Ulrich Spandau
Gabor Scharioth
Editors

Cutting Edge of Ophthalmic Surgery

From Refractive SMILE to Robotic Vitrectomy

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Preface

In order to become a top surgeon you need to be a specialist in two areas: in your surgical field as well as in technical innovations. This book contains the most innovative and modern ocular surgery of the complete eye: from the eyelid to the retina. Only leading surgeons and pioneers in their field present their surgery with videos and detailed step-by-step instructions.

Lacrimal duct surgery has changed dramatically through the introduction of microendoscopes and microdrills allowing a much more refined surgery than the traditional DCR. The eye hospital in Darmstadt, Germany, is one of the worldwide leading clinics in lacrimal duct surgery. Dr. Ungerechts will describe his experiences with endoscopic lacrimal duct surgery.

SMILE stands for *small incision lenticule extraction* and is the most recent revolution in corneal refractive surgery. During the SMILE procedure, the femtosecond laser cuts a lenticule inside the corneal stroma which is removed by a side incision. A corneal flap with all the negative side effects is no longer necessary. This technique was developed by the company Zeiss together with Prof. Sekundo (Marburg, Germany), Prof. Blum (Erfurt, Germany), and Prof. Meyer (Cologne, Germany). The authors describe the development of this new technique and demonstrate the surgery step by step.

In 2015, the German glaucoma patient association declared *canaloplasty* as the new gold standard in glaucoma surgery, as this operation combines good results with a low risk profile. Prof. Körber from Cologne, Germany, is a pioneer in the surgery of canaloplasty. During this surgery, an illuminated microcatheter is introduced in Schlemm's canal and the canal is then widened through injection of viscoelastics. Prof. Scharioth from Recklinghausen, Germany, will demonstrate a novel technique for canaloplasty using a special suture from Onatec (Onalene, Germany).

Iris surgery has made a huge leap forward with the advent of a foldable iris prosthesis from Human Optics, Germany, and new iris instruments from Geuder, Germany. The iris prosthesis enables the treatment of aniridia with a 2.5 mm incision and the new instruments allow a simple surgery for traumatic mydriasis. Asst. Prof. Spandau will demonstrate the surgical techniques step by step and show several videos.

The most exciting development in *cataract surgery* is surely the advent of the laser. Prof. Nagy from Budapest, Hungary, is a developer of femtosecond cataract surgery. He will present his technique step by step and show the pros and cons of this exciting new surgery. Prof. Sauder from Stuttgart, Germany, will demonstrate a novel phaco handpiece which removes the nucleus with laser instead of ultrasound. And finally, Dr. Nyström from Gothenburg, Sweden, will demonstrate congenital cataract surgery and implantation of a Tassignon IOL.

The amount of implanted *special lenses* has augmented dramatically in recent years. In this book, we will present two special lenses, the macula lens for improved reading ability and the add-on IOL. Prof. Scharioth from Recklinghausen, Germany, designed a novel macula lens which is implanted as a piggyback IOL and allows near vision for patients with AMD. Prof. Sauder from Stuttgart, Germany, will present the use and implantation of add-on IOLs for spherical, astigmatic, and presbyopic correction in pseudophakic eyes.

Glued IOL and the intrascleral IOL are the most common techniques for *secondary IOL implantations*. Prof. Scharioth from Recklinghausen, Germany, will present his famous technique of intrascleral IOL fixation and the modified glued IOL technique.

Vitreoretinal surgery has undergone dramatic changes in the last 10 years through the introduction of trocars. The most recent development is the advent of a new double-blade vitreous cutter (Geuder, Germany; Dorc, The Netherlands) which has a cutting rate of 16.000 cuts/min and simultaneous constant flow. Asst. Prof. Spandau from Uppsala, Sweden, will demonstrate 27G vitrectomy with a TDC cutter in pediatric patients – from ROP to FEVR.

Will *robotic surgery* be the future in ocular surgery? Dr. Charles Mango from New York, USA, will report on the latest state of robotic technology for eye surgery.

Ophthalmology has always been an innovative field. With constant development of technical innovations and surgical techniques, the potential for the future is unlimited.

Uppsala, Sweden — Ulrich Spandau
Recklinghausen, Germany — Gabor Scharioth

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About the Authors

Marcus Blum, MD Marcus Blum is chairman of ophthalmology at the Helios Klinikum Erfurt GmbH, Germany. He graduated from Heidelberg University Medical School and was a resident at the Department of Ophthalmology in Heidelberg. From 1995 onwards, he was Fellow at the University of Jena and was appointed associate professor. In 2001, he became head of department in Erfurt. He was clinical investigator for several new technologies and published more than 100 papers. Together with Walter Sekundo, he was the first surgeon to perform FLEx and SMILE with a femtosecond laser.

Jean-Pierre Hubschman, MD Jean-Pierre Hubschman is currently Associate Professor in Residence, Department of Ophthalmology, at the David Geffen School of Medicine – University of California Los Angeles (UCLA), Stein Eye Institute. Dr. Hubschman is also Chief of Retina at Olive View Medical Center at UCLA, and an Affiliate Faculty of the Bioengineering Department, Henry Samueli School of Engineering and Applied Science.

Jean-Pierre Hubschman is the author of more than 100 peer-reviewed papers, numerous book chapters, and the principal investigator or co-investigator of several grants including the NIH and NEI institutes.

Dr. Hubschman's research interest has focused, during the last 10 years on translational research in ophthalmology, specifically on robotics for ophthalmic surgery and surgical visualization improvement.

Norbert Körber, FEBO is born in 1952 in Germany. He finished his medical studies (1972–1978) 1979 with a PhD and 1984 he passed the exam as ophthalmologist. He is working in his own practice in Cologne since 1987; nowadays an ophthalmologic group practice with nine other colleagues. Since 20 years, he owns an ophthalmic outpatient surgery centre; a total of ten surgeons are performing surgery in the centre (approximately 6000 intraocular cases per year). He specializes in cataract and glaucoma surgery.

He showed scientific activities in microcirculation and hemorheology and published about cataract surgery, refractive surgery, and glaucoma surgery.

(In total more than 150 publications and presentations.)

As guest professor, he has been teaching at the University Eye Hospital in Padova, Italy, since 2002 and is honorary member of the AISG (Italian Society on Studies of Glaucoma). Further memberships are at ESCRS, ASCRS, DGII, board member of the BDOC, chairman of the VOA North Rhine, and fellow of the European Board of Ophthalmologists.

His operative spectrum covers cataract, refractive IOLs, glaucoma surgery, vitrectomy, and oculoplastic surgery.

Charles W. Mango, MD Dr. Charles W. Mango is a Clinical Associate Professor of Ophthalmology at the Weill Cornell Medical College. He is a board-certified ophthalmologist whose clinical practice involves the medical and surgical management of vitreoretinal disorders. He is actively involved as a teaching professor in the vitreoretinal fellowship training program at New York Presbyterian Hospital.

Dr. Mango completed a residency in Ophthalmology at the Weill Cornell Medical College – New York Presbyterian Hospital in New York. He has also completed a 2-year fellowship in vitreoretinal disease and surgery at the Jules Stein Eye Institute – University of California Los Angeles.

Dr. Mango serves on the editorial board for the official journal of the American Society of Retina Specialists. He has published and contributes as a reviewer to the major scientific journals. He has authored multiple textbook chapters. He is involved in several scientific research projects, which include robotic ocular surgery, retinal imaging modalities, and evaluation of electronic advances in the field of retina.

Dr. Mango has been a speaker and moderator at multiple national and international meetings. He has participated as a principal investigator and co-investigator in numerous clinical trials. Dr. Mango is a founder of the Vit-Buckle Society where he currently serves as an officer and executive board member.

Bertram Meyer, MD Dr. Bertram Meyer is specialist in laser refractive surgery since 1992 and is performing SMILE procedures since 2010. He works in private clinics in Cologne and in Dubai. He gives continuous and regular lectures and updates during the annual meetings of DOG, DOC, DGII, and European Society of Cataract and Refractive Surgeons (ESCRS) about Femto-Lasik and ReLEx® SMILE. He is member of Advisory Board for Refractive Laser Surgery for Carl Zeiss Meditec for many years.

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Sarah Mödl, FEBO is currently a fellow at the Eye Hospital Charlottenklinik in Stuttgart. She graduated from University of Ulm Medical School in 2010 and was afterwards a resident at Charlottenklinik. She performs cataract, oculoplastic and lacrimal surgery.

Zoltan Z. Nagy has been working in ophthalmology since 1986. Currently he is the Head of the Department of Ophthalmology Semmelweis University, Budapest, Hungary, and serves as a Dean of the Faculty of Health Sciences. His main interest in ophthalmology is cataract and refractive surgery.

He started refractive surgery first in Hungary in 1992, performed all kinds of refractive procedures: PRK, LASIK, epi-LASIK, LASEK, PTK, femto-LASIK, overall he operated more than 30,000 eyes with all kinds of refractive errors and more than 16,000 eyes with cataract. He discovered the role of harmful ultraviolet-B effect during corneal avascular wound healing, which has been published in *Ophthalmology* in 1997. He has published more than 139 articles in English and in Hungarian, contributed 5 books, and wrote 20 book chapters.

Dr. Nagy was the first who performed femtolaser-assisted cataract surgery in the world in 2008. He has published more than 22 papers, 1 book, and 5 book chapters regarding the clinical results of femtolaser-assisted cataract surgeries in peer-reviewed ophthalmic journals since the first procedure. In 2010, he was awarded the Waring Medal for the best publication in *Journal of Refractive Surgery*. In 2012, he received the Casebeer Award from the International Society of Refractive Surgeons (ISRS) as a recognition of his pioneer role and scientific contribution in femtolaser-assisted cataract surgery. In 2014, he received the Presidential Award of the International Society of Refractive Surgeons. He is an invited speaker in many European and international congresses. He is a Board member of the Executive Board of the

ISRS (International Society of Refractive Surgeons) and a coopted member of the ESCRS Board (European Society of Cataract and Refractive Surgeons). Presently he serves as a President of the Hungarian Society of Cataract and Refractive Surgeons (SHIOL). He received an invitation to the Editorial Board of *Journal of Cataract and Refractive Surgery* in 2012 and also to the *Journal of Refractive Surgery*. The Semmelweis University awarded him with Jendrassik Prize in 2012, with Emil Grósz Prize in 2013, and he received the Batthyany-Strattmann Prize in 2014.

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Alf Nyström, MD Dr. Alf Nyström works since 1992 as pediatric ophthalmologist at the University of Gothenburg, Sweden. He is responsible for congenital cataract and glaucoma. He operated approximately 2000 cases of congenital cataract.

Gangolf Sauder is Director at the Eye Hospital Charlottenklinik in Stuttgart, Germany. He is a board-certified ophthalmologist, whose surgical management involves the complete ocular spectrum from oculoplastic surgery to vitreoretinal disorders.

Prof.Dr. Sauder studied medicine at the University of Bonn, Germany, from 1988 to 1994. He completed his residency in Ophthalmology at the Stiftsklinikum in Koblenz, Germany. He worked as Vice-Director at the University of Heidelberg-Mannheim from 2000 to 2006. Since 2006, he is Director at the Charlottenklinik in Stuttgart. A total of 6 surgeons are performing surgery at this hospital. Annually, the Charlottenklinik performs 8000 cataract surgeries, 600 glaucoma surgeries, and 1400 vitreoretinal surgeries.

Prof. Sauder operated more than 800 patients with Add-On IOL and performed more than 3000 cases of laser phaco.

Gabor B. Scharioth graduated from Medical School in Humboldt University Berlin in 1993. During his residency program, he was trained in Augentagesklinik Groß-Pankow, Campus Virchow of University. Berlin. and Aravind Eye Hospitals. India. In 1998, he joined private practice in West Germany and founded Aurelios Eye Centers in 2004. His fields of expertise in ophthalmic surgery are cataract surgery, vitreoretinal surgery, reconstructive/trauma surgery, and modern glaucoma surgery. He has performed more than 30,000 surgeries during his career and trained many doctors around the world. He gave more than 250 scientific presentations at national and international conferences and performed more than 20 live surgeries at several international meetings around the world. Multiple scientific peer-reviewed publications are published and he was awarded several times at international meetings, including ASCRS, ESCRS, EVRS, and DOC. He is member of several ophthalmic organizations and scientific and advisory boards. During his professional career, he made several inventions like Scharioth Macula Lens for patients with advanced maculopathy, Glaucolight-assisted canaloplasty, microscope mounted angle viewing system, Light indentor for vitreoretinal surgery, and intrascleral haptic fixation of PCIOL in absence of capsular support. He was principal investigator and participated in multiple large prospective, multicenter studies. Since 2013, he is private professor at the University of Szeged in Hungary.

Lothar Schneider, MD Dr. Lothar Schneider works since 2011 at the University of Gothenburg, Sweden. He is mainly a VR surgeon and has started now with pediatric surgery.

Walter Sekundo, MD Prof. Dr.med. Walter Sekundo is Professor and Chairman, Department of Ophthalmology, Philipps University of Marburg, Germany. He studied Medicine in Frankfurt (Germany), New Orleans and Durham (USA). He was a resident at the University of Bonn in Germany and a Fellow in Corneal and Refractive surgery at Moorfields Eyes Hospital (UK) and Ocular Pathology at the University of Glasgow, UK. He also has a degree of "Health Care Manager". Prof. Sekundo has published over 100 original papers, 29 book chapters and is an editor of the newly appeared textbook on SMILE surgery. He gave over 300 presentations at national and international meetings. He is a reviewer for 21 Ophthalmic Journals and a Board Member of "Der Ophthalmologe". Prof. Sekundo performed over 20,000 surgical procedures in the entire field of ophthalmology and has been repeatedly named as one of the 30 top refractive and cataract surgeons in Germany. He was the first surgeon in the world who performed FLEx and SMILE.

Ulrich H.M. Spandau, MD Dr. Spandau is Assistant Professor at the University of Uppsala, Sweden. He is head of ocular surgery and works mainly as vitreoretinal surgeon. His special surgical interest is the diagnosis and treatment of vitreoretinal diseases of newborn.

Dr. Spandau was born 1968 in Grahamstown, South Africa, and moved to Germany in 1978. He studied at the Medical School of the University of Wuerzburg, Germany. He completed his ophthalmological residency at the University of Heidelberg and his surgical education at the Stiftsklinikum in Koblenz and the University of Mannheim, Germany. In 2008, he moved to Uppsala, Sweden, to learn modern VR surgery.

Dr. Spandau is author of the textbooks *Small Gauge Vitrectomy. A Practical Handbook*, *Complications During and After Cataract Surgery*, *Small Gauge Vitrectomy for Diabetic Retinopathy* and *27G Vitrectomy*.

Angelo Tsirbas, MD Dr. Angelo Tsirbas is a world-renowned ophthalmic facial plastic and reconstructive surgeon with a distinguished background. He was trained in Australia and then worked in NYC and Los Angeles for many years. During his time as faculty professor at UCLA, he maintained a private aesthetic practice based in Beverly Hills. Dr. Tsirbas is sought after by patients from around the world for help in correcting some of the most challenging complicated cases with his innovative surgical techniques. Dr. Tsirbas popularized modern endoscopic lacrimal surgery in the ophthalmic and oculoplastic community. He developed surgical techniques in the 1990s that are still used all around the world today. His work now specializes in obtaining the finest and most natural results for blepharoplasty, browlift, and aging facial surgery. The demand for his expertise in functional, reconstruction, revision, and cosmetic surgery has also found him consulting all across Australia. Dr. Tsirbas is based in the heart of Sydney's beautiful Harbour district.

Ralf Ungerechts, MD Ralf Ungerechts was born in 1967 in Moenchengladbach, Germany. He successfully completed his study of medicine at the Johannes Gutenberg University in Mainz, Germany. He has been working from 1997 first as a junior doctor and then as assistant doctor before progressing to senior consultant at the Eye Clinic in Darmstadt – an academic teaching hospital of the Universities of Frankfurt/Main and Heidelberg-Mannheim.

His major fields of expertise are dacryocystorhinostomy and minimal invasive lacrimal surgery. With a total of 15 years' experience, he has performed lacrimal surgery over 8000 times.

Part I

Lacrimal Duct: Endoscopic Surgery

Lacrimal duct surgery has changed dramatically through the introduction of microendoscopes and microdrills allowing a much more refined surgery than the traditional DCR. The eye hospital in Darmstadt, Germany, is one of the worldwide leading clinics in lacrimal duct surgery. **Dr Ungerechts** is vice director of the hospital and will report about his experiences and especially describe endoscopic lacrimal duct surgery.

Lacrimal Surgery

1

Ralf Ungerechts

Tears are essential for the normal function of the eye. A part of the tears is lost by evaporation. The majority of tears drain to the inferior meatus of the nose. The parasympathetic nervous system controls the tear volume reflex by the fifth cranial nerve. When the volume increases or the passage is obstructed, the patient complains about epiphora and blurred vision. Bacterial invasion of an obstructed lacrimal system can occasionally lead to acute dacryocystitis with fistula formation. The patient should be informed that in almost every case (except for orbital abscess) the operation is elective and optional.

Assessment of Lacrimal System

To choose the correct therapy a careful history and an examination of the eyelid and the lacrimal system are necessary [4, 6, 7].

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History

Symptoms? Unilateral or bilateral? Duration (at least 3 months before surgery)
Previous inflammation e.g. dacryocystitis, herpetic eyelid involvement?
Nasal or sinus problems? (referral to an otolaryngologist)
Bloody tears?
Previous surgery (nose, sinus, tear duct, intraocular (to prevent pressure on a glaucoma eye))
Chemotherapy e.g. doxetacel after breast cancer?
Radiotherapy?
Trauma (need for preoperative imaging)?
Medication? Chronic endonasal therapy (because of the mucosa)?
Motivation for surgery?

Examination

Eyelid: laxity, lagophthalmus, fistula, blepharitis, ectropion, entropion, trichiasis, induration, swelling, exprimable pus, etc.

Slit lamp: conjunctivitis, scars, intraocular inflammation, etc.

Syringing: after inferior punctum dilatation insert a lacrimal cannula at right angles to the lid margin. Rotate the cannula to the nose and continue about 5 mm further, irrigate with saline (for interpretation of the results see Fig. 1.1), exact description of the result: e.g. insertion of

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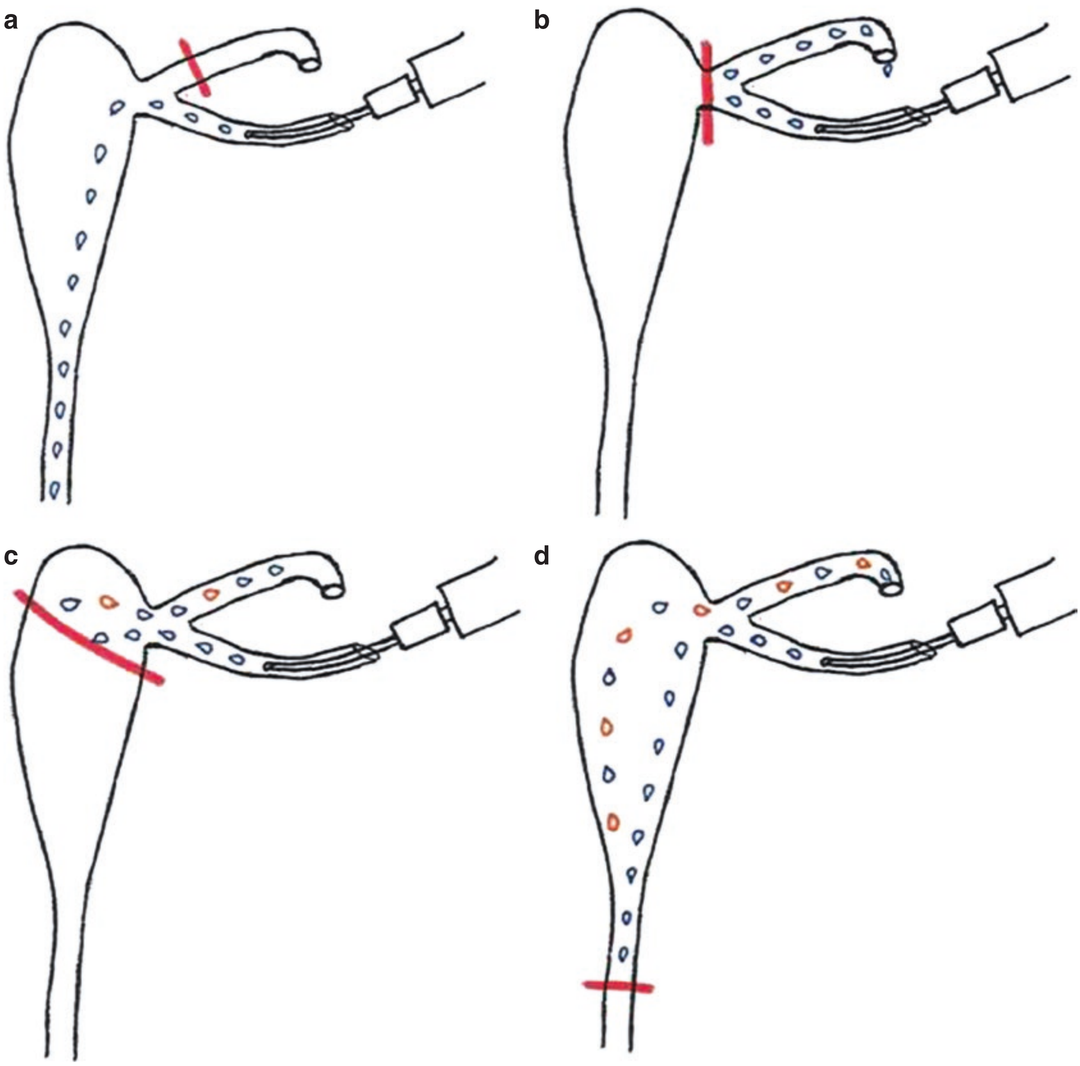

Fig. 1.1 (**a**) Canaliculus superior stenosis. (**b**) Canaliculus communis stenosis. (**c**) Stenosis of superior portion of lacrimal sac. (**d**) Deep stenosis of lacrimal sac

the inferior canaliculus without resistance or soft stop after 6 mm with sudden regurgitation of clear saline over the opposite canaliculus.

Dacryocystography: the level and severity of stenosis, identification of fistulae or tumors,

ENT examination: exclusion of local obstructions e.g. by polyps, deviated septum.

Sonography: exclusion of foreign bodies e.g. calcified stones, lost punctum plugs.

Functional tear tests:

Dye test with 2 % fluorescein into the conjunctival sac: if fluorescein is in the nose after 2 min, then the test is said to be positive. If the dye appears after syringing with saline in the nose, this means a positive secondary dye test.

Taste test: The presence of saline in the nasopharynx can be tasted.

Results of Syringing (Fig. 1.1)

Stenosis of the inferior canaliculus: the saline regurgitates along the same canaliculus.

Stenosis of the common canaliculus or superior saccus: the saline regurgitates along the opposite canaliculus.

Stenosis of the sac or the nasolacrimal duct: mucus regurgitates along the opposite canaliculus.

Anesthesia for Lacrimal Surgery

Probing and syringing in children up to 1 year of age and adults can be done under topical anesthesia with eye drops e.g. tetracaine or proxymetacaine hydrochloride. We recommend general anesthesia for most lacrimal procedures for other patients, e.g. older children or handicapped patients.

