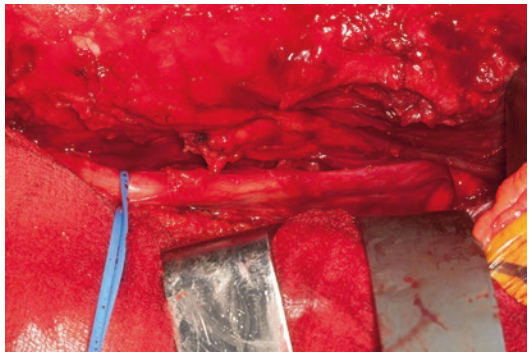

Fig. 21.7 Intraoperative photograph of left hip with the sciatic nerve isolated with blue nerve band

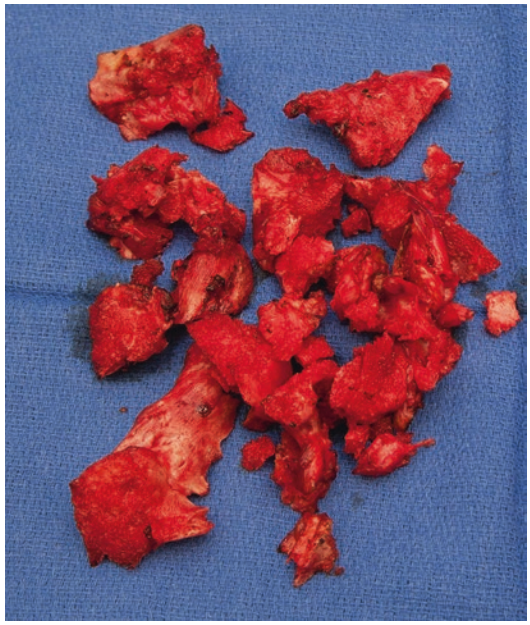

Fig. 21.8 Intraoperative photograph of heterotopic bone removed from left hip

secure. Additional heterotopic bone encasing the proximal femur was gradually removed, decreasing the size and bulk of the femur and trochanteric area, particularly posteriorly to prevent impingement. After identifying the entire rim of the cup, the cup was found to be neutral in orientation and very much under-anteverted. Cup revision was needed to insure stability. The new cup was impacted into position with good restoration of anteversion and inclination for hip stability and excellent coverage by host bone. After placement of the acetabular liner, a 40 mm +0 head was selected. This was impacted into position, and the overall stability of the hip was quite good. The hip was still quite stiff due to the scar and soft-tissue changes about the hip, though flexion was possible to about 70°. There was good rotation and no impingement with rotation of the hip, even in an adducted position. The abductor mechanism was then repaired. The gluteus maximum attachment to the femur distally was repaired. Remnants of the posterior capsular structures were repaired to the posterior aspect of the femur and gluteus medius attachment. A deep drain was left. The fascia was closed, and the skin was closed in a normal fashion. The patient was allowed to weight bear as tolerated with dislocation precautions.

At latest follow-up of 2 years, the patient has 95° of flexion and has minimal pain. Radiographic examination reveals minimal reformation of heterotopic ossification (Fig. 21.9a, b).

Summary

The exact physiologic cause of heterotopic bone remains elusive. However, we continue to make gains in the assessment of risk factors, prevention, and effective management of heterotopic bone. Basic science research will continue to refine our knowledge of the underlying genetic causes of HO as well. However, arthroplasty surgeons must remember that in addition to the preoperative and postoperative modulation of medications or radiation treatments, damage of the muscle and soft tissue remains the cause of the heterotopic bone. Efforts to reduce the trauma to those tissues while performing a well-done total hip arthroplasty will result in superior patient outcomes.

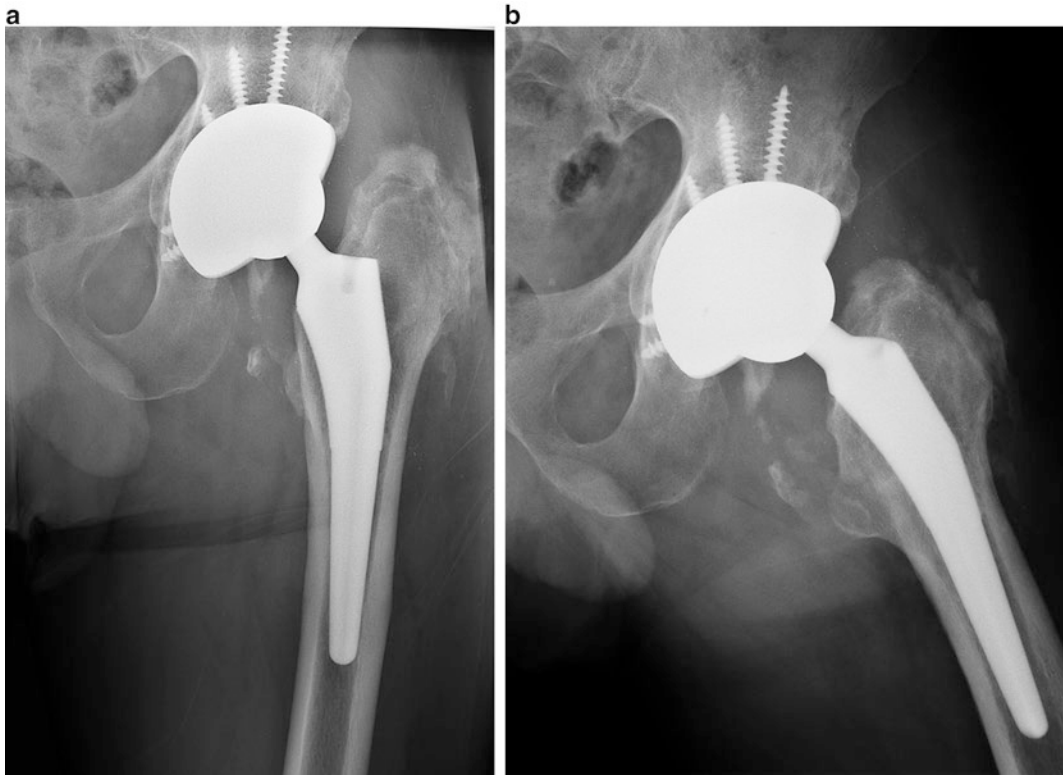

Fig. 21.9 (**a**) AP radiograph, (**b**) frog leg lateral radiographs of left total hip arthroplasty after removal of heterotopic bone

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M.P. Abdel, C.J. Della Valle (eds.), *Complications after Primary Total Hip Arthroplasty*,
DOI 10.1007/978-3-319-54913-2