In children, lacrimal surgery is usually done under general anesthesia. Children are rarely presented with complex congenital syndromes. The saline used for syringing after probing could be aspirated. The anesthesiologist must protect the airways from obstruction by saline solution and blood. Due to these complications endotracheal intubation is preferred. After surgery the fluids should be suctioned, the head should be placed head-down. Lacrimal surgery in adults may be carried out conveniently using general anaesthesia. If general anaesthesia is not possible some minimal invasive methods could be done using local anaesthesia. Usually general anesthesia is preferred. General anaesthesia has the advantage that both the airways and the blood pressure are under control. This is much more comfortable for the patient and the surgeon. If the patient needs local anaesthesia, a spray containing cocaine 4 % with a drop 1:1000 adrenaline is sprayed into the nose. The skin over the lacrimal sac is infiltrated with mepivacaine and adrenaline. The nasociliary nerve has to be blocked below the trochlea and the superior alveolar nerve proximal to the infraorbital foramen. Usually systemic sedation is helpful.

Adults undergoing lacrimal surgery are mostly older than 55 years of age. Others diseases, e.g. asthma, bleeding diathesis, hypertension, have to be identified before surgery and controlled during anesthesia. A detailed history and physical examination allow the anesthesiologist to assess the risk of complications. Aspirin therapy or other antiplatelet drugs should be stopped at least 8 days, or preferably, 14 days before surgery otherwise platelet infusions may be required. New antiplatelet drugs e.g. Dabigatran, Rivaroxaban or Apixaban should be stopped before surgery, if possible. Heparin should be discontinued 5 h before surgery and continued 5 h after surgery. Special patients (e.g. bleeder) should be crossed and typed for blood transfusion. Antiplatelet drugs should only be stopped after consultation with the general practitioner.

Antihypertensive medication should be taken on the day of surgery because arterial hypotension during the surgery is an advantage (limit to 70 % of the patient's normal systolic and diastolic blood pressure). To reduce the swelling of the nasal mucosa Xylometazoline or Tetryzoline nasal spray is administered before surgery. DCR may be performed under local anesthesia, but general anesthesia is preferable. An oral right atrial enlargement tube and a throat pack can be used. For local nerve block Xylocaine and Epinephrine 1:100,000 is injected in combination with systemically administered sedative agents. It is important not to obtund protective airway reflexes. During surgery the patient should be positioned with head-up, feet-down position (reverse Trendelenburg position) to control the blood loss.

Patients should be prepared so that they will wake up with one eye patched and both nasal passages packed. With DCR involving the sinus the anesthesiologist should be aware of the oculocardiac reflex and the potential for blood loss. Drug interactions and side effects must be expected.

Management of Lacrimal Obstruction

Congenital Stenosis (Figs. 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11, 1.12, 1.13, and 1.14)

The most common cause for congenital stenosis with epiphora is the imperforation of the valve of Hasner. Therefore the common location of the obstruction is the end of the nasolacrimal duct under the inferior turbinate. Within most full-term babies the Hasner valve opens spontaneously at the age of 6 weeks. In case of chronic epiphora other causes e.g. absent puncta or punctual occlusion, accessory cana-

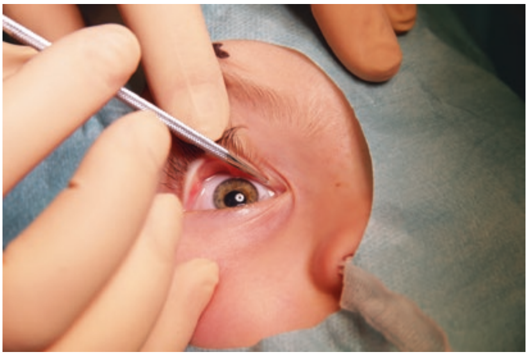

Fig. 1.2 Dilatation with Wilder Lacrimal probe

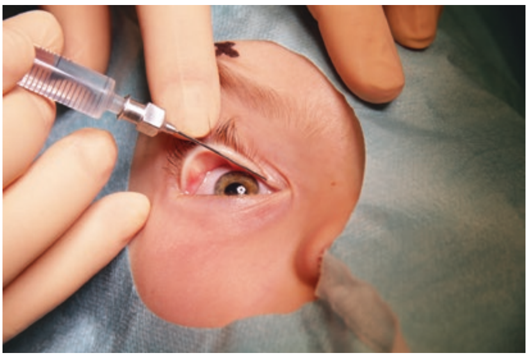

Fig. 1.3 Syringing with Bangerter lacrimal probe

Fig. 1.4 Probing with Bangerter Lacrimal Probe Cannula

liculi, dacryocystocele, mucocele, craniofacial disorder, congenital glaucoma etc. should be ruled out. Before any surgical intervention the parents are recommended to massage the area around the nasalacrimal sac with a little finger

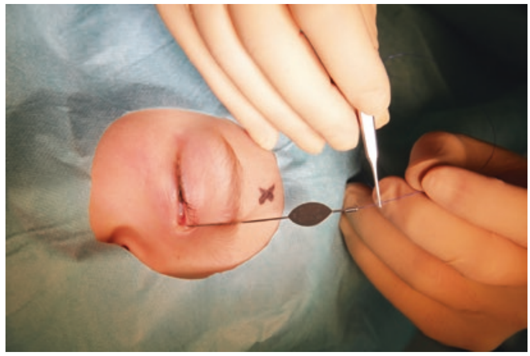

Fig. 1.5 Introducing a polypropylene suture with Juenemann Probe

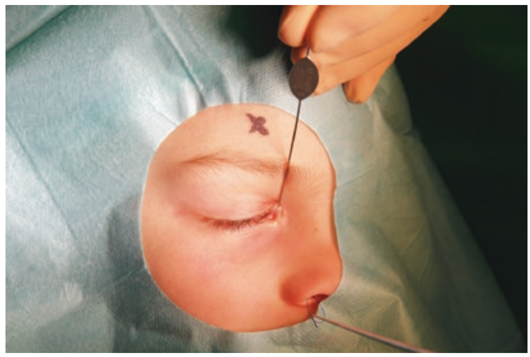

Fig. 1.6 Picking the suture with a squint hook

(short cut nail) to reduce the risk of dacryocystitis and, hopefully, to treat the obstruction. Most problems are resolved in the first year and a further 60 % in the second year without intervention. The parents are informed about the importance of lid hygiene. Sticky lids and lashes can be cleaned with water, in case of dry periocular skin paraffin ointment can be applied. Topical antibiotics are only required in case of conjunctivitis after obtaining a culture and definition of the antibiotic sensitivity. In case of dacryocystitis systemic antibiotics are recommended. For the parents the most reassuring thing is the detailed information about the natural history of this disease. Usually they want to avoid invasive procedures and they will be patient.

Fig. 1.7 Intubation Seldinger 1

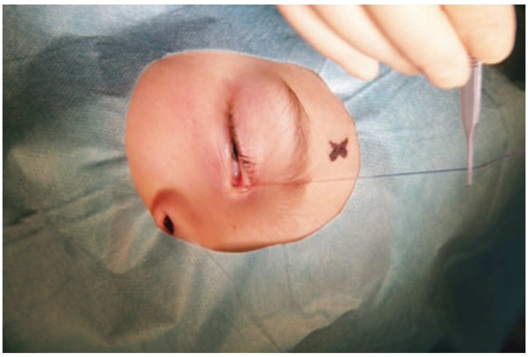

Fig. 1.8 Intubation Seldinger 2

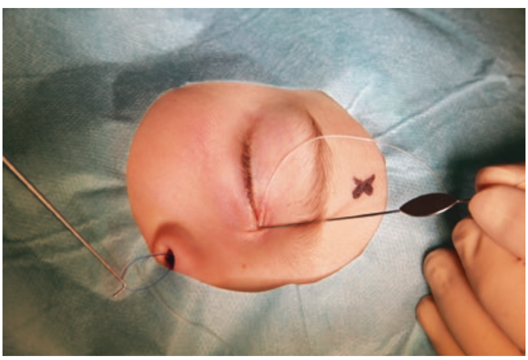

Fig. 1.9 Intubation Seldinger 3

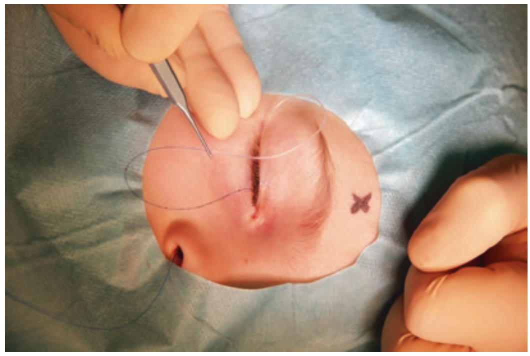

Fig. 1.10 Intubation Seldinger 4

Fig. 1.11 Intubation Seldinger 5

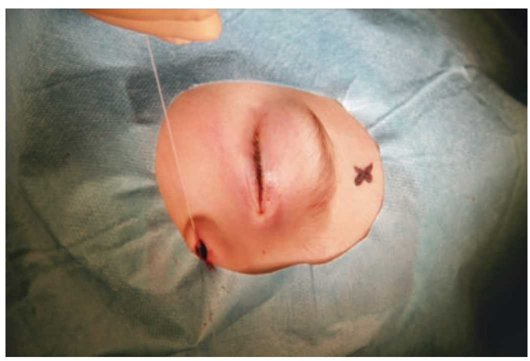

Fig. 1.12 Knot

In case no improvement is observed after conservative treatment, probing can be performed between 3 and 12 months of age depending on the occurrence of mucopurulent infections. Newborns with congenital dacryocele (other terms: amniocele, amniotocele, dacryocystocele, neonatal mucocele,...) usually need therapy within 10 days after diagnosis. If probing alone fails within younger children (up to 10 months) then the additional insertion of a silastic

Fig. 1.13 Cut

Fig. 1.14 Intubation

intubation is recommended during general anesthesia. The success rate of probing alone is reduced with age because only the more severe obstructions remain. Therefore in cases of difficult probing or older children (older than 12 months) the silicone intubation should be performed additionally under general anesthesia.

Instruments for Probing and Intubation

Wilder lacrimal probe
Bangerter Lacrimal Probe Cannula
Juenemann Lacrimal Probe
Strabismus Hook short
5 ml saline filled syringe
4.0 prolene suture
Silicon Tubing diameter 0.6 mm (e.g. Hurricane Medical USA via Fa. Geuder Germany)
Alternative: Ritleng intubation system with an external diameter 0.64 mm (Fa. FCI): central silicone and polypropylene ends, Ritleng introducer

Medication and Dye

Xylometazoline 0.025 % nasal spray
Ophtocaine eye drops
Topical antibiotic eye drops
Fluorescein

Individual Steps

1. **Oxymetazoline hydrochloride 0.025 % tamponade**
2. **Ophtocaine eye drops**
3. **Punctal dilatation**
4. **Syringing**
5. **Probing**
6. **Second syringing**
7. **Intubation**
8. **Postoperative care**

The Surgery Step-by-Step

1. **Oxymetazoline hydrochloride 0.025 % tamponade**

Oxymetazoline hydrochloride 0.025 % should be administered into the nose to reduce the swelling of the nasal mucosa and the risk of bleeding.

2. **Ophtocaine eye drops**

Ophtocaine eye drops are administered into the conjunctival fornix.

3. **Punctal dilatation**

The Wilder Lacrimal Probe Cannula is inserted vertically for 2 mm. Then with the eyelid stretched the dilatator is rotated to the nose. The superior and inferior punctum and the proximal canaliculi are dilated horizontally.

Pitfall

Peripendicular rotating movements should be avoided because of the risk of injuring the canaliculus.

4. **Syringing**

The Bangerter Lacrimal Probe Cannula is inserted into the canaliculus. To identify a canaliculus problem by way of the reflux, irrigation of about 1 ml in the mid-canaliculus should be performed. With deeper irrigation mucus of the sac may regurgitate.

Pitfall
There is a risk of proximal false passage during syringing and probing. To prevent kinking of the canaliculus the lateral eyelid may be stretched gently.

5. **Probing**
The Bangerter Lacrimal Probe Cannula is inserted through the upper canaliculus by placing the upper eyelid on gentle lateral traction. To avoid canaliculus injury the probe is advanced initially for 2 mm vertically and then 8 mm horizontally until the bone at the medial sac wall can be palpated. After minimal withdrawal the Bangerter Lacrimal Probe Cannula is swung gently vertically down the nasolacrimal duct. During this procedure the external part of the probe keeps contact with the child's eyebrow. The probe can be advanced in an inferomedial direction (angle 10–15°). Every surgeon should keep in mind that the length of the nasolacrimal excretory system is 22–24 mm in a 1-year-old child. In case of uncertainty the distance down the duct can be calculated by measuring the external part of the Bangerter Lacrimal Probe Cannula. Passing the obstructed valve a little resistance is felt. Visualization of the probe means an additional risk of additional nasal bleeding so it should be avoided in this situation.

Pitfall
The lateral traction of the eyelid is important to avoid false passageway. If it is impossible to pass the probe down the nasolacrimal duct, every repetition means a higher risk of mucosal damage and via falsa. After the surgery a preseptal orbital cellulitis or dacryocystitis may occur in cases with a false passageway.

6. **Second syringing**
After probing another irrigation follows to confirm that the fluorescein stained saline reaches the nose e.g. by aspirating with a suction tube from the nose or the throat. If no intubation is planned proceed to point 8.

The presence of saline in the nose following a further syringing confirms that patency has been achieved.

7. **Intubation**
A Juenemann Lacrimal Probe is inserted into the lacrimal system via the upper canaliculus. A 6.0 polypropylene suture is introduced via the probe into the nose. The suture is removed from the nose with a small Strabismus Hook. The Strabismus Hook is inserted into the nose and then gently pulled out along the lateral wall. Over this suture a silastic intubation is brought into the system. The lower canaliculus is inserted the same way. Make a knot in the nose. Gently pull the silastic suture out of the nose and make 2–3 knots. When the suture is relaxed, the knot should be free in the nose.

Pitfall
Two to three attempts may be needed to catch the suture with the strabimushook. When this manoeuvre is performed for the first time more attempts may be necessary. Remain calm. The suture will be found. If it cannot be found, intubate the polypropylene suture anew, do not use any power in fishing for the suture. Severe bleeding or a fracture of the turbinate can occur. If you cannot find the suture, try to use a speculum. If one punctum and canaliculi are missing a monocanalicular intubation with a Monoka is indicated. If a dacryocystorhinostomy is required to ensure the child's condition, it is better to wait until the child is aged 2–4 years.

8. **Postoperative care**
Topical antibiotic eye drops are recommended for up to 3 weeks. Usually a systemic antibiotic is only necessary in case of a complication. In case of extreme nasal bleeding the nose should be packed. Bloody tears or discharge from the nose could appear up to 2 weeks after surgery. Patients should avoidblowing their nose or rubbing their eyes.

The silastic tube is left in place for 3 months. To remove the tube mask anesthesia in the surgery room is rarely necessary. Usually topical anesthesia with ophtocaine eye drops is sufficient. Then hold the tube near the superior punctum, cut it near the inferior punctum and retrieve it through the superior canaliculus.

After removal the same eye drops as after surgery are recommended three times a day for 1–3 weeks.

Pitfall

If the intubation is fixed too tightly an incision of the punctum may appear. Tube prolapse may cause an erosion of the cornea or conjunctiva. To avoid this especially with children, it is recommended to put an eye shield on the eye at bedtime. A repositioning during the first month may be achieved by nasal visualization and by pulling on the node. Otherwise the intubation has to be removed.

If the tube rips off during removal tell the patient to blow its nose.

If the procedure has not brought about a resolution of the symptoms, then it can be repeated after about 3 months. After two technically satisfactory procedures the parents are informed that a DCR may be necessary to solve the problem.

Microsurgery of the Lacrimal System by Microendoscopic Techniques

Since the 1990s it was possible to view the lacrimal system directly by microendoscopic transcanalicular techniques [2, 3]. These methods facilitate selection of the appropriate operative procedure for a mechanical obstruction of the lacrimal system, visualization and removal of foreign bodies or dacryoliths and identification and taking a biopsy of tumors. During the endoscopy the pictures are visible on a TV monitor and can be documented. Illumination is delivered by a cold light source connected to the camera by a TV adapter. The working channel allows the introduction of miniaturized tools e.g. a laser fiber, a sling or a drill. The microsurgery makes it possible to perform surgery on the lacrimal system and eliminate obstructions without external scars. The latest endoscopes have a diameter of 0.65–1.15 mm and allow transmission of 3000–10,000 pixels resulting in pictures of an acceptable quality (Figs. 1.15, 1.16 and 1.17).

Dacryoendoscopy should be performed before every lacrimal surgery except in children under 1 year of age and acute infections (e.g. dacryocystitis). Microendoscopic procedures are less suitable in mucoceles, after viral infections and midface fractures. Concerning the indications and contraindications the success rate (decrease of epiphora) of the microsurgery is up to 80 % with a follow-up period of 2 years. This rate is remarkable for a minimally invasive procedure with a low rate of complications.

In the following chapter a typical microdrill endoscopic treatment is described which is the most often used manoeuvre.

Instruments for Microdrillplasty

Wilder Lacrimal Probe
Bangerter Lacrimal Probe Cannula
Juenemann Lacrimal Probe
Strabismus Hook short
5 ml saline filled syringe
4.0 prolene suture
Silicon Tubing diameter 0,6 mm (e.g. Hurricane Medical USA via Fa. Geuder Germany)
Endoscope with 185 mm spiral drill (Polydiagnost, Germany) (Figs. 1.15, 1.16 and 1.17). The handpiece has an one-way PolyShaft® cannula. The most common size for diagnostic treatment is 1.15 mm. The irrigation is connected to a 5 ml Syringe. The modular optic with a 70° wide field is connected to the handpiece over an optic fixation. The most common optic has 6000 pixels.

Medication

Xylometazoline 0.05 %
Topical antibiotic and steroid eye drops
Vasoconstrictive eye drops
Vasoconstrictive nose drops

Individual Steps

1. **Xylometazoline 0.05 % nasal tamponade**
2. **Dilatation of the punctum**
3. **Insertion of the endoscope**
4. **Microdrilldacryoplasty**
5. **Bicanalicular silicon intubation**
6. **Postoperative care**

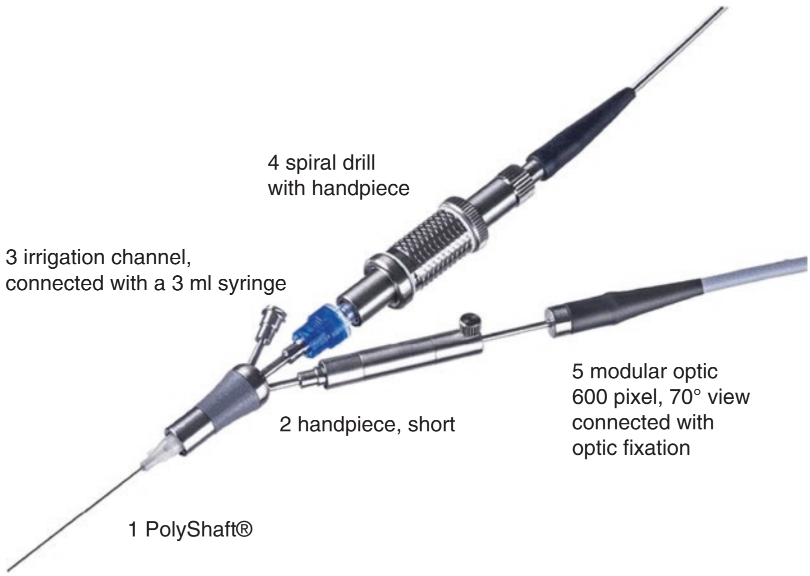

Fig. 1.15 Semirigid modular endoscope with single use tip: Irrigation, microdrill and optic fiber

Fig. 1.16 The endoscope in action

Fig. 1.17 The monitor for the endoscope, the lightsource and the microdrill motor

The Surgery Step-by-Step

1. **Xylometazoline 0.05 % nasal tamponade**

   To reduce mucosa swelling an adstringent solution is administered.

2. **Dilatation of the punctum** (Figs. 1.18 and 1.19)

   The upper punctum has to be dilated before endoscopy. It is easier to introduce the endoscope via the upper punctum.

3. **Insertion of the endoscope**

   Under gently irrigation the endoscope is inserted and pushed forward as far as possible (Figs. 1.20 and 1.21). By retracting the endoscope and simultaneous irrigation the lacrimal passage can be judged. In normal findings, nasal structures are intense red with a smooth surface (Figs. 1.22 and 1.23). The nasolacrimal duct is narrow without any valves and has a reddish structure (Fig. 1.24). Before reaching the lacrimal sac the Krause valve can be seen.

Fig. 1.18 Punctal dilatation

Fig. 1.19 Syringing with Bangerter lacrimal probe

Fig. 1.20 Introducing of the endoscope over the upper punctum

The lacrimal sac has a reddish mucosa (transitional epithelium), a wall with flat valves and a wide lumen (Fig. 1.25). There is a natural border between canaliculi and lacrimal sac, the Rosenmueller valve. The mucosa of the canaliculi is white and smooth with a homogenous structure of the walls, histologically a squamous epithelium (Fig. 1.26). A mucosa touch can cause a small amount of bleeding. In case of an acute inflammation the bleeding is enforced. In chronic inflammation membranes may be identified which may cause a subtotal closure, especially at the pre-exsisting valves. Furthermore submucosal scarring may lead to a shrinking of the lacrimal sac. Sometimes polyps can be found especially after inflammation or intubation (Fig. 1.27). Foreign bodies or remains of earlier intubation are easily identified.

Other endoscopic findings:

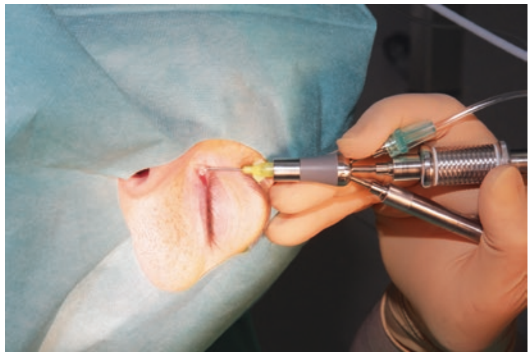

Fig. 1.21 Introducing the endoscope as far as possible

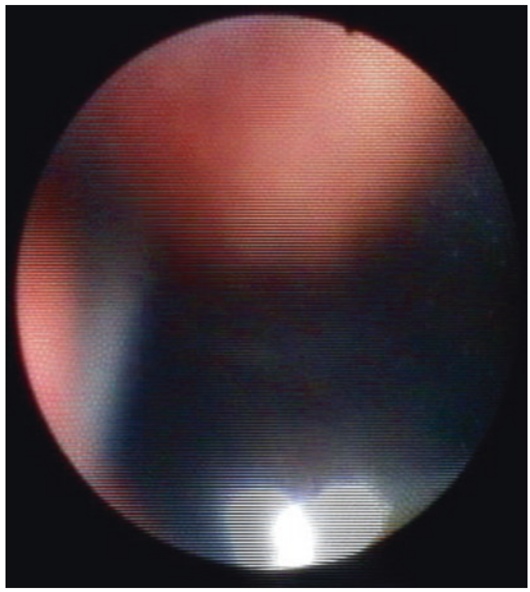

Fig. 1.22 Nose

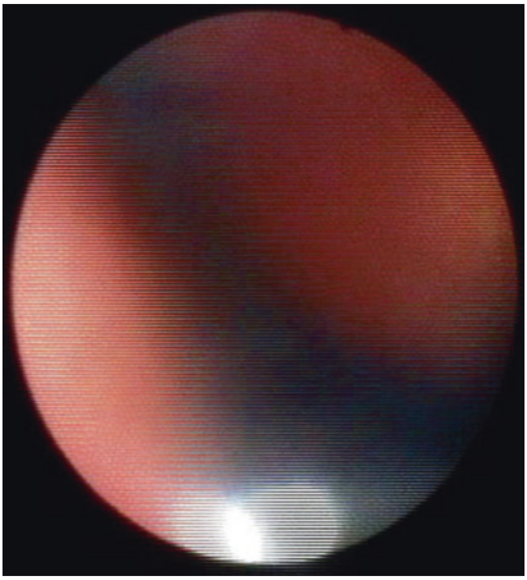

Fig. 1.23 Nose

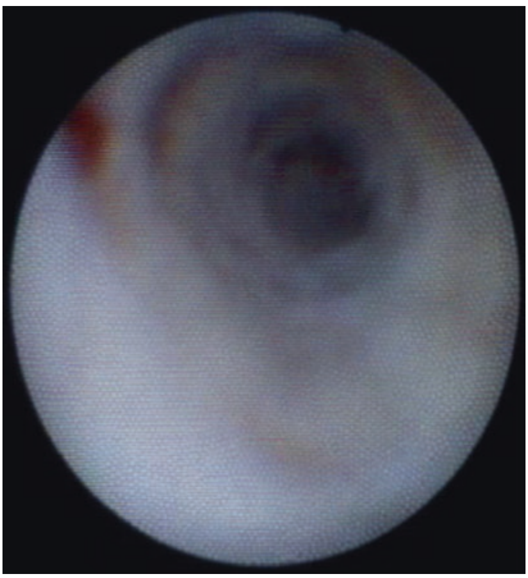

Fig. 1.24 Nasolacrimal duct

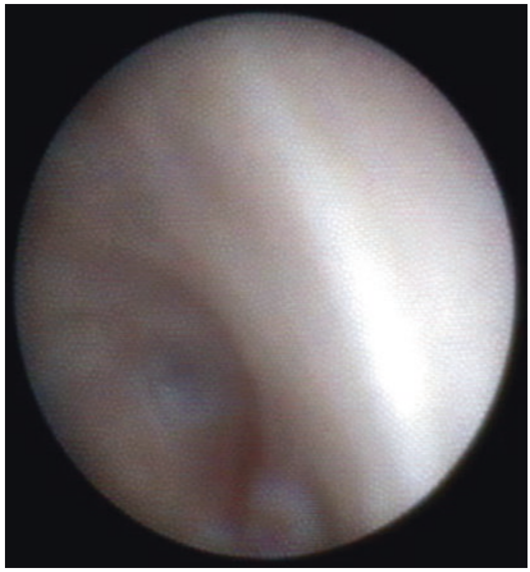

Fig. 1.25 Lacrimal Sac

Fig. 1.26 Canaliculus

Canaliculitis (Fig. 1.28).
Dacryocystitis (Figs. 1.29, 1.30, 1.31, 1.32, 1.33, 1.34 and 1.35).
Submucosal scars in the sac (Figs. 1.36 and 1.37).
Saccus stenosis (Video 1.3: Microdrill dacryoplasty of dacryoliths and scars in the lacrimal sac).
Inflammation (Video 1.4: Polyps and bleeding in the lacrimal sac due to chronic dacryocystitis).

Pitfalls

Because of a via falsa the eyelid may be swollen and blue after surgery (2 %).

Fig. 1.27 Polyp in Canaliculus

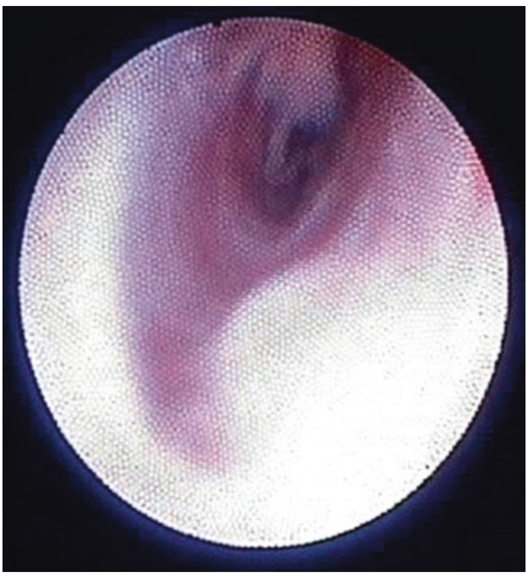

Fig. 1.28 Canaliculitis

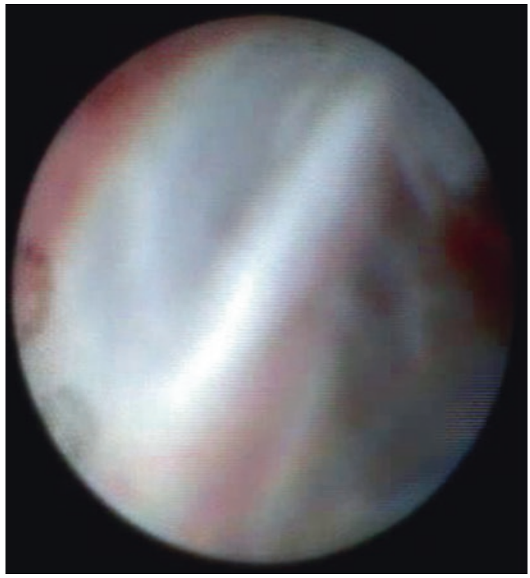

Fig. 1.29 Dacryocystitis 1

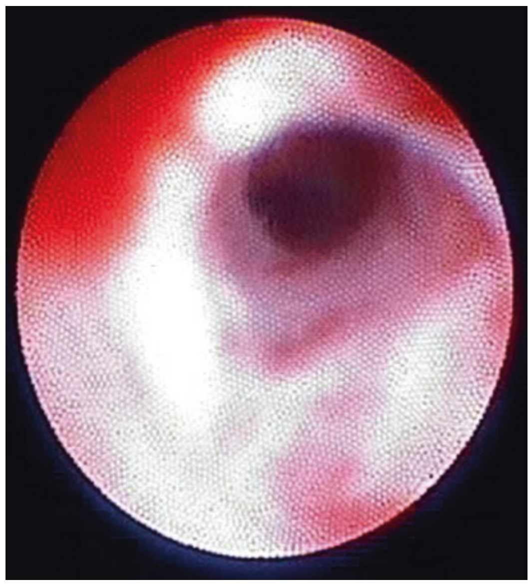

Fig. 1.30 Dacryocystitis 2

4. Microdrill Dacryoplasty

Video 1.1: Microdrill dacryoplasty of a button hole stenosis of the lacrimal sac

Video 1.2: Microdrill dacryoplasty of a subtotal stenosis of the nasolacrimal duct.

If a relative stenosis is seen during the diagnostic endoscopy, a microdrill dacryoplasty is performed under irrigation (Figs. 1.36, 1.37 and 1.38). A miniaturized drill (diameter of 0.38 mm, 50 Hz) is inserted into the endoscope. Most stenoses are so-called “button-hole” stenoses at the exit of the lacrimal sac (Fig. 1.38). In these cases the microdrill is especially effective but also strong enough to perform holes

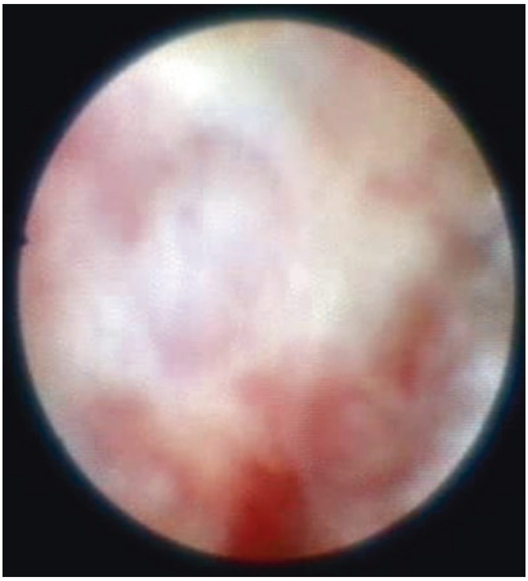

Fig. 1.31 Dacryocystitis 3

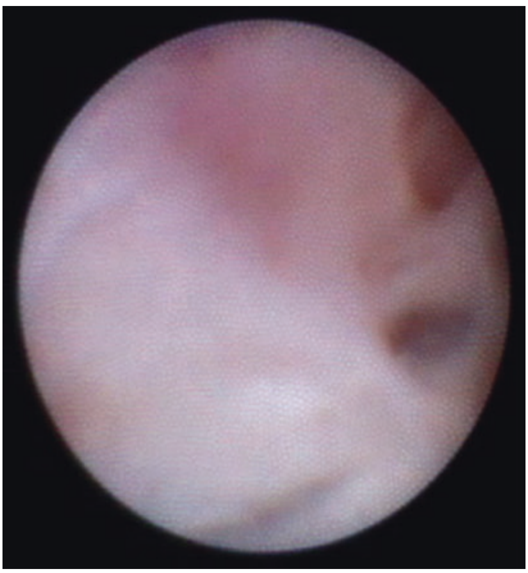

Fig. 1.32 Submucosal scars (sac)

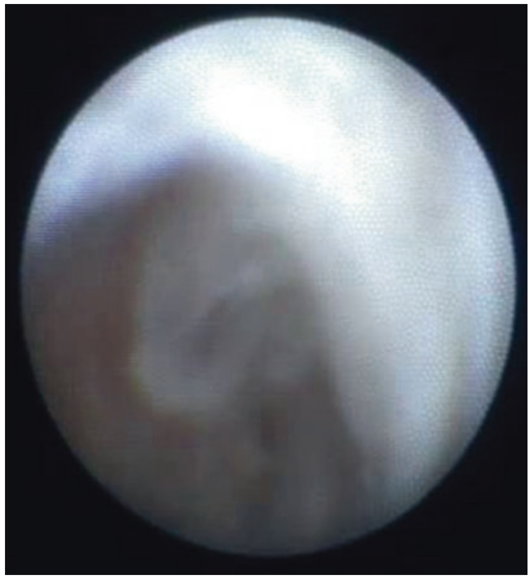

Fig. 1.33 Scars after Dacryocystitis (sac)

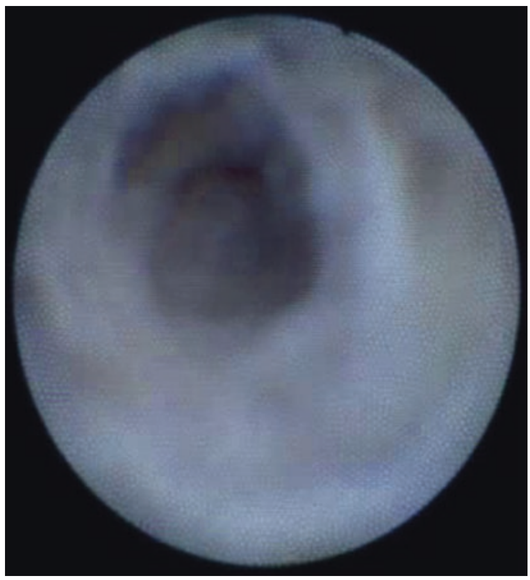

Fig. 1.34 Relative stenosis (sac)

in membranes if a laser device is not available (Fig. 1.39). The microdrill is brought up to the location of the stenosis and pushed forward in front of the optic under endoscopic control and continuous irrigation. The microdrill performs a kind of mucosa curettage and enlarges the tight lumen. The opening may be confirmed by the endoscope. Irrigation without any resistance is now possible.

5. **Bicanalicular silicon intubation**

To prevent adhesions of the mucosa a bicanalicular intubation is inserted using a silicon tube (diameter 0.64 mm). The tubes usually stay in

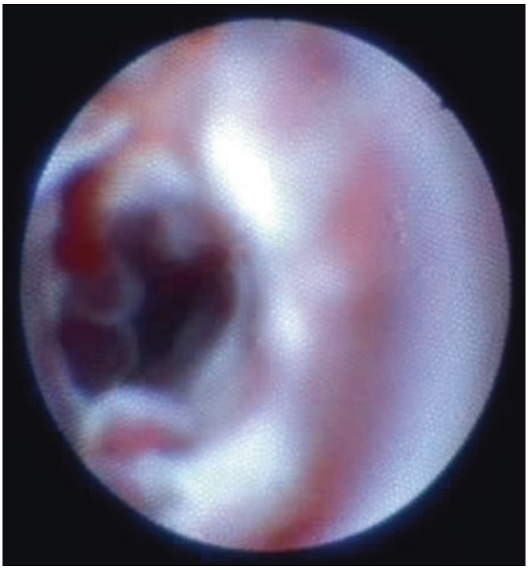

Fig. 1.35 Bloody inflammation (sac)

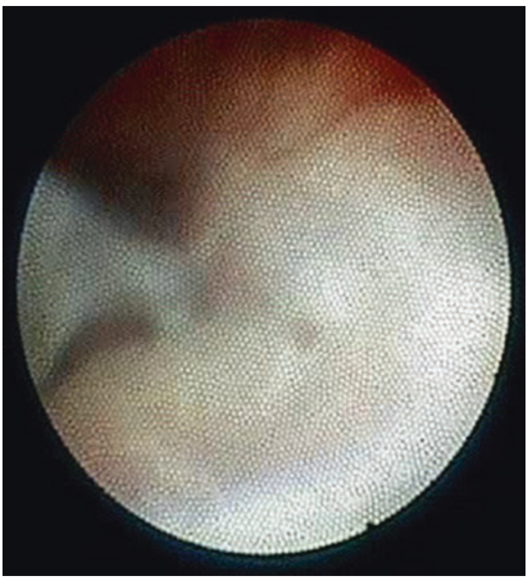

Fig. 1.36 Microdrill

Fig. 1.37 Microdrill

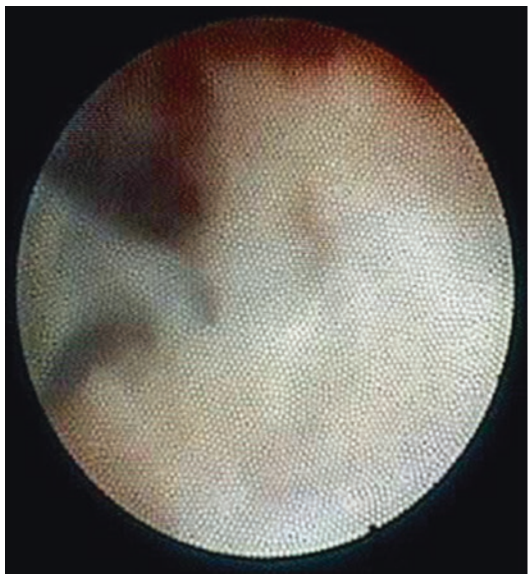

Fig. 1.38 Microdrill

place for 3 months and are removed transcanalicularly (for details see above under section "Congenital Stenosis").

Pitfalls
Alternatively a Monoka intubation, a monocanalicular stent, can be used. In approximately 5 % of patients a spontaneous dislocation of the silicon intubation or slitting of the puncta may occur.

6. Postoperative care

Eye drops containing steroids and antibiotics and vasoconstrictive eye drops are recommended for 3 weeks and vasoconstrictive nose drops for 1 week. In case of dacryoliths or infection with

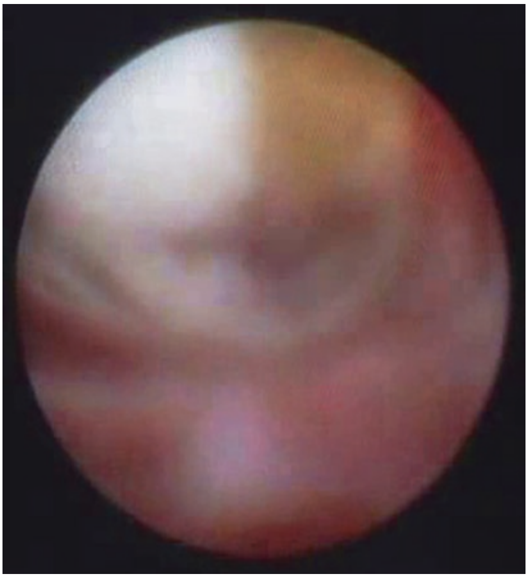

Fig. 1.39 Laserdacryoplasty

actinomyces or nocardia eye drops or eye ointment with erythromycin or tetracycline are administered for 6 weeks. Additionally erythromycin is recommended orally for 3 weeks. In case of extreme nasal bleeding the nose should be packed. Bloody tears or discharge from the nose could appear up to 2 weeks after surgery. Patients should avoid blowing their nose or rubbing their eyes.

The silastic tube is left in place for 3 months. Usually topical anesthesia with ophtocaine eye drops is sufficient for removal. Then hold the tube near the superior punctum, cut it near the inferior punctum and retrieve it through the superior canaliculus. After removal of the silicon intubation bleeding at the nose may occur (2 %). The same eye drops as after surgery are recommended three times a day for 1–3 weeks.

External Dacryocystorhinostomy (DCR, Toti)

A DCR can be performed for obstructions within the lacrimal sac or the nasolacrimal duct [1, 5]. An irrigation helps to differentiate between the different locations of the obstruction (see superior). Typical indications for a DCR are chronic dacryocystitis, dacryocele (mucocele), mid-face fractures, dacryolithiasis and persisting epiphora after minimal invasive lacrimal surgery of an obstruction in the lacrimal sac or the nasolacrimal duct. An operation in patients with acute dacryocystitis or under suspicion of a lacrimal sac tumor should be avoided. The goal of the surgery is that the common canaliculus drain tears directly into the nose. The success rate of this kind of surgery is usually over 90 %, therefore it is called the “gold standard”. The endonasal DCR avoids an external scar and allows correction of nasal pathologies e.g. chronic sinusitis, septal deviation, which may be a causative factor of epiphora, too. The results are almost as good as after the external DCR. Therefore the nose should be looked up with a nasal speculum to exclude nasal abnormalities.

The surgery is usually performed under general anesthesia. If the surgery has to be performed in an acute situation perioperatively cefuroxime can be administered intravenously.

Instruments for DCR (Fig. 1.40)
Center pointed scalpel
Suction with bottle
Bipolar cautery
Dressing forceps 1 × 2 teeth
Coagulation device
Strabismus scissor
Raspatory
Elevatory
Bone nibbling rongeur (small, medium, big)
Needle holder
Nasal forceps
Dressing forceps serrated
Wilder Lacrimal Probe
Bangerter Lacrimal Probe Cannula
Juenemann Lacrimal Probe
Strabismus Hook short
Retractor
5 ml saline filled syringe
4.0 prolene suture
Curved knife
Silicon Tubing diameter 0,6 mm (e.g. Hurricane Medical USA via Fa. Geuder Germany)

Fig. 1.40 Instruments

5.0 Vicryl suture
Nasal packing

Medication
Xylometazoline 0.05 %
Naphazoline nasal spray
Adrenaline (1:100.000)
Scandicaine and epinephrine
Antibiotic eye drops

Individual Steps
1. **Check indication**
2. **Local infiltration with scandicaine and adrenaline**
3. **Nasal packing with Xylometazoline 0.05 % and adrenaline cottonoids**
4. **Skin incision**
5. **Dissection of lateral nasal wall**
6. **Subperiosteal dissection**
7. **Creating osteum with elevatory and bone nibbling rongeur**
8. **Opening nasal mucosa**
9. **Dilation of the punctum and insertion of a probe/bicanalicular intubation**
10. **Incision of the lacrimal sac**
11. **Passing tubes**
12. **Suturing the flaps**
13. **Closure**
14. **Postoperative care**

Surgery Step-by-Step
1. Check indication:

(a) Dilatation with Wilder lacrimal probe (Fig. 1.41).

(b) Irrigation with Bangerter lacrimal probe (Fig. 1.42).

Fig. 1.41 Dilatation with Wilder lacrimal probe

Fig. 1.42 Syringing with Bangerter lacrimal probe

To achieve a vasoconstriction and decongestant of the mucosa in the nasal fossa/middle meatus on the lateral wall above the inferior turbinate cottonoids with Oxymetazoline are applied 10–15 minutes prior to surgery. Or two puffs of naphazoline nasal spray aresprayed into the nostril which will undergo surgery.

2. Local infiltration with scandicaine and adrenaline (Fig. 1.44)

To reduce bleeding an infiltration of the skin above the lacrimal sac is performed with local anesthesia (e.g. scandicaine) and epinephrine (1:100,000).

3. Nasal packing with Xylometazoline 0.05 % and adrenaline cottonoids (Fig. 1.45)**.**

4. Skin incision (Figs. 1.43, 1.44, 1.45 and 1.46)

After marking, a vertical incision is placed medial to the angular vein and on the posterior edge of the crista maxillaris (maxillary line) and starts at the level of the medial canthus with a distance of 10–12 mm to medial canthus. The size of the skin incision should be as small as

Fig. 1.43 Marking cut

Fig. 1.44 Local infiltration with Adrenaline and Scandicaine

Fig. 1.45 Nose pack

possible – about 8–10 mm. Bipolar diathermy is used to close off the angularis vessels if they are in the way. To open the wound a retractor can be used.

Pitfall

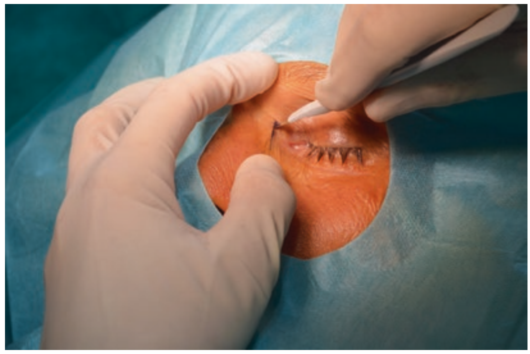

Fig. 1.46 Cut

Making the incision too medial the angularis vessels may be cut. Therefore the incision goes through the skin only and then the vessels can be identified. If a larger incision is needed, try to perform a Z-plasty incision.

5. **Dissection of lateral nasal wall** (Fig. 1.47a, b)

The orbital and palpebral fibres of the Musculus orbicularis have to be separated to identify the periosteum over the orbital rim. The periosteum is incised and separated medially by a sharp raspatory for about 5-7 mm. If the periosteum is overhanging then excise it or secure it with tractions sutures. An elaborately cautery should follow, but avoid touching the angularis vessels.

6. **Subperiosteal dissection**

A subperiosteal dissection to anterior lacrimal crest is performed. The lacrimal sac has a layer of periosteum overlying it. Then the lacrimal sac is mobilized laterally, so that the frontal process of the maxilla and the lacrimal bone can be identified. The sac overlying part of the anterior limb of the medial canthal tendon could be cut, but the surgeon should be aware of the anterior limb as a landmark to the most inferior projection of the cribriform plate of the ethmoid bone.

7. **Creating osteum with elevatory and bone nibbling rongeur** (Figs. 1.48 and 1.49)

The bone of the lacrimal fossa consists of the frontal process of the maxilla and the lacrimal bone posteriorly. It is important to keep the nasal mucosa intact. Due to this the mucosa should be gently pushed posteriorly. First opening can be performed with anelevatory. Bone nibbling rongeurin increasing sizes are used to remove the

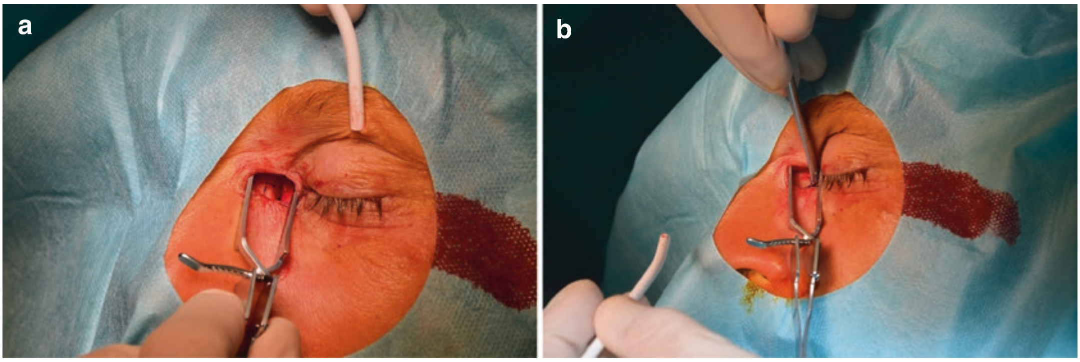

Fig. 1.47 (**a**) Marking the Anastomosis. (**b**) Raspatory

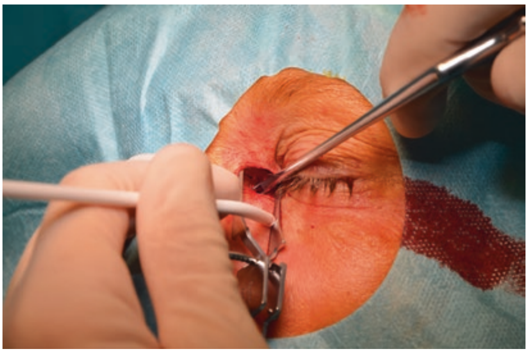

Fig. 1.48 Bone Rongeur

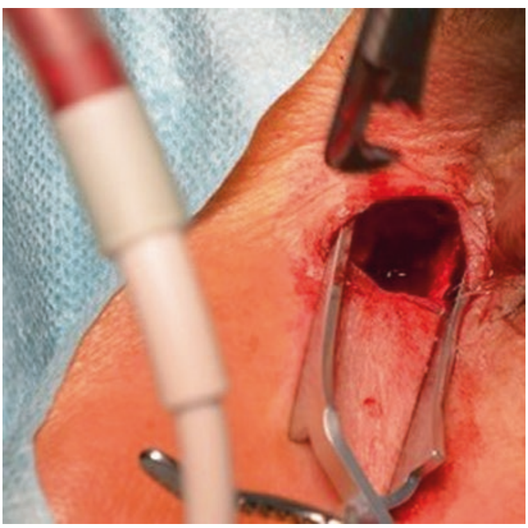

Fig. 1.49 Open osseal anastomosis

bone anteriorly and inferiorly. The osteum should be at least 12 mm in diameter. The sac measures 12 mm in height and 4–8 mm in an anterior posterior measurement and almost the same in width.

Fig. 1.50 Mucosa anastomosis

Pitfall
Cerebrospinal fluid (CSF) leak can be a complication after bone removal higher than the anterior limb of the medial canthal tendon or by rotational forces from the bone punch. It is important not to remove any of the bone of the nasolacrimal canal laterally because of the origin of the inferior oblique muscle. We recommend not to enlarge the osteum superiorly in a posterior direction because injury of the anterior ethmoidal artery can cause a very serious bleeding.

If it is impossible to make an opening with a rongeur then additionally a bone trephine, drill or hammer and chisel may be used.

8. Opening nasal mucosa (Figs. 1.50 and 1.51)

Using a scalpel or blunt curved scissors the nasal mucosa is incised and a flap is created. Perhaps small relieving incisions are necessary to mobilize the flap anteriorly. Put at one corner of the nasal flap a Vicryl 5.0 suture for performing the anastomosis later.

Pitfall

Patients may develop frontal sinusitis after DCR if the nasalfrontal duct is closed by scarring. The opening lies about 4 mm posterior to where the standard bony osteum is performed. As a result avoid extending too far posteriorly.

9. **Dilation of the punctum and insertion of a probe/bicanalicular intubation** (Fig. 1.52a, b)

Usually the lower punctum is dilated and a probe is inserted into the sac. The incision of the lacrimal sac is easier to perform with a probe inside. There are two layers overlying the probe: the periosteum and the sac mucosa.

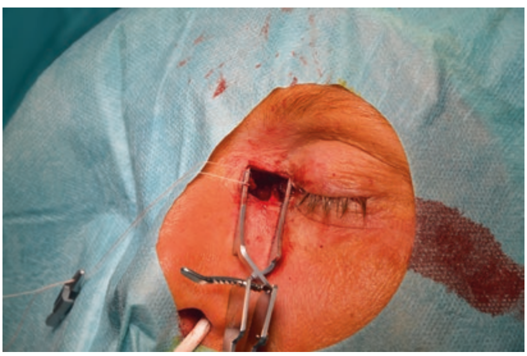

Fig. 1.51 Mucosa anastomosis

10. **Incision of the lacrimal sac** (Fig. 1.53)**.**

Using a curved knife the lacrimal sac is opened about 1–2 mm anterior to the most medial tenting of the sac by the probe. In case of problems in finding the right area for incision an injection with e.g. fluorescein stained sodium hyaluronate can help. Opening the sac the healon is deliberated. The incision has to be enlarged in a vertical fashion. Only an anterior flap is created with good results. To allow the flap lying flat relieving incisions into the lacrimal sac should be made. By inserting a probe through the upper canaliculus one makes sure to have an intact upper system and a common internal punctum. A 5 mm large bone free area is needed around the internal punctum. If there is mucus or pus in the sac, then a culture should be taken. One should ensure that there is no tumor or stone in the lacrimal system. Otherwise a biopsy is performed.

Pitfall

There could be an exposure of the orbital fat, if one has incised too far laterally into the sac. The fat may be shrinked using bipolar cautery. In about 14 % ethmoidal cells are between the sac and the nasal mucosa. They should be removed using artery forceps. In case of significant bleeding cautery and reconstituted collagen can be used.

11. **Passing tubes**

A silastic or silicon tube with an outer diameter of 0.6 mm is placed in the lacrimal system. Passthe silicon tubes through the osteum into the

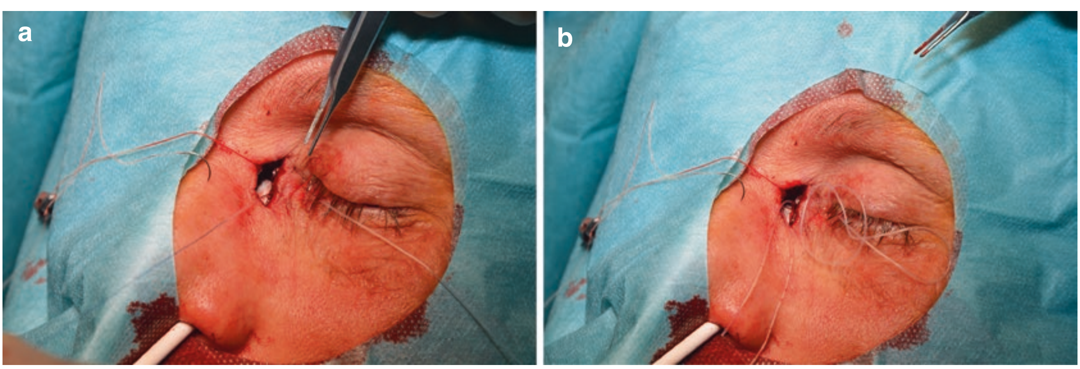

Fig. 1.52 (**a**) Intubation: (**b**) Intubation

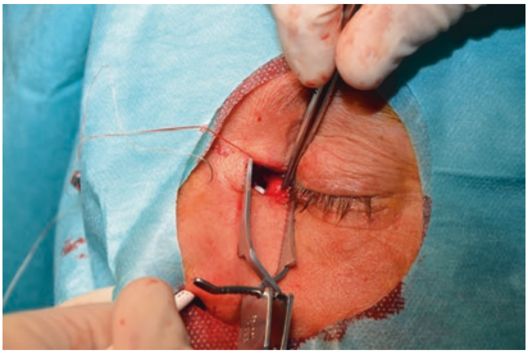

Fig. 1.53 Preparation sac

Fig. 1.54 Anastomosis

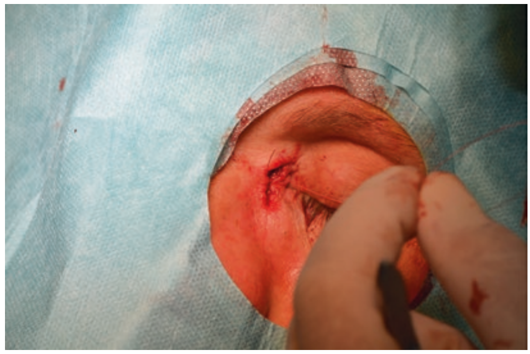

Fig. 1.55 Suture

Fig. 1.56 Suture

nose. The eyelids are held apart so that the tube is not stretching the canaliculus. Though others emphasize that an intubation is only necessary in tiny sac with only small flaps and in problems with suturing the flaps the insertion of stents is our standard procedure.

Pitfall

If the tubes are fixed too tight they may migrate along the canaliculi and form a slit in the punctum or the canaliculus. The tubes themselves can incite significant inflammation, granuloma or can induce failure.

12. Suturing the flaps (Fig. 1.54)

The next step is suturing the lacrimal sac to nasal mucosa: We prefer to suture only the anterior flap. A 5.0 vicryl suture with a long curved needle is used from sac towards the nasal mucosa. One suture at the upper and one suture at the lower corner of the nasal flap is performed.

Pitfall

If you perform an anterior and a posterior flap one suture is placed in the middle of the flaps, one as far inferiorly as possible and one as high up as possible. It is important that the posterior flaps lie flatly when sutured otherwise they should be excised. Not suturing any flap the tube is important to make sure that the anastomosis stays open.

13. Closure (Figs. 1.55 and 1.56)

The medial canthal tendon cannot be reattached in the right place because the bone is removed. As a result it should not be reattached.

The musculus orbicularis can be sutured by a 5.0 Nylon suture. The skin is closed with two Vicryl 5.0 and three 6.0 prolene sutures that are removed after 1 week.

Pitfall

Fixing the medial canthal tendon in a false place could cause postoperative tearing.

Pitfall

Due to collection of mucus in the remnant sac epiphora can start again (lacrimal sump syndrome). In this case soft external massage should be recommended.

Persistent bleeding when the patient leaves the operating room.

14. Postoperative care

The patient stays for at least two nights because of the potential for immediate postoperative bleeding but usually bleeding of the nose can occur during the first 2 weeks following surgery. Patients are not allowed to blow their nose for 10 days. Antibiotic eye drops are prescribed at least for 3 weeks. Usually a systemic antibiotic is only necessary in case of an inflammation. The sutures are removed 1 week postoperatively.

In case of bleeding measures at home are pinching the nose, ice packs and rest otherwise they have to come into the hospital for packing the nose. Patients are advised to rinse their nose with saline once a day from the second week on. After removal of the sutures they are asked to perform gentle massage in the inner angle of the eye. The scar on the side of the nose tends to fade over a period of 3 months. Eyeglasses on top of the scar may cause some kind of discomfort. The silicon tubes stay in place for at least 3 weeks and usually for 3 months. Epiphora can continue until the tube is taken out. Sometimes the knot of the tubes falls out of the nose. Patients are recommended to put this back into the nose. The intubation should be left in place for 6 weeks after surgery. Usually topical anesthesia with ophtocaine eye drops is sufficient for removal. Then hold the tube near the superior punctum, cut it near the inferior punctum and retrieve it through the superior canaliculus. The same eye drops as after surgery are recommended three times a day for 1–3 weeks. After removal of the tubes the patients may be able to blow some air through the puncta.

Pitfall

The inner canthal loop of the silicon tube may come out into the palpebral aperture early after surgery. The patient is asked to blow its nose to make the nasal end visible. If this procedure fails the patient is sent away to an ear, nose and throat specialist to look for the knot and replace the intubation.

Material and Companies Address

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Part II

Cornea: SMILE

SMILE stands for Small Incision Lenticule Extraction and is the most recent revolution in corneal refractive surgery. During the SMILE procedure the femto laser cuts a lenticule inside the corneal stroma which is removed by a side incision. A corneal flap with all negative side effects is no longer necessary. This technique was developed by the company Zeiss together with **Prof Sekundo** (Marburg, Germany), **Prof Blum** (Erfurt, Germany) and **Dr. Prof Meyer** (Cologne, Germany). The authors describe the development of this new technique and demonstrate the surgery step-by-step.

Historical Overview of the Clinical Development of "All in One" Femtosecond Refractive Laser Surgery

2

Marcus Blum and Walter Sekundo

Corneal resectional refractive procedures for the correction of myopia were pioneered by Barraquer and Ruiz in the 60s and 70s [1]. They removed a layer of intrastromal tissue utilizing a microkeratome and called this procedure "in situ keratomileusis". However, the results of the procedure performed with mechanical devices were not entirely satisfactory [2, 3].

Few years later, lasers entered the field of refractive surgery, and in 1989, Stern reported the use of lasers to ablate the cornea [4]. For many years a number of sophisticated excimer laser systems have been available to perform laser in situ keratomileusis (LASIK) with a very high accuracy. The microkeratome was used to create the corneal flap. The first use of a laser instead of a microkeratome to achieve an intrastromal lenticule was described in 1996 [5]. Using a picosecond laser an intrastromal lenticule was generated and was then removed manually after lifting the flap. In two highly myopic eyes a fair amount of manual dissection was required resulting in an irregular surface [6]. Its use was therefore limited to animal studies [7, 8]. It is noteworthy that in the early 90s of the last century, the idea of full femtosecond laser system based refractive correction had already been born.

First clinical results with a laser induced extraction of a refractive lenticule were reported with five blind or amblyopic eyes in 2003 [9]. Unfortunately, these first studies lack a sufficient number of eyes and a detailed analysis of the achieved refractive data. The studies have not been continued with a representative study cohort.

For several years femtosecond laser technology was used solely to the creation of flaps and thus to take the place of the microkeratome. The actual refractive procedure was still performed with the 193 nm excimer laser [10]. With regard to the quality of the surgical outcome, femtosecond laser microkeratomes have advantages over mechanical devices [11–13].

After a series of experiments in the laboratory and in animal models as well as after some initial treatments of blind eyes a prototype femtosecond laser system – now known as VisuMax® (Carl Zeiss Meditec, Jena, Germany) came on the market. To prove the function of the fs-laser a study combining the fs-flap cut with the MEL 80 Excimer laser was performed first [14]. During the same time a series of studies (unpublished data) with animals and blind eyes underwent a new refractive procedure which no longer required an excimer laser (Fig. 2.1a–e). The procedure was called Femtosecond Lenticule Extraction (FLEx) in order to distinguish

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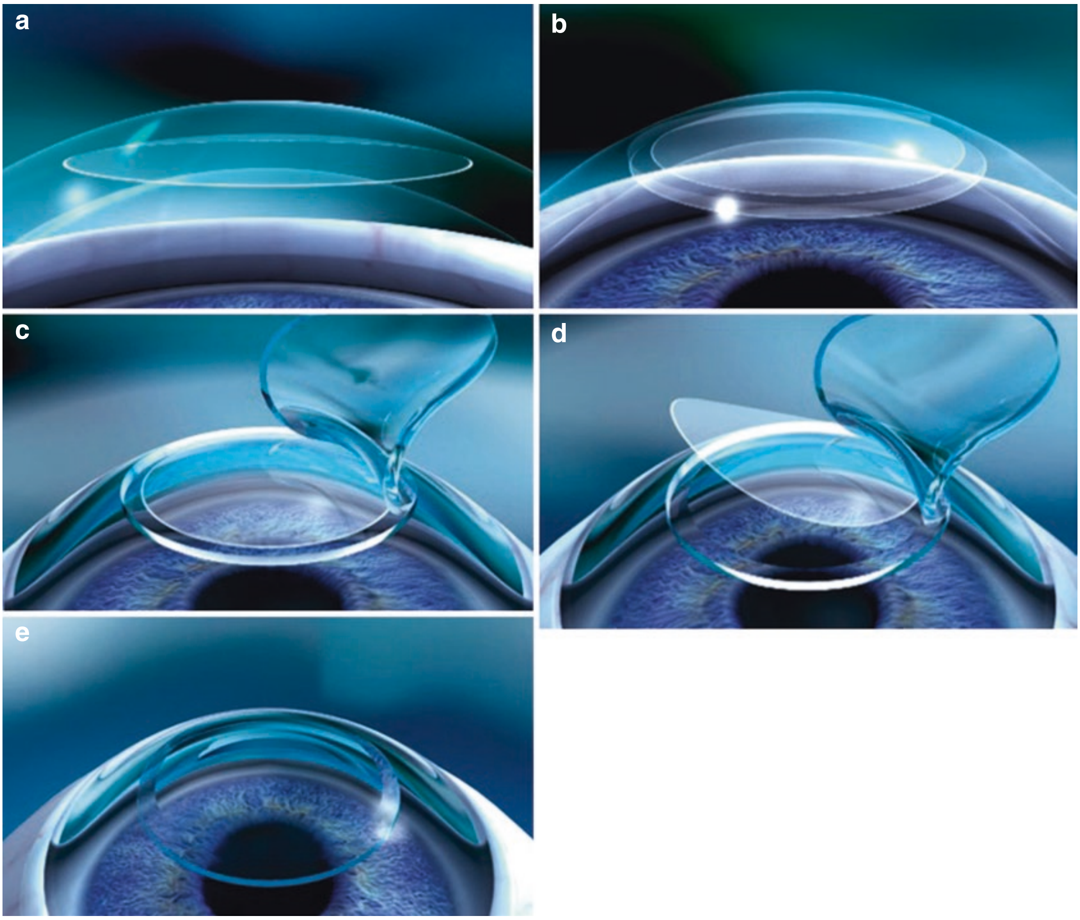

Fig. 2.1 (**a**–**e**) A schematic drawing of the FLEx-procedure. The VisuMax® femtosecond laser system cuts the back of the refractive lenticule (**a**) followed by its front surface incision (**b**) followed by a vertical incision leaving an arc of 50° untouched (hinge) (**c**). The final step is performed manually, with the flap being lifted with the spatula and the lenticule removed manually using forceps (**d**). The flap is then repositioned (**e**)

it from other known refractive procedures. When performing FLEx, both the flap and the refractive lenticule are cut in a "one step"-procedure by the femtosecond laser. The first ten cases were presented by Sekundo at the 2006 annual meeting of the American Academy of Ophthalmology (AAO) and published in 2008 [15].

This very first report was followed by a cohort of fully seeing eyes treated for myopia. A total of 108 eyes had been recruited and treated from 56 patients with spherical myopia between −2 and −8.5 D and myopic astigmatism up to −6 D cyl. The eyes were followed up for 6 months and - on a voluntary basis - for 12 months [16, 17]. Meanwhile 5 year results were published [18].

The consequent improvement of the FLEx technique which requires a flap was the development of a flapless technique. A flapless technique would enable a mechanic stable cornea. FLEx turned out to be just one step towards developing a new technique without lifting the flap - made possible by continuous improvements in surgical performance, energy settings, and laser technology [19–21]. This procedure was named Small Incision Lenticule Extraction (SMILE): by passing a dissector through a small 2–3 mm incision the anterior and posterior lenticular interfaces are separated and the lenticule is than removed through the incision (Fig. 2.2a–c). This eliminates the need to create a flap and the cornea

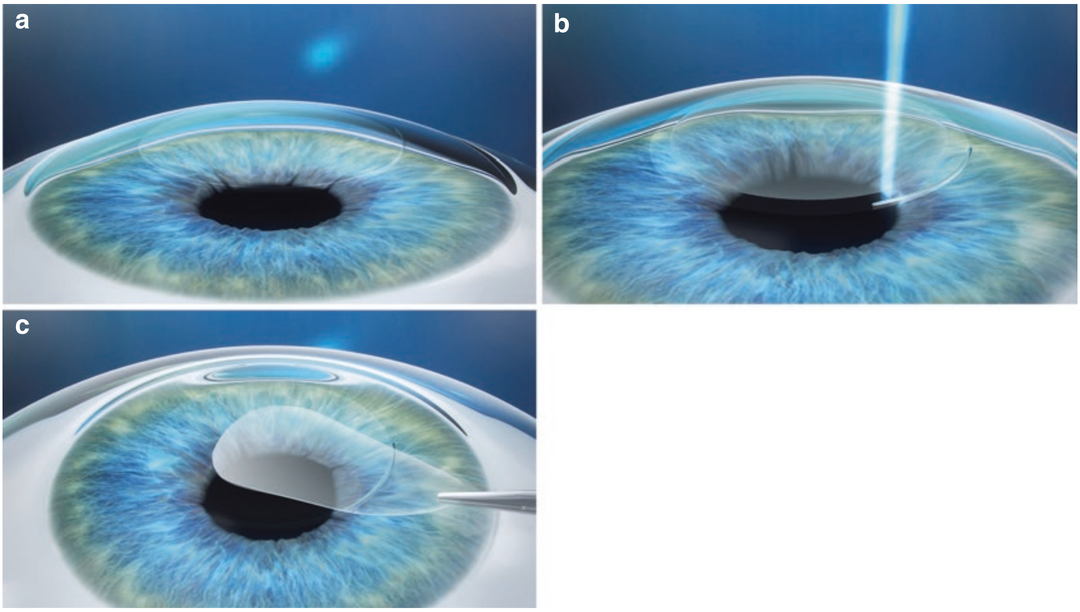

Fig. 2.2 (**a**–**c**) A schematic drawing of the SMILE procedure. The fs-Laser cuts the posterior and anterior surface of the lenticule in the corneal stroma (**a**), followed by a small incision of the epithelium (**b**). The lenticule is removed through this small incision (**c**) by the use of forceps without lifting a flap. The tissue above the lenticule is therefore referred to as the "cap"

above the upper interface of the lenticule is now referred to as the cap.

First results of this minimally invasive procedure have been published by our group in 2011 [22]. The potential advantages of this refined technique have encouraged a number of international groups to employ the newly developed 500 kHz femto second laser for refractive lenticule extraction [23–25]. In order to avoid confusion, the "all in one" femtosecond laser alone procedures have been patented by the manufacturer of the VisuMax laser as refractive lenticule extraction (ReLEx®) with two possible techniques: the ReLEx® flex and ReLEx® smile. Meanwhile the small incision lenticule extraction (SMILE) became a well-known term, which in our opinion will remain irrespective of the manufacturer of the laser.

The rapid increase in available clinical data has led to an ongoing discussion about the advantages and disadvantages of ReLEx femtosecond lenticule extraction [26–36]. We will now describe the technique in its different stages and its current clinical applications.

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3 SMILE: Small Incision Lenticule Extraction – A Basic Guideline

Bertram Meyer

Flapless and all femto – SMILE is the first minimal invasive procedure in laser refractive surgery.

The significant difference between SMILE and traditional Femto-Lasik is that with the femtosecond laser an intrastromal lenticule is created which is removed manually throughout a small incision in a second step. That way refractive correction is not achieved by laser ablation but by tissue removal. The predictability of the refractive outcomes depends on the accuracy of the femtosecond laser only.

At the moment the VISUMAX femtosecond laser from ZEISS (Fig. 3.1) is the only device worldwide which enables to perform SMILE.

Practical Advices

Treatment range for SMILE:

Currently the SMILE treatment range is for pure myopia from −0.50 D to −10.0 D (SEQ) and for myopic astigmatism up to −5.0 D. Hyperopic SMILE treatments are not commercially available yet (Fig. 3.2).

General preparation of the patient:

- low-dose tranquilizer 1 h before surgery
- local anesthesia with eye drops
- local routine periocular disinfection
- covering of eye lashes with drape

Samples of surgical instruments for SMILE from GENDER and MALOSA are shown in Figs. 3.21–3.24.

- aspirating lid speculum (e.g. Knorz)
- curved dissector (e.g. Chansue, Blum, Guell, Pfaeffl and others)
- colibri style forceps for stabilizing the globe (if necessary)
- crocodile-style micro-forceps for removal of the lenticule (e.g.Shah)

SMILE Surgery Step-by-Step (Videos 3.1 and 3.2)

A curved contact glass (size S or M; mostly S depending on the corneal size) is fixed at the laser opening and automatically calibrated. Next steps: Routine local disinfection periocular, application of local anesthetic drops, coverage of eyelashes with sterile drape, placement of eyelid speculum, flushing with BSS and aspiration of pooled fluids

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-319-47226-3_3) contains supplementary material, which is available to authorized users.

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Fig. 3.1 VISUMAX femtosecond laser

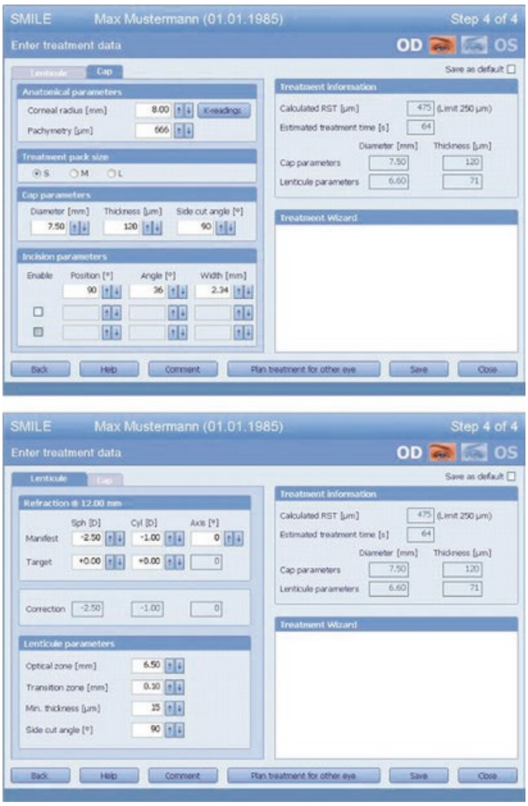

Fig. 3.2 Treatment data display

and secrets out of the fornix for a clean corneal surface. Then the patient's eye is moved towards to the contact glass by lifting the bed, and the contact glass is gently docked on the corneal surface (Fig. 3.3). Be sure that the contact glass has free

Fig. 3.3 Docking procedure

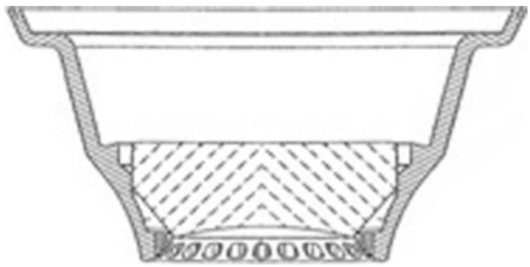

Fig. 3.4 Curved contact glass

access to the cornea and that there is no touch with a prominent nose, the speculum or orbital bones. If there is need you can move the head rest of the bed up and down, elevate the chin or turn the face in the opposite direction. Watch out that the patient's head is lying straight and comfortable.

The big advantage of the curved contact glass (Fig. 3.4) is that there is no strong applanation but only soft acurvation of the corneal surface. Thus we have only a low increase of the intraocular pressure and a minimized tissue distortion during the whole suction procedure. Moreover, the advantage is that with this soft docking the patient fixation is maintained during the whole laser procedure but with the risk of suction loss if the contact glass is not docked properly.

During the docking procedure the patient has to cooperate by fixating a green blinking light (Fig. 3.5); this guarantees a perfect centration of

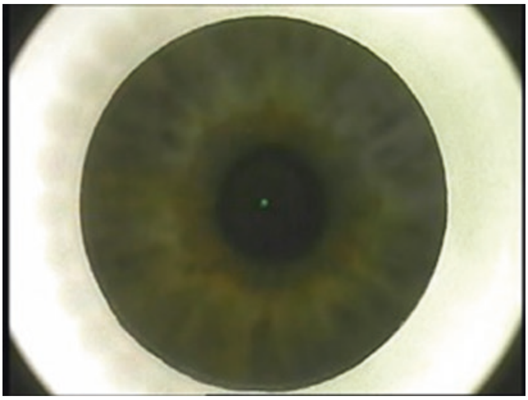

Fig. 3.5 Centration onto optical axis

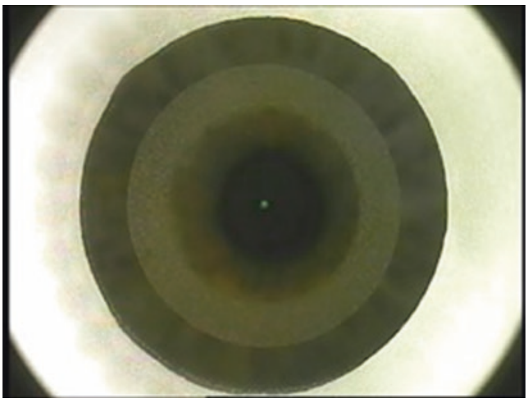

Fig. 3.6 Preparation of the refractive part of the lenticule

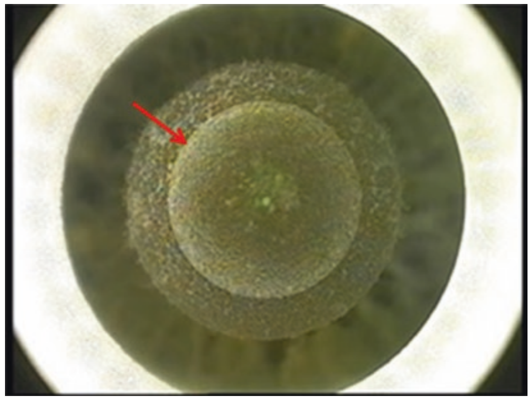

Fig. 3.7 Preparation of the frontside of the lenticule

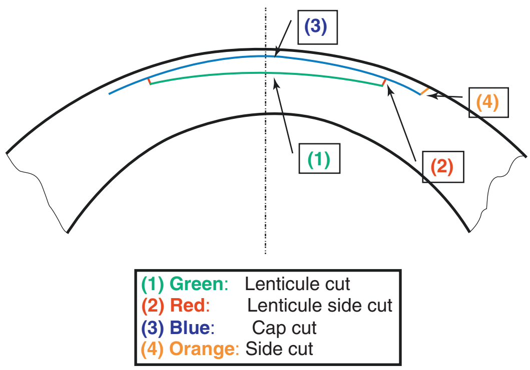

Fig. 3.8 SMILE: Drawing of corneal cut

the contact glass and consequently an exact centration of the lenticule onto the visual axis. After more than 90 % of contact between cornea and contact glass you press the suction button; be sure that there is hardly any fluid and Meibom's secret between cornea and contact glass.

After the VISUMAX confirms the end of a correct suction procedure with the word "ready" you press the foot switch and the laser application is starting. First the laser prepares the refractive part of the lenticule (= backside of the lenticule) with a spiral starting from outside (Fig. 3.6) followed by the lenticule's side cut. Typically the optical zone of the lenticule is between 6 and 7 mm (standard is 6.5 mm).

Second, the VISUMAX is preparing the front side of the lenticule (Fig. 3.7) which is a plane-parallel spiral cut starting from inside (Fig. 3.7). The laser procedure is finished by the incision preparation with a size of 2–4 mm (free choice). Normally the cap diameter is chosen between 7.3 and 7.8 mm (Figs. 3.8 and 3.9). When the procedure is finished suction is released automatically. The whole suction time including the laser application takes not more than 30–35 seconds depending on the diameter.

Be sure that you have the correct spot and track distance and an optimized spot energy; this guarantees a minimum of opaque bubble layer (OBL) and consequently an easy mechanical dissection of the residual micro-bridges of the lenticule. As the energy levels are specific and different for each device your application specialist from ZEISS will instruct you at the beginning (standard energy levels are between 150 and 170 nJ per spot depending on each single device).

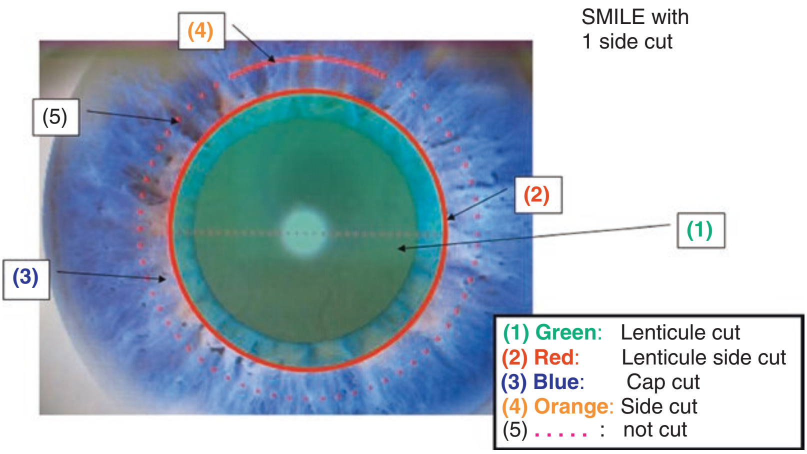

Fig. 3.9 SMILE: Drawing of corneal cut

For an easy lenticule dissection you first open the incision with a Sinskey hook or similar. Next you prepare two small pockets (1 × 1 mm) with the hook – one in the front and one in the back plane of the lenticule. This is most important. For an uncomplicated dissection of the lenticule you have to ensure to start the dissection with the front side of the lenticule first followed by the backside. The dissection is to be done with gender swinging moves all over the whole expanse of the pocket (Fig. 3.10). If there is need you can fix the bulb with a scleral micro-forceps.

After a complete dissection the lenticule is easily extracted with a forceps (Fig. 3.11). Please check that the lenticule is removed in total (you can place it on the cornea and spread it out and check whether edges are intact and circular). Few surgeons prefer to irrigate the interface with BSS, others don't. Post-operative application of combined antibiotic and steroid eye drops is recommended four times per day for 1 week. As SMILE is a flapless procedure there is no need for eye patches or eye shields after surgery. Regular follow ups are recommended after 1 day, 1 week and 1 month.

Re-treatment Options After ReLEx-Smile

With an incidence of less than 2 %, re-treatments after SMILE are rare. The reason is a very high stability of refractive outcomes and a high tolerance of

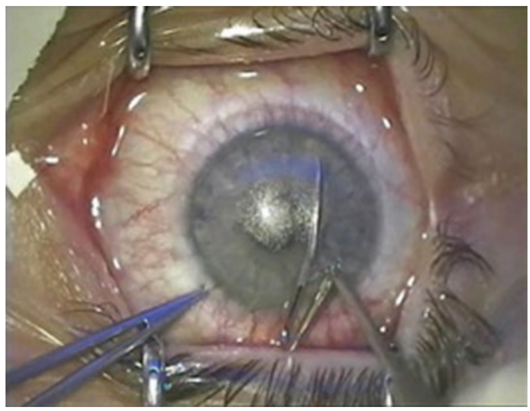

Fig. 3.10 Lenticule dissection

small refractive errors post-operatively. If a touchup is required we have different options:

1. **Surface ablation (= PRK/LASEK):**
   - corneal abrasion, refractive correction done by excimer laser ablation
   - use of Mitomycin C
   - advantage: preservation of corneal stability
   - disadvantage: painful healing, prolonged visual recovery time (up to 3 or even 6 months)
2. **Standard Femto-flap procedure:**
   - same parameters, same size of contact glass and laser settings to convert the cap into a flap
   - refractive correction done by excimer laser ablation

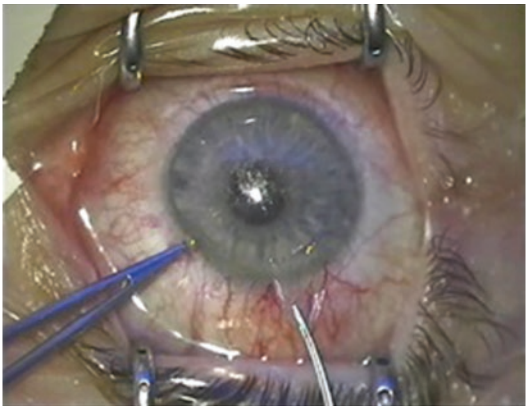

Fig. 3.11 Lenticule extraction

– advantage: fast visual recovery time
– disadvantage: reduction of corneal stability generating the flap side cut.

3. **Thin flap Femto-LASIK** (off label) with a 100 µ thick flap:
   – only advised if the cap created in the initial treatment is thick enough (>140 µ) and only a small refractive error is to be corrected
   – refractive correction done by excimer laser ablation
   – advantage: fast visual recovery time
   – disadvantage: reduction of corneal stability generating a flap side cut, risk of gas breakthrough or cryptic button hole

4. **Circle procedure:**
   – "Circle" was invented by Carl Zeiss Meditec for touch up after SMILE and extends the previous SMILE interface to a flap (Fig. 3.12).
   – refractive correction done by excimer laser ablation
   – advantage: fast visual recovery time; no risk of an additional sectional plane
   – disadvantage: reduction of corneal stability generating a side cut.

5. **Capless SMILE** (off label):
   – First published by David Donate (Lyon) in 2015
   – preparation of a second lenticule while taking advantage of the initial interface and initial incision (Fig. 3.13)
   – advantage: innovative option which preserves all SMILE advantages, fast visual recovery time and preservation of corneal stability
   – disadvantage: risk of distorted lenticule, very small corrections ($< -1{,}0$ D) not possible

The advantages of the second, third and fourth option benefit in a short recovery time and absence of pain. At the same time the advantages of SMILE (e. g. better corneal stability and less cut nerves with reduced dry-eye-symptoms) are becoming obsolete, as you would cut a flap and do the refractive correction using an excimer laser.

Complications and Complication Management

1. **Suction-loss during lenticule and side cut preparation** (Video 3.3)**:**

If suction loss occurs during laser preparation of the refractive part (posterior cut) of the lenticule it is not advisable to continue (Fig. 3.14). Abort the procedure and perform a Femto-Lasik or a PRK after 4–6 weeks.

In case of suction loss during the cap cut (anterior cut), which is a non-refractive plane-parallel cut, you can immediately re-dock and easily proceed with the laser preparation. A perfect centration in respect of the initial cuts is a matter of course. There will be no negative effects on the refractive outcomes.

In all situations the VISUMAX software will automatically recommend how to proceed.

2. **Dissection in wrong layer:**

The golden rule is: front side first than backside. In case of preparing the deeper plane first the lenticule is sticking on the posterior part of the cap. If so, the anterior layer is not easy to be prepared as there is a lack of resistance. Try to find the edge of the lenticule by moving the hook pointed slightly up carefully and dissect with slow moves.

If you cannot manage the dissection through the small incision convert to ReLEx-Flex with a

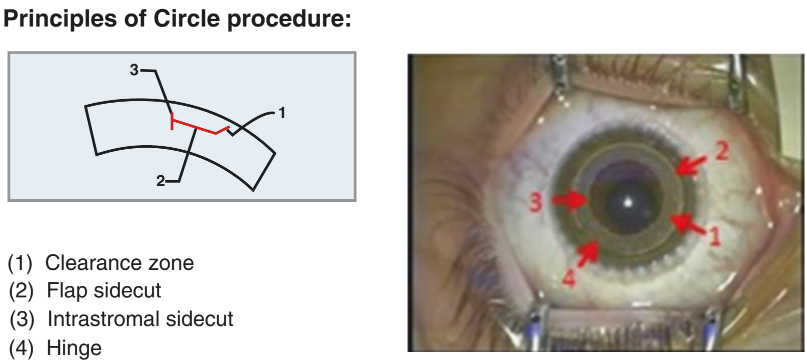

Fig. 3.12 Circle procedure

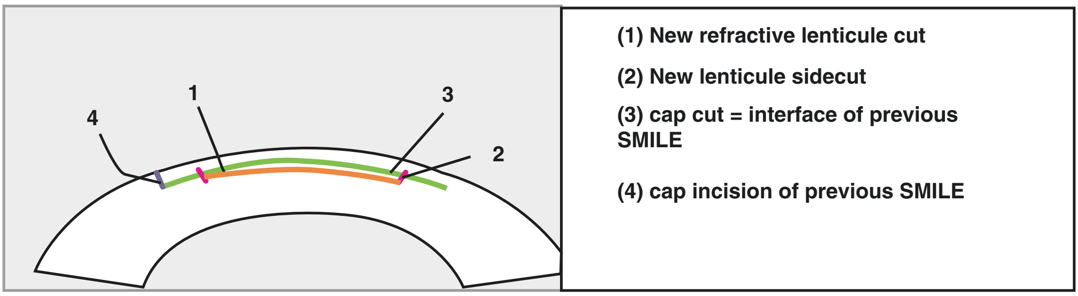

Fig. 3.13 Drawing of corneal cut of "capless SMILE"

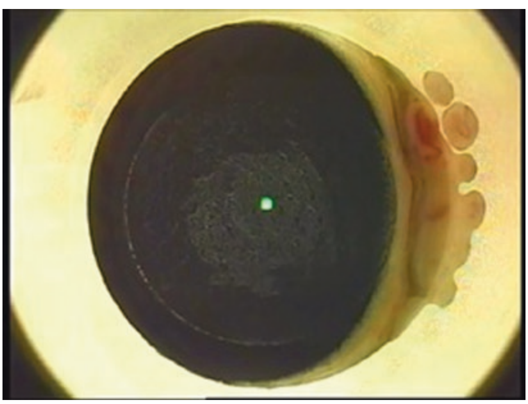

Fig. 3.14 Suction loss

side cut procedure (Circle: side cut only), open the "new" flap and carefully strip the lenticule from the backside of the flap.

To avoid this critical situation you should first prepare two small pockets (1 × 1 mm) in both sectional planes after opening the incision to identify each layer (Fig. 3.15). For the anterior plane you turn the hook slightly upside down; for the posterior plane the hook is pointed down towards the center of the globe.

3. **Black spots and incomplete cut during laser preparation**

Normally, by choosing the right combination of energy level and spot/track distance you will get a homogenous layer with an excellent cut quality and easy tissue separation. Only if the tear film between contact glass and cornea is not clear but oily and dirty caused by e.g. Meibom's secret or filaments you will get areas of low cut quality (looks like an untouched "black" spot; Fig. 3.16). Small local areas outside the visual axis or in the periphery of the optical zone are without consequences. If these small spots conflate to larger areas troubles during the followed mechanical tissue separation are to be expected (Fig. 3.17). Depending on the size of the "black spots" you have to go for a second laser run or you have to abort and to convert the procedure to Femto-LASIK or PRK later.

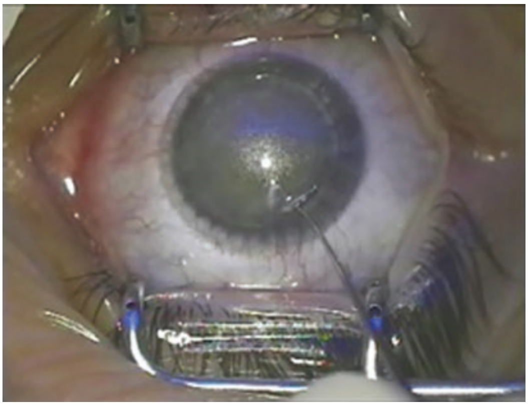

Fig. 3.15 Pocket preparation

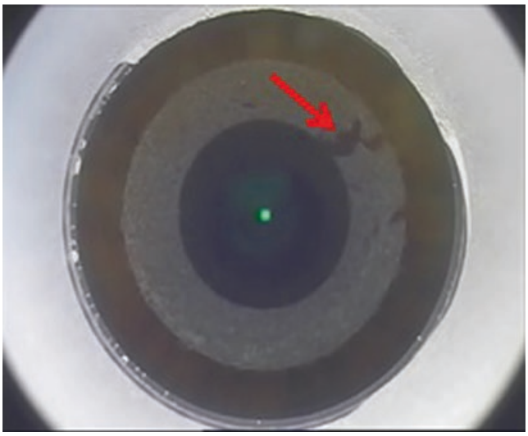

Fig. 3.16 Localized black spot

Advice: If you see an oily liquid film or other dirt on the corneal surface after the docking procedure, do not start the laser application. Drop the suction and clean the corneal surface by irrigating with BSS, take advantage of the aspirating lid speculum and re-dock with a new contact glass.

4. **Epithelium in the interface**

Epithelium is rarely "growing" into the interface but mostly left iatrogenic by the surgeon (Fig. 3.18). It causes topography irregularities and –if in the center- reduces visual acuity. It has a consistency like jelly and can easily be removed with a hook or a spatula before corneal melting effects are initiated.

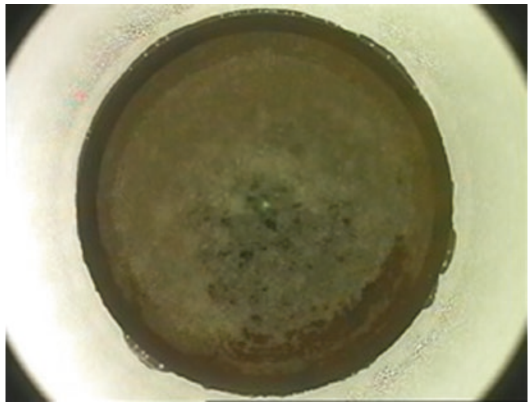

Fig. 3.17 Confluent black spot area

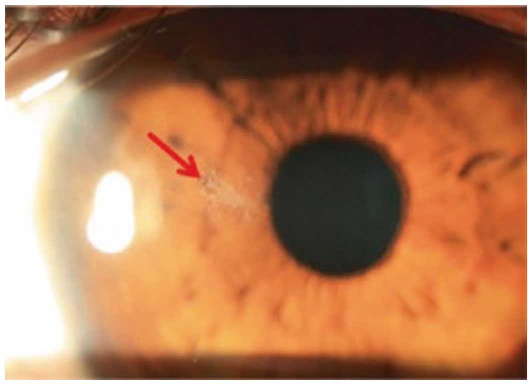

Fig. 3.18 Epithelium in interface

5. **SMILE in low myopia**

Also for low myopic diopters SMILE has become an excellent option. During the last years we have performed SMILE on low myopic eyes between −0.75 and −3.0 diopters. To simplify the management of the thin lenticule we have decided for a larger optical zone (7.0 mm) and added an additional and refraction neutral corneal tissue base; the minimal thickness of the lenticule has to be at least 40 μm. Safety and refractive outcomes are excellent (Fig. 3.19).

Clinical Results

Since 2010 we performed more than 2,500 SMILE procedures, using the ZEISS solution ReLEx SMILE, on myopic and myopic-astigmatic

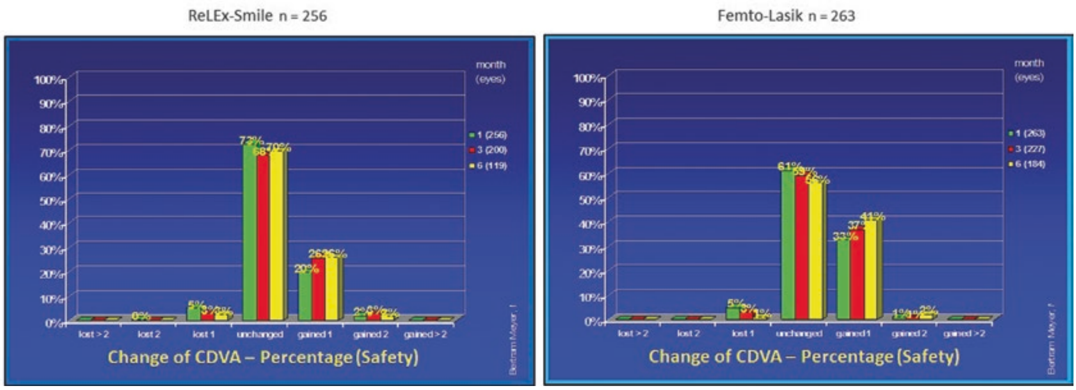

Fig. 3.19 Correction of high myopia: –6, 0 D to –9, 0 D (SEQ): Advantage of ReLEx-Smile vs F-Lasik: high safety

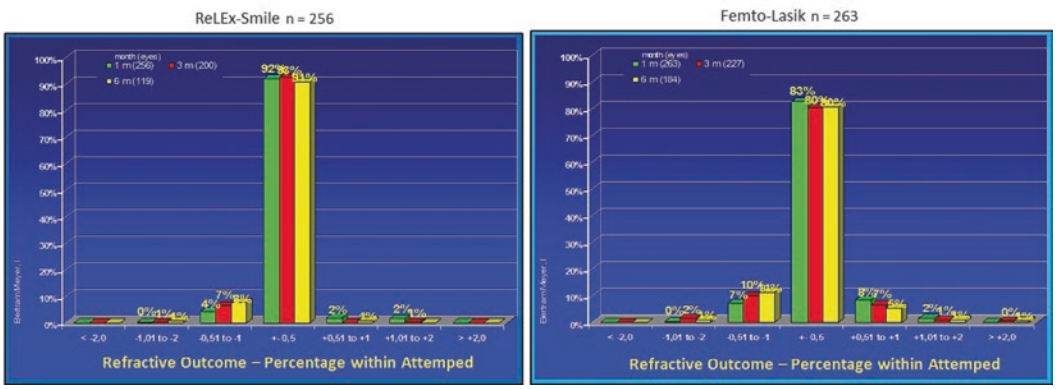

Fig. 3.20 Correction of high myopia: –6, 0 D to –9, 0 D (SEQ): Advantage of ReLEx-Smile vs F-Lasik: high accuracy, high predictability

eyes between −0.75 and −12.5 diopters (SEQ). The clinical outcomes are outstanding and even slightly better compared with those after traditional Femto-LASIK (Fig. 3.20): After 3 months, more than 92 % are within + 0.5 diopters. There is an excellent stability over time and an excellent safety (distance corrected visual acuity preop versus distance corrected visual acuity postop). The recovery of post-operative visual acuity takes slightly longer compared to conventional Femto-Lasik, however most of our patients fulfill the requirements for car driving 1 day after surgery. Post-operative corneal topographies show a large and homogeneous optical zone with a slightly prolate shape. The achieved effective optical zone is identical to the laser setting independent of the refractive correction. Wavefront measurements have confirmed that there is no significant change in aberrations prior and after surgery, especially no spherical aberrations (Z 4/0) have been induced by the lenticule creation and extraction (Figs. 3.21, 3.22, 3.23, and 3.24).

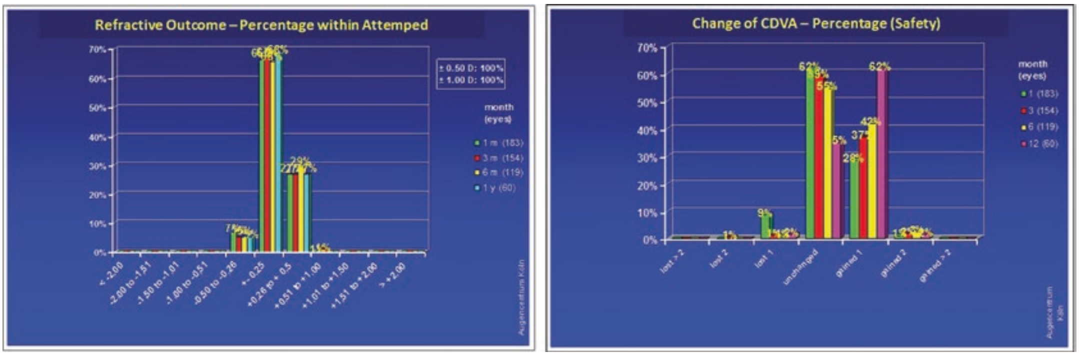

Fig. 3.21 SMILE in low myopia: high accuracy, high safety

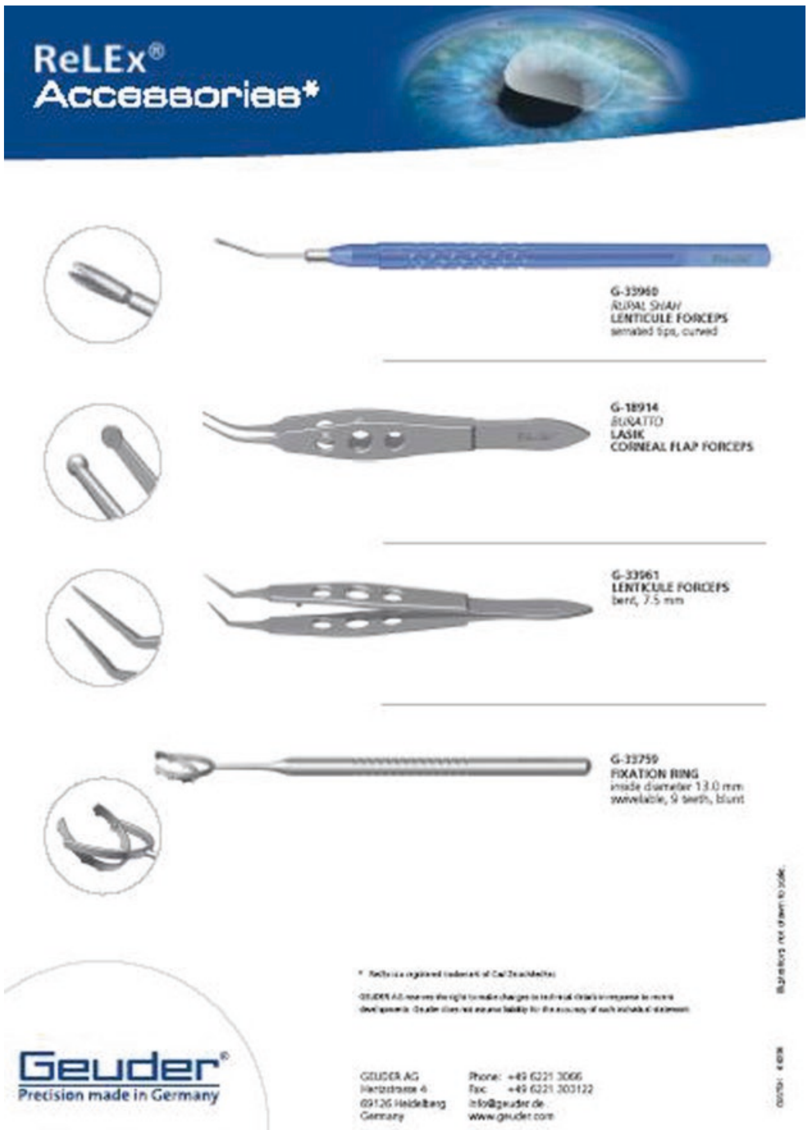

Fig. 3.22 Surgical instruments for SMILE from Geuder, Germany. Part 2

Fig. 3.23 Surgical instruments for SMILE from Malosa, UK. Part 1

Fig. 3.24 Surgical instruments for SMILE from Malosa, UK. Part 2

Summary

SMILE represents the 3rd generation of laser refractive surgery beyond PRK and LASIK. SMILE is the first minimal invasive keyhole procedure with excellent refractive and visual outcomes combined with a maximum of safety. To round up the treatment range, hyperopic SMILE and the correction of myopia with more than −10 diopters are currently investigated.

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Part III

Glaucoma: Canaloplasty

In 2015 the German patient glaucoma association declared canaloplasty as the new gold standard in glaucoma surgery, as this operation combines good results with a low risk profile. **Prof Scharioth** from Gelsenkirchen, Germany will demonstrate a novel technique for canaloplasty using a special suture from Onatec (Onalene, Germany). **Prof Körber** from Cologne, Germany, is a pioneer in the surgery of canaloplasty. During this surgery an illuminated microcatheter is introduced in Schlemm's canal and the canal is then widened through injection of viscoelastics.

4 Canaloplasty

Gabor B. Scharioth

First successful antiglaucomatous surgery was performed by the German ophthalmologist Albrecht von Graefe in 1852. The described technique did work only in acute angle closure glaucoma. In the following 100 years various surgical techniques addressed open angle glaucoma problematic. Since early 1970th trabeculectomy became the standard of care in open-angle glaucoma surgery. This widely used procedure involves a surgically formed pathway for aqueous humour between the anterior chamber and the subconjunctival space to lower intraocular pressure (IOP) in treatment of glaucoma. Main goal is the formation of a conjunctival filtering bleb. This is a relatively unphysiological approach and scleral as well as conjunctival scarring led to introduction of antimetabolites as adjunctive for filtering bleb depending glaucoma surgeries. Numerous intraoperative and postoperative complications have been cited [1–5]. These include hypotony, maculopathy, blebitis/endophthlamitis, hyphema, suprachoroidal hemorrhage or effusions, encapsulation of the bleb with resultant IOP elevation, loss of visual acuity, and increased risk for cataract formation. In addition, intensive postoperative care, including bleb massage, laser suturolysis, release of releasable sutures, needling, or 5-fluorouracil injections, may be needed to achieve primary success. Recently several authors reported relatively high failure rate of trabeculectomy after long term follow-up [1].

All this led surgeons to search for a more physiological and bleb independent surgical approach in IOP lowering glaucoma surgery. Surgical treatment of the natural aqueous outflow system, including Schlemm's canal, to restore normal function and IOP control without penetration of the intraocular space has long been the interest in the study of open-angle glaucoma as an alternative to penetrating and bleb depending methods [6, 7]. In the late 1950s [8] and early 1960s [9], surgical procedures, often described as sinusotomy, were introduced to expose Schlemm's canal and induce aqueous outflow without intraocular penetration. Further development of non-penetrating approaches included the use of a guarded scleral flap and creation of a descemetic window in the 1980s (deep sclerectomy) [10–12], dilatation of the surgical ostia of Schlemm's canal with viscoelastic substance in the late 1990s (viscocanalostomy) [13], and the use of implants at the

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surgical site in the late 1990s and early 2000s [14–16]. These implants were either resorbable (i.e. SK Gel, AquaFlow) or non-resorbable (T-Flux). Most surgeons preferred to close the scleral flap loose to induce subconjunctival filtration in contrast to a watertight closure in viscocanalostomy, which could be named the first bleb independent non-penetrating glaucoma surgery. Although these non-penetrating surgical procedures for glaucoma effectively reduced IOP and lowered the incidence of postoperative complications compared with penetrating procedures such as trabeculectomy, comparative clinical studies indicates that IOP decreases more significantly with trabeculectomy, especially when used in conjunction with antimetabolites [17–23].

Cannulation of Schlemm's canal with a silk suture was described in 1960 for partial trabeculotomy [24]. A modified technique using a 6 × 0 polypropylene suture was later used for 360° trabeculotomy for treatment of congenital glaucoma [25]. All previous non-penetrating glaucoma surgeries were able to reach two to three clock hours of Schlemm's canal while a procedure treating the entire canal should be theoretically more effective. We reported a technique using the 6 × 0 polypropylene suture for catheterization of the entire Schlemm's canal and while withdrawing the suture a 10 × 0 polypropylene suture is installed in the canal and finally knotted under tension [26]. Postoperative intraocular pressure after 1 year was 12.4 mmHg and medication was 0.3 IOP lowering drugs. This is a very difficult and time consuming technique with a relatively high risk of mispassage of the 6 × 0 polypropylene suture into the anterior chamber or suprachoroidal space. Recent advances in technology have allowed surgeons to use a flexible microcatheter to access the entire length of Schlemm's canal more atraumatically. This technique is called canaloplasty (Fig. 4.1, Videos 4.1 and 4.2) and seems to be the logical evolution to viscocanalostomy [27, 28].

This procedure is intended to overcome some of the problems of the previous procedures with deep sclerectomy.

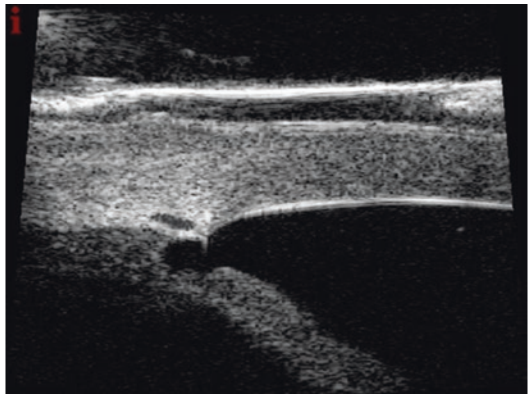

Fig. 4.1 UBM image after canaloplasty, Note: Schlemm's canal clearly visible, gut distension of trabecular meshwork

The idea of implanting a fine tensioning suture into the Schlemm's canal to enlarge the entire 360° of Schlemm's canal [29, 30] should theoretically

– widen the intertrabecular spaces,
– preventing collapse of the canal, the surgical ostia and the descemetic window and herniation of the inner wall into the ostia of collector channels,
– keep the entire Schlemm's canal open
– and
– make collector channels away from the surgical site available for drainage.

First commercially available microcatheter for this technique was iTrack (Ellex, Australia, initially marketed from iScience Interventional, USA). This microcatheter has a 200 μm diameter shaft with an atraumatic distal tip approximately 250 μm in diameter. The device incorporates an optical fiber to provide an illuminated beacon tip to assist in surgical guidance. The illuminated tip is visible transsclerally during catheterization of Schlemm's canal to identify the location of the distal tip of the microcatheter. The iTrack is connected to an external light source (iLumin, Ellex, Australia). The microcatheter has a lumen of about 70 μm with a proximal Luer lock connector through which an OVD (e.g. Healon GV or Healon 5) or dye (e.g. trypane blue, indocyanin green, fluo-

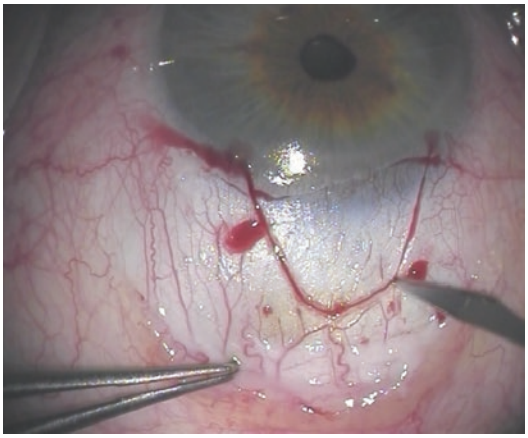

Fig. 4.2 Superficial scleral flap, note no diathermy of episcleral vessels is performed

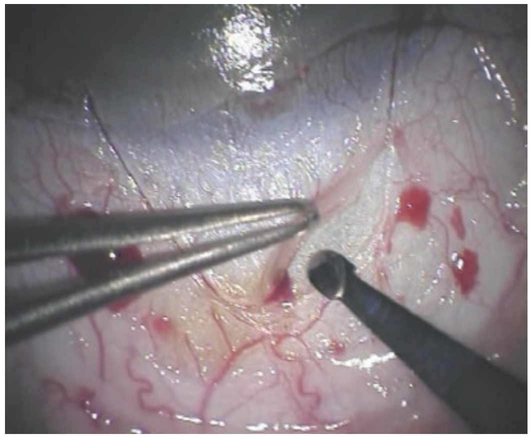

Fig. 4.3 Preparation of the superficial scleral flap with a mini crescent knife

rescein) could be delivered. The procedure is called viscocanaloplasty if OVD is injected to further stretch and enlarge the Schlemm's canal. A dye could be used intraoperatively to control outflow system [31]. Later we developed a microcatheter (Glaucolight, DORC, The Netherlands) without lumen but reduced outer diameter for canaloplasty [32]. This device was directly connected to a sterile light source and less expensive. Currently Glaucolight is not commercially available. Recently a twisted polypropylene suture (Onalene for canaloplasty, Onatec, Germany) was marketed. The tip is atraumatic and catheterization seems to have a high success rate (personal experience). As it is not illuminated the advancement of the suture during catheterization cannot be controlled.

Surgical Technique (Videos 4.1 and 4.2)

1. **Preparation of a superficial scleral flap.**

   The conjunctiva may be opened either at the fornix or at the limbus. A 5 × 5 mm rectangular or parabolic shaped scleral flap (scleral flap marqueur) is performed (Fig. 4.2) including one-third of the scleral thickness (about 300 μm, depending on the total scleral thickness in the particular case) (Fig. 4.1). To be able to reach the Descemet's membrane later during the dissection of the deeper scleral flap, the superficial scleral flap has to be prepared 1–1.5 mm anteriorly into the perilimbal clear cornea (Fig. 4.3). The initial incision is made with a no.11 stainless steel blade (i.e. 15° slit knife for paracentesis) or a diamond knife. The flap dissection is made with a ruby blade or a bevel-up delicate crescent knife (i.e. 1 mm ultrasharp minidisc knife, Grieshaber Alcon, USA) (Fig. 4.4). Diathermy of episcleral vessels is prevented or reduced to a minimum. The episcleral vessels are part of the draining system and needed for successful canaloplasty. In case of excessive bleeding we use a delicate diathermy probe (25G endodiathermy probe) to perform focal diathermy.

2. **Preparation of a deep scleral flap.**

   Next deep sclerokeratectomy is performed by making a slightly smaller second flap then the superficial one, leaving a step of sclera at the sides allowing for a tighter closure of the superficial flap in case of an intraoperative perforation of the trabeculo-Descemet's-membrane or intended watertight closure for viscocanalostomy/canaloplasty. Then the deep scleral flap is dissected towards the cornea using ruby knife or delicate crescent stainless steel knife (Fig. 4.5). This dissection has to be made down to a depth very close to the choroids/ciliary body and carefully carried anteriorly keeping the level of dissection as constant as possible. In case of opening of the suprachoroidal space dissection is

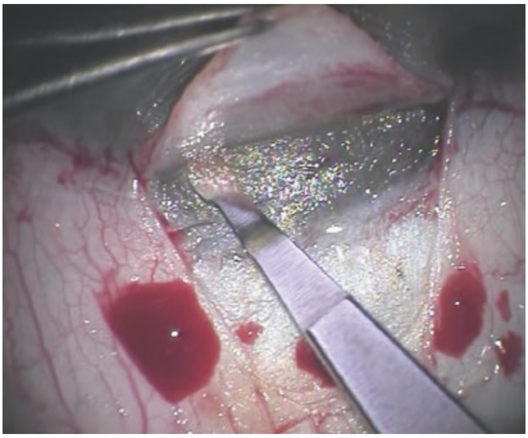

Fig. 4.4 Dissecting the superficial scleral flap into the clear cornea

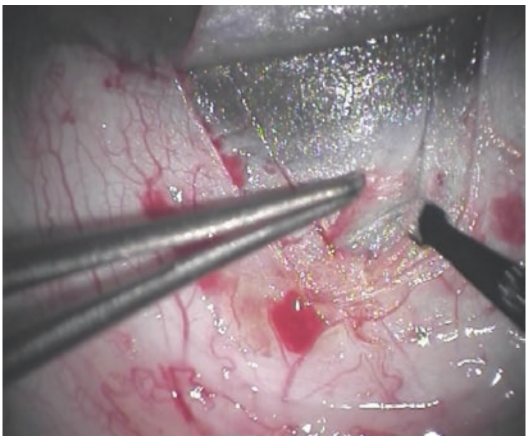

Fig. 4.5 Preparation of the deeper scleral flap using a mini crescent knife, note the smaller size of the deeper scleral flap

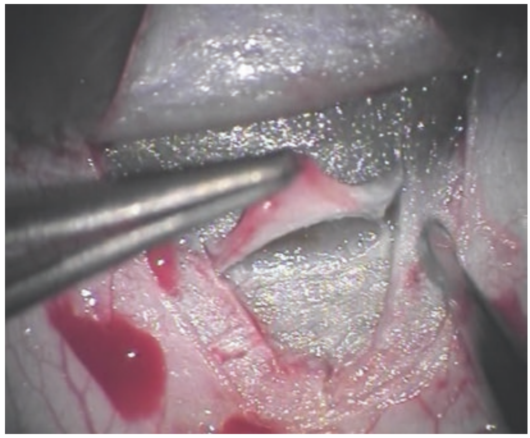

Fig. 4.6 Opening of the Schlemm's canal, note the colour difference in the scleral bed indicating the right depth of preparation

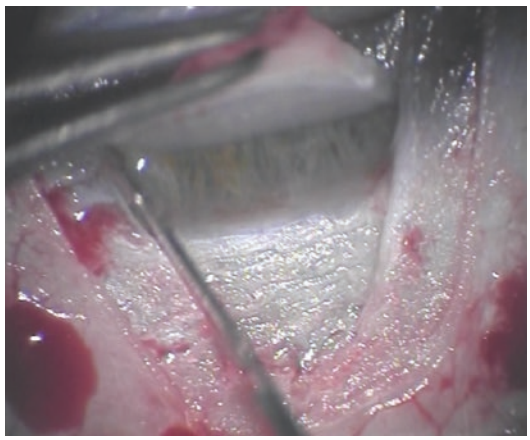

Fig. 4.7 Enlarging the descemetic window for optimal exposure of the trabeculo-Descemetic membrane, note the percolation of aqueous humour without perforation of the membrane, iris is visible through the intact membrane

continued just a few scleral fibers above. The change of the direction of the scleral fibers to a limbusparallel bundle indicates the scleral spur (Fig. 4.6). Just behind this the Schlemm's canal is opened and unroofed. Care is taken to dissect the ostia of Schlemm's canal clearly, because it is believed that this reduces the risk of collapse and scarring of these surgical ostia. Also entering the Schlemm's canal with the microcatheter or a cannula is easier if the ostia can be identified clearly.

3. **Reduction of IOP.**

A paracentesis/side port incision, which should be performed latest now is used to reduce intraocular pressure to very low level. This manoeuvre reduces the risk of perforation of the trabeculo-Descemet's-membrane. Also it is necessary to control later IOP or inject air in the anterior chamber.

4. **Creating a trabeculo-descemetic window**

The dissection is then carried forward to expose a small segment of the Descemet's membrane, creating a trabeculo-descemetic window of about 1–1.5 mm (Fig. 4.7). The corneal stroma can be blunt separated from the Descemet's membrane i.e. with a sponge while the edges of the deep scleral flap are cut towards

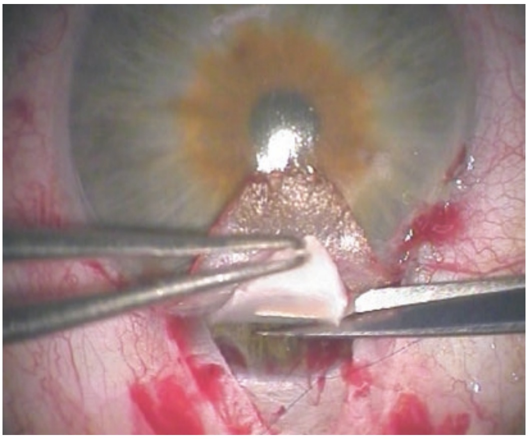

Fig. 4.8 Deep sclerectomy - dissection of the deeper scleral flap with Vannas scissors

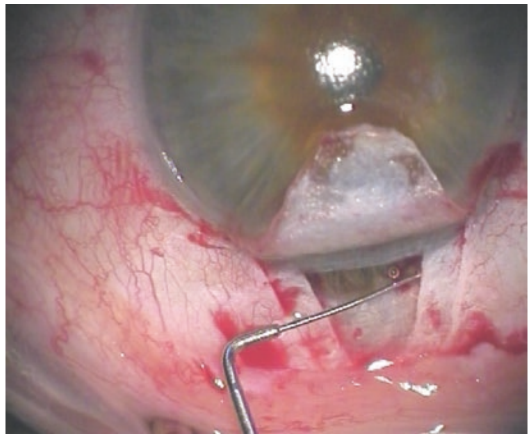

Fig. 4.9 Viscocanalostomy with injection of OVD into the ostia of Schlemm's canal with a special cannula

the cornea with the knife. In some cases the adhesion of Descemet's membrane to the stroma is tighter. In these cases a blunt spatula or the mini crescent knife could be used with sweeping like limbusparallel motion to release these adhesions. This part of the surgery is quite challenging because there is a high risk of perforation of the anterior chamber. The deep sclerocorneal flap is then removed by cutting in the clear corneal part with a delicate small and very sharp scissor (i.e. Vannas or Galand scissor) (Fig. 4.8).

5. **Insertion of the microcatheter**

Now the ostia of Schlemm's canal are gently enlarged by injecting a high viscosity OVD with the help of a special 31G cannula (Fig. 4.9). This will also help to reduce reflux bleeding into the surgical field. As the IOP starts to drop this occurs frequently at this stage of surgery. A specially designed forceps (Glaucolight forceps, DORC, The Netherlands) or a tying forceps is used to manipulate the microcatheter and place the tip into the surgically created ostia of Schlemm's canal (Fig. 4.10). The microcatheter is advanced 12 clock h within the canal while the surgeon observes the location of the beacon tip through the sclera (Figs. 4.11, 4.12 and 4.13). After the catheterization of the entire canal length with the microcatheter and with the distal tip exposed at the surgical site, a 10 × 0 polypropylene suture is tied to the distal tip and

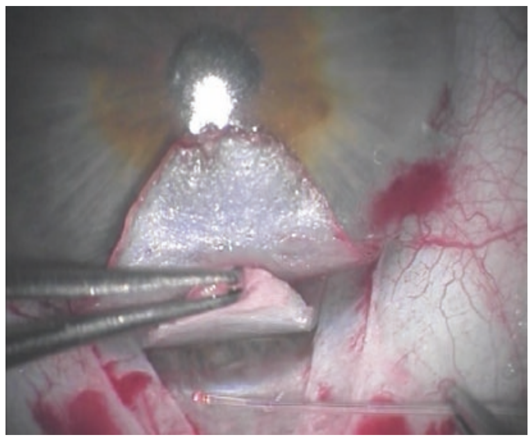

Fig. 4.10 Microcatheter before insertion into the Schlemm's canal

the microcatheter withdrawn, pulling the suture into the canal (Fig. 4.14). To enhance the effect of canaloplasty an OVD can be injected while the iTrack microcatheter is retracted. If this additional injection of OVD into the entire canal is necessary, is unclear, while we could prove that the procedure did work without the use of iTrack catheter and circumferential injection of OVD **33**.

6. **Insertion of a 10 × 0 polypropylene suture**

After the microcatheter is removed from Schlemm's canal the suture is cut from the microcatheter and then tied in a loop, encircling the inner wall of the canal using a slip knot or a

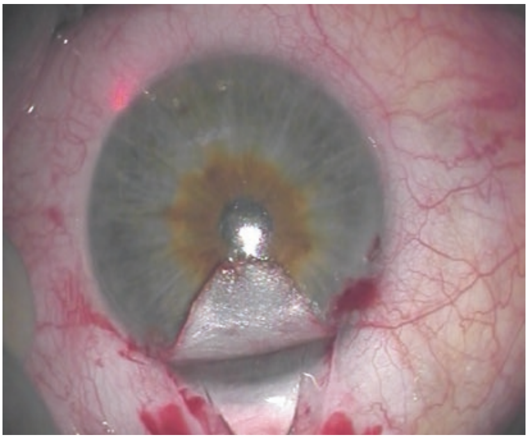

Fig. 4.11 Red spot indicating the position of the microcatheter at 5 o'clock position in the Schlemm's canal

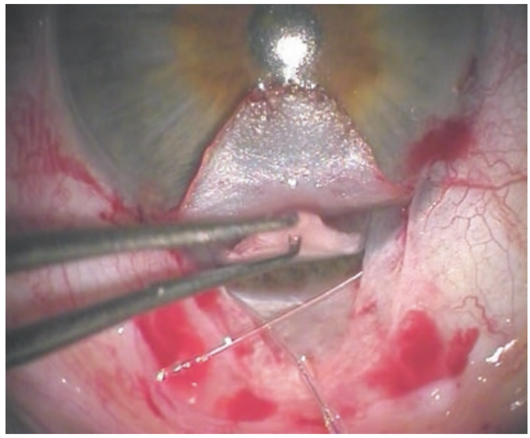

Fig. 4.13 After complete 360° cannulation of the Schlemm's canal

Fig. 4.12 Intraoperative gonioscopic few with illuminated tip of the microcatheter (red dot) in the Schlemm's canal, note the heavily pigmented trabecular meshwork in this eye

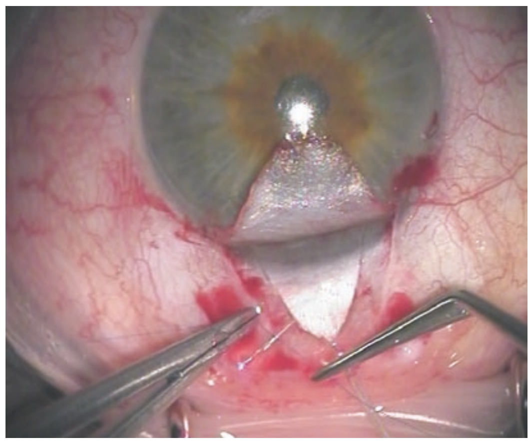

Fig. 4.14 10 × 0 Prolene tensioning suture is fixed to the microcatheter

locked four throw knot (Fig. 4.15). To reduce risk of rupture of descemetic membrane and to facilitate a more effective tensioning of the 10 × 0 polypropylene suture the IOP was previously lowered through a paracentesis.

7. **Check for perculation of aqueous**

At this stage of the procedure, there should be perculation of aqueous through the remaining membrane evident. This can be checked also by applicating fluorescein to the surgical area (s.c. Rentsch-Seidel test). The amount of perculation is checked while drying the surgical area with a sponge. To increase the outflow facility, we peel partially the inner wall of the Schlemm's canal, including the endothelium and the juxtacanalicular trabecular meshwork. A special designed forceps or an ordinary capsulorhexis forceps could be used. Occasional the inner wall of the Schlemm's canal is fibrosed and an initial radial cut is necessary to be able to start the peeling. The next step of the surgery ophthalmic viscosurgical device (OVD) is injected in the surgical ostia of Schlemm's canal.

8. **Suturing of superficial scleral flap**

The superficial scleral flap is repositioned and tightly closed with five to seven single absorbable sutures (i.e. 10 × 0 Vicryl, Ethicon). The

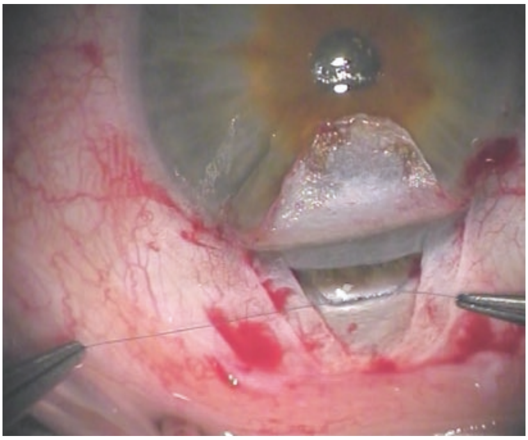

Fig. 4.15 After withdrawing of the microcatheter the suture is cut off and knotted under tension to pull the inner wall of Schlemm's canal and the descemetic window towards the anterior chamber to prevent failure of the surgery due to collapse of these structures

Fig. 4.16 Watertight closure of the superficial scleral flap with 5–7 interrupted sutures (9/0 absorbable suture), same suture is used to close conjunctiva

superficial scleral flap is sutured as watertight as possible for forcing internal filtration into the Schlemm's canal and then into the collector channels (Fig. 4.16). Now OVD is gently injected under the scleral flap to reduce the risk of bleeding into the sclerectomy site and to prevent scarring in this area. This will preserve the scleral lake. Anterior chamber is refilled with balanced salt solution to normal or slightly elevated IOP. In case of perforation or unstable anterior chamber alternatively air could be injected. Conjunctiva is repositioned and fixed with two to four single absorbable sutures.

Canaloplasty could be performed in combination with phacoemulsification. In contrast to phacotrabeculectomy results of phacocanaloplasty is not negatively affected by cataract surgery. It seems that the non perforating character of canaloplasty and the postoperative stable anterior chamber are important factors for the favourable outcome. There is no evidence that separate or shared incision is better. If separate incision is planned first a clear cornea microincisional cataract surgery is performed. This is then followed by deep sclerectomy and canaloplasty as described. We favour a shared incision. Preparation of deep sclerectomy is carried out until the Schlemm's canal is opened. Then the phacoincision is placed between the superficial and deep scleral flap and a standard MICS is performed with injector assisted IOL implantation. OVD is left in the anterior chamber and canaloplasty is performed. After superficial flap is sutured the OVD is removed with bimanual irrigation-aspiration.

Complications

Only very limited data are available about complications in canaloplasty. Intraoperative complications should be separately discussed from those occurring in the postoperative period. Most intraoperative complications are related to difficulties during the deep sclerectomy and are not specially caused by the catheterization of Schlemm's canal and the placement of a tensioning suture.

Typical intraoperative complications of deep sclerectomy are:

– Superficial preparation of the scleral flaps
  This will cause either a button holing in the superficial scleral flap or difficulties to localize and open Schlemm's canal during preparation of deep scleral flap. The superficial flap should be about one third scleral thickness. This is needed to leave enough scleral tissue for deeper scleral flap and to facilitate surgical manipulations. Deep scleral flap should be

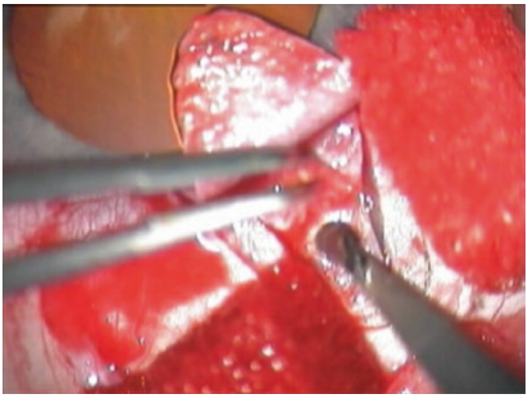

Fig. 4.17 Radial opening of suprachoroidal space during preparation of deep scleral flap, Note: minimal prolapse of ciliary body, no bleeding, and canaloplasty was completed without any further complication

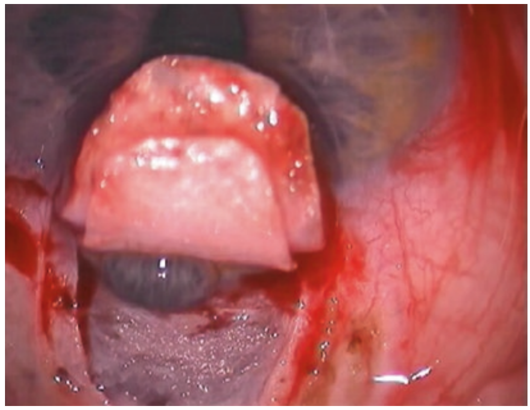

Fig. 4.18 Intraoperative iris prolapse through Descemet's membrane during preparation of deep scleral flap

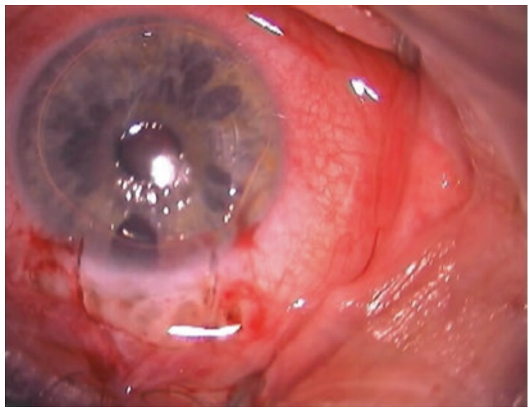

Fig. 4.19 Same eye after deep sclerectomy, peripheral iridectomy and air injection in anterior chamber

almost opening the suprachoroidal space. As scleral thickness is variable a preset knife is not recommended. We have performed deep sclerectomy in patients with very thin sclera of less then 400 µm. Here only surgeons experience can help to create the correct scleral flaps.

– Deep preparation of scleral flaps
  Opening the suprachoroidal space usually is not causing severe complication. After the surgeon has realized this problem preparation can be continue a few microns more superficial. And if then this level is kept during preparation this will guide to anatomical landmark scleral spur and finally to Schlemm's canal.
– Perforation of Descemet's membrane
  Most frequent complication in deep sclerectomy is a perforation of the Descemet's membrane (Figs. 4.17, 4.18 and 4.19). As a standard in all non-penetrating procedures a paracentesis should be performed latest when Schlemm's canal is reached. This will allow control of intraocular pressure, as experience has shown, that lowering the IOP will reduce stress to Descemet's membrane and reduce risk for perforation. In case of perforation further strategy will depend on size of perforation and appearance of iris prolapse. If the perforation is minimal surgery can be continued. Anterior chamber might be refilled with balanced salt solution or even better with air (higher surface tension) to form the eye. Miochol could be gently injected to bring the pupil down and to pull the iris root away from the perforation side. If a larger perforation with iris prolapse occurs surgery usually needs to be converted into a "modified" trabeculectomy. Iridectomy is performed and superficial flap is closed.

Typical intraoperative complications of canaloplasty:

– Difficult catheterization
  The most frequent complication is an unsuccessful catheterization (Fig. 4.20). In the

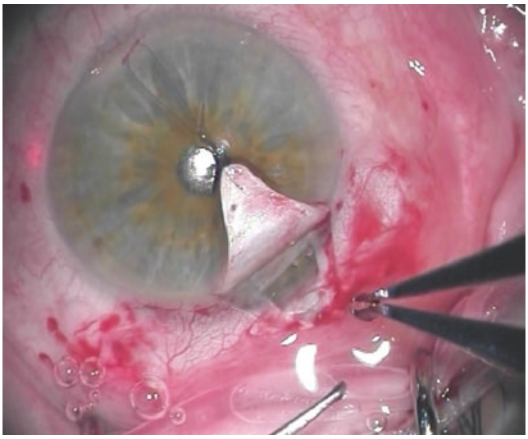

Fig. 4.20 Illuminated tip of microcatheter is indicating correct position in the Schlemm's canal

Fig. 4.21 Placement of a second tighter tensioning suture, Note: first suture became very loose after tightening the second suture

literature it is reported in up to 30 % of cases. This could be caused by a non-perfect deep sclerectomy resulting in difficulties to find the surgically created ostia of Schlemm's canal. But more frequent in difficulties during 360° catheterization. The microcatheter could stop at any point during passage. This is mostly caused by larger ostia of collector channels in the outer wall of Schlemm's canal. Gently massage ab externo in this area might help sometimes to overcome this problem. If this does not help the microcatheter is withdrawn and the tip is bended a little. Then the microcatheter is again inserted. The bended tip should be directed towards the trabecular meshwork to reduce the risk for mispassage into an ostia of a collector channel. If this will not overcome the problem the microcatheter is again withdrawn and introduced in the opposite ostia of Schlemm's canal. In almost all cases this will lead to a successful passage.

– Mispassage

The tip of the microcatheter could perforate the wall of Schlemm's canal and become located suprachoroidal or in the anterior chamber. If the microcatheter will perforate into the anterior chamber usually it will be advanced in the anterior chamber angle. First sign could be a reduced distance to the limbus. This will be usually followed by little iris movement. In most cases this will not cause any severe complications and catheterization could be performed successfully in the opposite direction. But in some cases the tip can damage the peripheral iris vessels and cause anterior chamber bleeding. Also the tip can penetrate the anterior chamber angle and appears in the suprachoroidal space. The illuminated tip will indicate if the microcatheter enters the suprachoroidal space. Distance to the limbus will increase and finally the tip will move posteriorly. Microcatheter should be removed. Depending on surgeons experience catheterization could be repeated. Most cases passage will be possible in the opposite direction. Special care should be taken that the tip of the microcatheter is correctly introduced in the ostia of Schlemm's canal.

– Suture related problems

Placement of the polypropylene suture into the Schlemm's canal is the next step during canaloplasty (Fig. 4.21). The suture is knotted to the microcatheter. If this knot is loose the suture could be lost and the catheterization has to be repeated. A larger knot could stop at the ostium of Schlemm's canal. One should not pull to strong as this could cause perforation of trabecular meshwork or Descemet's

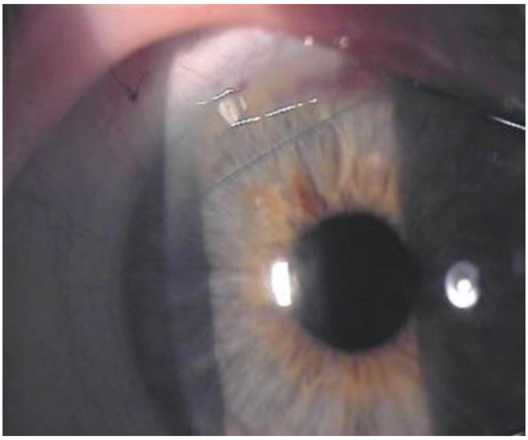

Fig. 4.22 Tensioning suture in the superior nasal quadrant of anterior chamber after complicated canaloplasty, Note: no pupil distortion, no inflammation, IOP 13 mmHg

membrane. The knot should be turned towards the trabecular meshwork.

Tightening the polypropylene suture is the major step in canaloplasty. This will prevent collapse of Schlemm's canal and will overcome some problems of other non-penetrating procedures. There are different techniques how to create a tensioned suture (e.g. slippage knot and four throw blocked knot). Correct tension should be checked by pulling the suture before cutting the loose ends. If the knot cannot be moved over the scleral spur and the surgeons feels some tension from the suture it is believed to be the right tension. To verify the so called distension and status of Schlemm's canal an intraoperative ultrasound biomicroscopy or optical coherence tomography could be performed. If the suture is loose and cannot be tightened more a new suture should be placed into Schlemm's canal (Fig. 4.21).

Rarely a too tight suture could cause cheese wiring of trabecular meshwork (Fig. 4.22). This is usually related to a more complicated surgery and/or unexperienced surgeon. If the suture is only in the peripheral anterior chamber visible it could be left. In our experience this will not cause further complications. If the suture is in the pupillary area or has contact to iris surface it is recommended to remove it. There are only very few cases reported on this complication. Some were recognized only later postoperative and thought to be caused by the permanent tension of the suture. But we believe they where always caused intraoperative. The tension of the 10/0 polypropylene suture is minimal and if accidentally cut during NdYAG goniopuncture procedure the loose ends will move only one or maximum 2 mm.

– Descemet's membrane detachment
  In viscocanaloplasty vasodilatation of Schlemm's canal is intended. A special syringe is used with iTrack® to inject viscoelastic device through the microcatheter. Originally this was used for 360° viscocanalostomy, but this procedure did not prove to be more effective then standard viscocanalostomy. The effect of viscoinjection in the more or less closed system is not predictable. The same amount of viscoelastic device may cause only dilatation of Schlemm's canal, microrupture of trabecular meshwork, Descemet's membrane detachment or even viscodetachment into suprachoroidal space [33]. There are several reports on hemorrhagic Descemet's membrane detachment in the literature (Figs. 4.23 and 4.24). Spontaneous resorption will take up to 1 year. But if central cornea is not affected vision is stable and cornea stroma remains clear. An immediate surgical intervention with lavage of the hemorrhagic Descemet's membrane detachment could be indicated if the visual axis is affected [34]. Because of this complication we have abandoned vasodilatation and have not found any difference with regards to postoperative intraocular pressure.
– Bleeding from anterior chamber angle
  Even in uncomplicated canaloplasty intraoperative bleeding from anterior chamber angle might occur. This is related to a reflux bleeding from episcleral vessels into Schlemm's canal caused by low intraocular pressure. If trabecular meshwork is permeable the blood might appear in the anterior chamber angle and is not a sign of a complication. Early postoperative it might be followed by hyphaema.

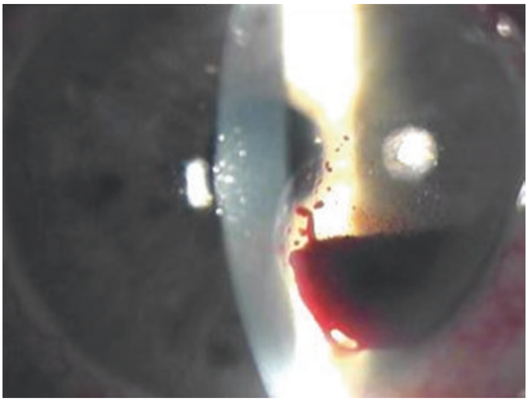

Fig. 4.23 Hemorrhagic Descemet's membrane detachment after viscocanaloplasty with iTrack® bleb is filled with blood and viscoelastic device.

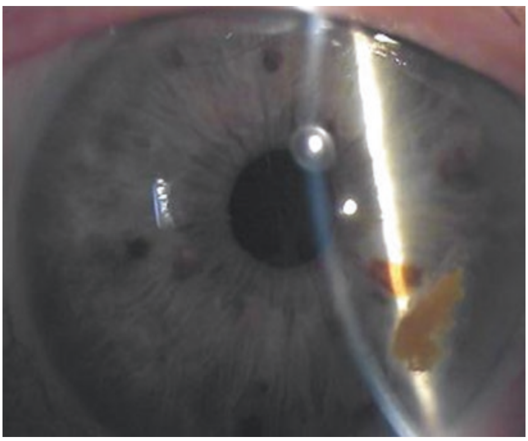

Fig. 4.24 Same eye 10 months postoperative, visual acuity remained 20/20, IOP 13 mmHg

Resorption will take a few days and only very rarely anterior chamber lavage is needed.

Typical postoperative complications of canaloplasty:

– Early postoperative hyphaema
  If intraocular pressure early postoperative is lower then episcleral vein pressure a reflux bleeding via collector channels, Schlemm's canal and trabecular meshwork might cause intracameral hemorrhage. This could result in a microhyphaema (frequent postoperative appearance) or even a excessive hyphaema of up to 4–5 mm. Reduced visual acuity stresses patients and the surgeon but spontaneous resorption should be awaited at least for one week. In case of missing resorption or intraocular pressure rise the anterior chamber could be lavaged with bimanual irrigation/aspiration.
  As a minor anterior chamber bleeding is very common and does not affect the final outcome it should not be considered a complication. Some surgeons consider it as a positive prognostic sign and have found a positive correlation between early postoperative microhyphaema and lower postoperative intraocular pressure after 1 year follow up.
– Transient decreased visual acuity
  Even in case of clear optical media in some patients visual acuity is decreased for some weeks or even months postoperatively. Beside surgically induced astigmatism no specific reason was found and in almost all cases visual acuity recovered spontaneously.
– Steroid induced elevation of intraocular pressure
  As canaloplasty is a non-penetrating procedure in up to thirty percent of cases steroid response is possible. Most surgeons are using prednisolone acetate or dexamethasone eye drops as standard postoperative care. If two weeks postoperatively the intraocular pressure rises and gonioscopy does not show any abnormality this might be caused by steroid response and therapy should be changed to NSAID. In most cases intraocular pressure will drop again after one to two weeks.
– Postoperative hypotonia
  Sometimes postoperative intraocular pressure is below 6 mmHg. This might be caused by some subconjunctival filtration. After uncomplicated canaloplasty anterior chamber is formed even in this cases and choroidal detachment is very rare. Interruption of postoperative antiphlogistic therapy for 1 or 2 days is usually enough to induce healing processes at the scleral flap and to stop subconjunctival filtration. After increase of intraocular pressure steroid eye drops should be continued for about 4 weeks. If this does not help reintervention with placement of additional sutures

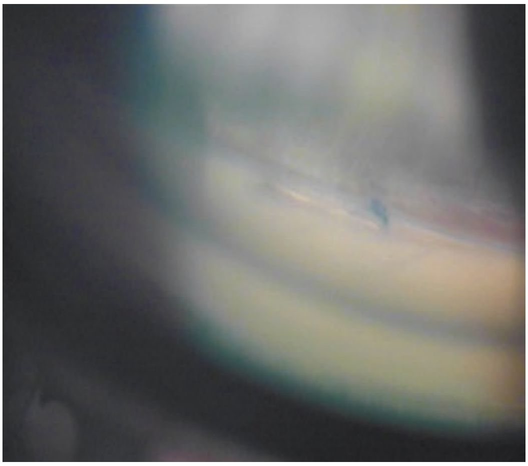

Fig. 4.25 Gonioscopic view after NDYAG goniopuncture, Note: defects in descemetic window, tensioning suture intact, scleral lake open

Fig. 4.26 Late postoperative iris prolapse after blunt trauma

to scleral flap might be indicated. In case of flat anterior chamber injection of air is very helpful.

– Postoperative pressure rise
  Other causes for postoperative uncontrolled intraocular pressure could be increased outflow resistance in trabecular pressure or gonosynechiae in the area of deep sclerectomy / Descemet's window. Usually NdYAG laser synechiolysis and/or goniopuncture are very effective (Fig. 4.25). Special care should be taken, that the tensioning suture is not cut by the laser.
– Iris prolapse
  There is an increased risk for iris prolapse through descemetic window into the sclerectomy area (scleral lake) after complicated surgery or blunt trauma. This is a rare complication and if intraocular pressure remains low and optical axis is not affected from pupil distortion no intervention is required. If needed iris prolapse could be repositioned ab interno in early phase. Miochol and air is injected into the anterior chamber. Additionally a peripheral iridectomy could be performed with a vitrectome. Later a revision ab externo is preferable. After conjunctival peritomy superficial scleral flap is lifted and prolapsed iris dissected.
– Expulsive intraocular haemorrhage
  One of the worst complication of a surgical intervention in a seeing eye is an expulsive suprachoroidal haemorrhage. This is usually caused by very low intraocular pressure in the early postoperative phase, fragile choroidal vessels, sudden elevation of cranial blood pressure (e.g. forward bending or pressing) and anticoagulation. There is no report of such an event in the literature. We have had two cases with expulsive suprachoroidal haemorrhage in canaloplasty. Both eyes where high myopic and vitrectomized. Early postoperative pressure was very low. In the first patient the complication occurred during the first night whereas in the second patient it occurs at third postoperative morning during tooth brushing. One should wait 7–10 days before intervention. We favour pars plana vitrectomy, suprachoroidal lavage via sclerotomy and silicone oil tamponade.
– Endophthalmitis
  There is no endophthalmitis reported after canaloplasty. In the last 15 years we have performed more then 3000 non-penetrating glaucoma surgeries without any endophthalmitis. If endophthalmitis occur one should take same considerations like for a case of endophthalmitis after phacoemulsification.

Fig. 4.27 Status 4 years post canaloplasty, IOP 13 mmHG, no antiglaucomatous medication, Note: no bleb formation or sign of subconjunctival filtration

Postoperative Treatment

In routine canaloplasty only minimal postoperative care is needed. The anterior chamber is deep and the IOP in the first postoperative days is around 10 mmHg. As described hyphaema might be present, but is usually absorbed within 2–3 days spontaneously.

We refer for local steroid therapy with five times daily prednisolone 1 % eye drops. This therapy is continued for 5–6 weeks.

IOP fluctuations within the first few weeks might be present. We use gonioscopy to differentiate between steroid response, iris adhesion, bleeding into scleral lake, early excessive scaring of scleral lake etc. Intervention is adapted to the cause of IOP rise.

Canaloplasty is a highly effective non-perforating bleb independent glaucoma surgery (Fig. 4.27). The postoperative IOP is usually in the low tens and comparable to the results of trabeculectomy. But there is a much lower complication rate reported. It has the potential to re-establish the natural pathway of aqueous humour outflow in patients with open angle glaucoma.

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5 Canaloplasty with iTrack

Norbert Körber

In black patients all fistularising procedures tend to heal aggressively and thereby the success rate is low, even with the use of mitomycin.

Robert Stegmann worked very early with Healon for various indications as ocular trauma, pediatric and senile cataract surgery and glaucoma.

His first studies involved visco-trabeculotomy, which was disappointing as there was scarring of the trabecular meshwork in the trabeculotomy segments and also descemet's membrane dissection occurred frequently.

Thus, he developed viscocanalostomy and later canaloplasty as a logical step to improve the results.

Viscocanalostomy showed good long term results in a long term follow up study for black as well as for Caucasian patients.

Canaloplasty is effective on a long term base as well, as the international multicenter study could show.

In Europe, canaloplasty was performed for the first time in 2005 in three surgical centers in Germany (v.Wolffand Bull; Tetz; Koerber) and one in the UK (C.Peckar).

Since then, canaloplasty has been adopted by numerous surgeons in Europe. In Germany, it is coded in the DRG system and in the public health system. Thus, we can state, that this operation has been accepted officially. This year, a patient association named canaloplasty as the new gold standard in glaucoma surgery, as this operation offers good results with a low risk profile.

Viscocanalostomy

The Surgery Step-by-Step

Viscocanalostomy is performed according to Stegmann's[15] technique, with the creation of a parabolic 5 × 5 mm limbal-based one-third scleral thickness flap (Figs. 5.1 and 5.2). With the goal of achieving a watertight closure, cautery is avoided and 1:10,000 epinephrine is applied using a Weck-cel sponge to achieve hemostasis (Fig. 5.3). A deep scleral flap is created 0.5 mm inside the superficial flap, dissecting down until the choroid is just visible. Schlemm's canal is unroofed and a membrane is cleaved from the cornea, creating a Descemetic window through which aqueous can permeate (Fig. 5.4). The inner, deep scleral flap is then excised, forming the scleral lake (Fig. 5.5). The two surgically created ostia of Schlemm's canal are injected six

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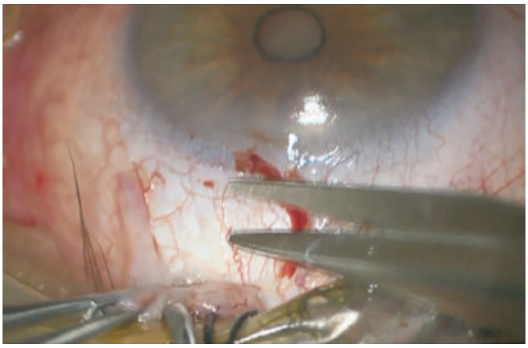

Fig. 5.1 Opening of the conjunctiva

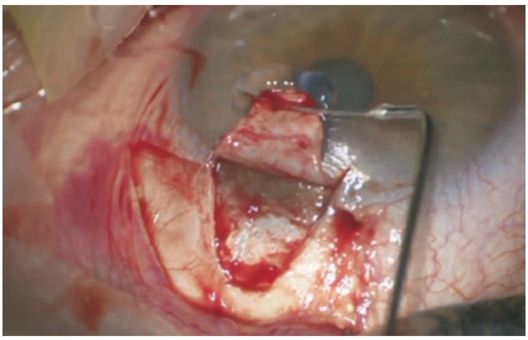

Fig. 5.2 First flap

Fig. 5.3 Compression of sclera with suprarenine

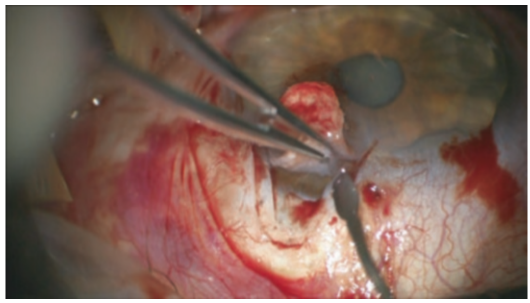

Fig. 5.4 Preparation of the inner flap – descemet window

times with Healon™ GV (Abbott Medical Optics, Santa Ana, California) using a 150 μm cannula (ViscoCanalostomy Cannula, Grieshaber, Schaffhausen, Switzerland) (Fig. 5.6).

The superficial flap is sutured tight to achieve internal drainage and prevent bleb formation (Fig. 5.7).

Canaloplasty (Videos 5.1, 5.2, and 5.3)

The Surgery Step-by-Step

Canaloplasty essentially uses the same non-penetrating surgical technique discussed for viscocanalostomy and has been described in detail in previous reports. After exposing Schlemm's canal, a flexible microcatheter (iTrack™ 250A Canaloplasty Microcatheter, Ellex/IScience Interventional Corp., Menlo Park, California) is used to dilate the full circumference of the canal by injecting Healon GV during catheterization (Fig. 5.8). The microcatheter has a 200 micron diameter shaft with an atraumatic distal tip of approximately 250 microns in diameter (Figs. 5.9 and 5.10). The device, which has a lumen through which the viscoelastics is delivered, has an illuminated tip so that the surgeon can observe the location of the beacon tip trans-sclerally (Fig. 5.11). A 10-0 prolene suture (Ethicon Inc., Somerville, New Jersey) is tied to the distal tip (Fig. 5.12) and the microcatheter is withdrawn slowly, pulling the suture into the canal. After tying the suture in a loop encircling the inner wall of the canal, the suture loop is tightened to distend the trabecular meshwork inwards placing the tissues in tension and then locking knots are added (Fig. 5.13).

The scleral lake and the ostia of Schlemm's canal are filled with Healon GV (Fig. 5.14) and the superficial flap is closed with typically 7 10-0 vicryl sutures. The conjunctiva is reattached with one 10-0 vicryl suture with an inverted knot to prevent foreign body sensation during the first days.

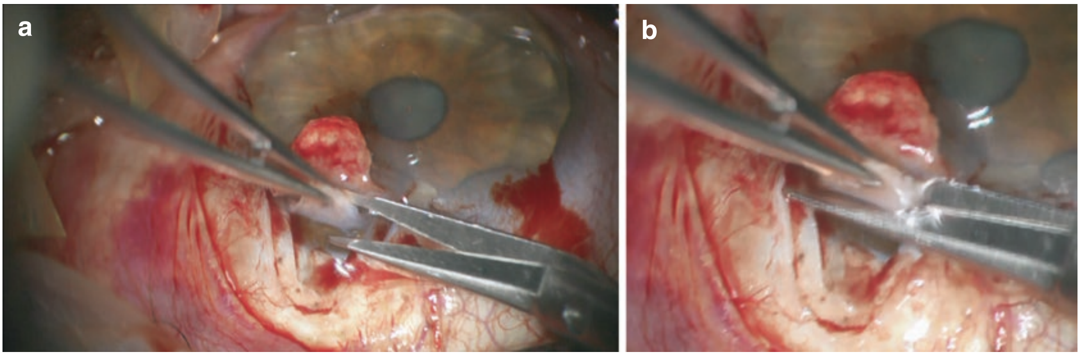

Fig. 5.5 (**a**) Deep sclerectomy bei CP. (**b**) Excision of the inner flap

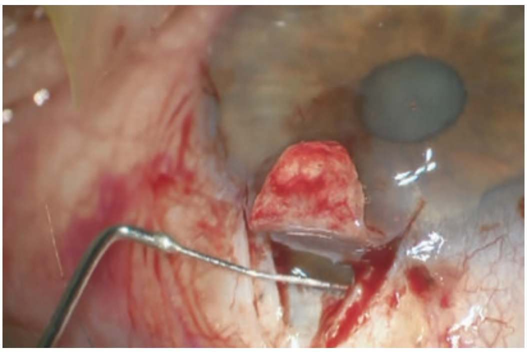

Fig. 5.6 Dilation of Schlemm's canal ostium

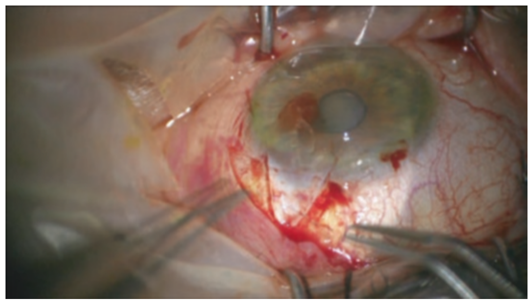

Fig. 5.7 Suturing the outer flap

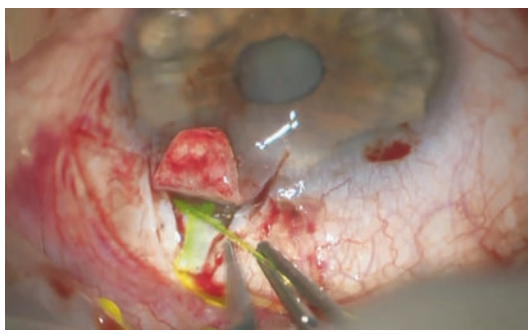

Fig. 5.8 iTrack entering Schlemm's canal

Complications

The complication profile of viscocanalostomy and canaloplasty is not much different, so we will describe both in one chapter.

Ocular-related surgical and post-surgical complications (3 year study Europe)	
Surgical/early postoperative complications (≤ 90 days post-op)	n (%)
Microhyphema: < 1.0 mm layered blood	14 (12.8 %)
Hyphema: ≥ 1.0 mm layered blood	6 (5.5 %)
Elevated intraocular pressure	6 (5.5 %)
Descemet's membrane detachment	4 (3.7 %)
Hypotony: IOP ≤ 5 mm Hg with shallow anterior chamber	0
Flat/shallow anterior chamber	0

n sample size, *mm* millimeter

Management of Complications

Hyphema and microhyphema usually do not make an intervention necessary. They resolve in a few days up to 1 week.

Post-op pressure rises during the first days are rare and the reason is still unknown. A local and systemic therapy is sufficient – a surgical intervention/revision is not indicated. Exception:

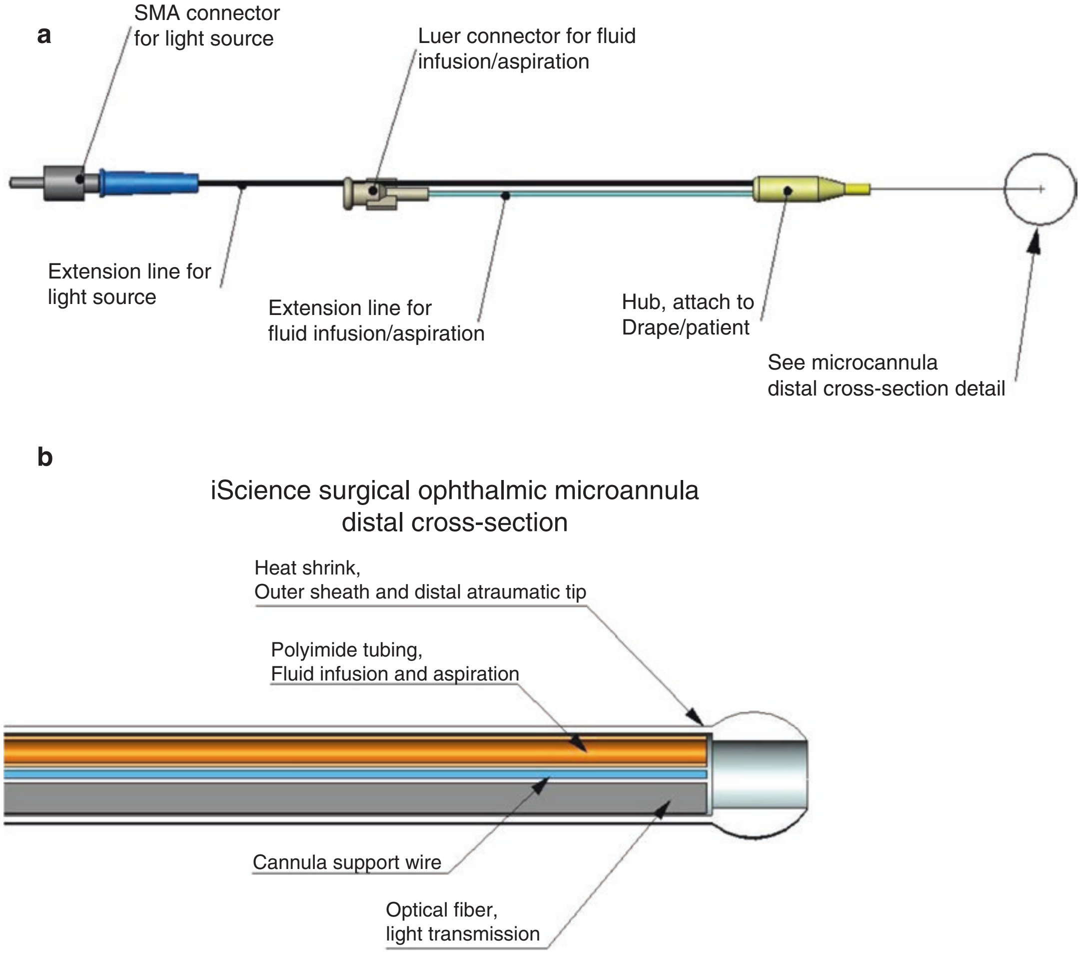

Fig. 5.9 The images show the complete catheter design (**a**). In detail (**b**) we can see a cross-section of the tip depicting the size of the inner structure. We can imagine, that passing a high viscositiy OVD like Healon GV creates an enormous pressure inside the inner tubing, which is made from polyimide.

trauma with subsequent incarceration of iris to the scleral lake.

After 2–3 weeks steroid-induced pressure rises are not uncommon. Local therapy and change of steroid (from pred forte to fluorometholone) or stop of steroids and therapy with NSAID's alone is usually sufficient and effective.

Descemet detachment occurs intraoperatively, when a local "overdose" of Healon GV is injected into the canal while being dilated. Most of the detachments are only peripheral and resolve spontaneously after some weeks. If blood enters the detachment space and the visual axis is close or covered, intraoperative aspiration by a paracentesis and air tamponade of the anterior chamber is indicated.

If during the preparation of the Descemet window a Descemet's rupture (parallel to the trabecular meshwork) occurs, it is necessary to perform a small iridotomy to prevent an iris adhesion or prolapse into the scleral lake post-op. Usually the canaloplasty or viscocanalostomy can be continued successfully, as it is still possible to enter the ostia of Schlemm's canal.

Fig. 5.10 The light source (iLumin II). The light fiber connection is on the left side. On the right side is the on-off switch and a selection button for continuous or intermittent light.

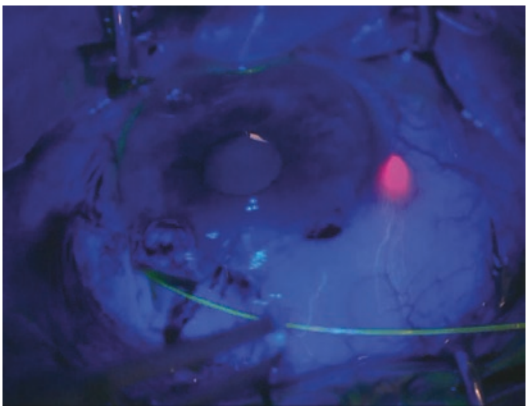

Fig. 5.11 Tip of catheter visible by red dot and visible outflow vessels

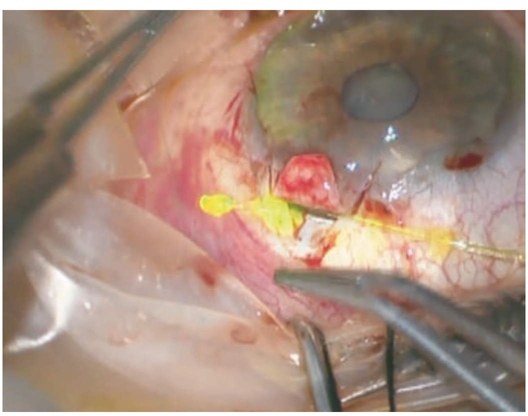

Fig. 5.12 iTrack after 360° dilation, fixation of the 10-0 prolene.

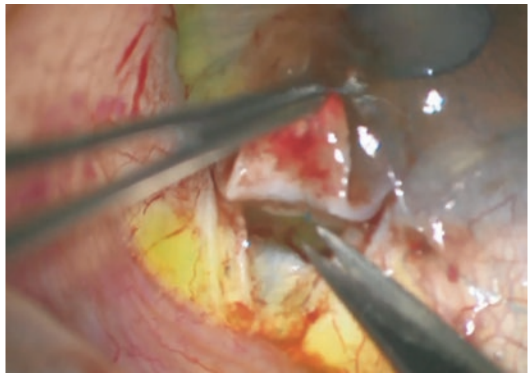

Fig. 5.13 Prolene suture in place, cutting of the end

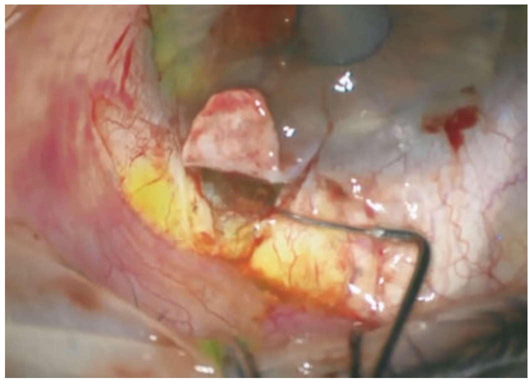

Fig. 5.14 Filling of the lake with Healon GV before suturing the flap

Material and Companies Address
Ellex Head Office – Australia

Ellex Medical Lasers Ltd.
82 Gilbert Street,
Adelaide, SA 5000 Australia
Phone +61 8 8104 5200
http://www.ellex.com

Part IV

Iris: Iris Surgery

Iris surgery has made a huge leap forward with the advent of a foldable iris prosthesis from Human Optics, Germany, and new iris instruments from Geuder, Germany. The iris prosthesis enables the treatment of aniridia with a 2.5 mm incision and the new instruments allow a simple surgery for traumatic mydriasis. **Asst. Prof. Spandau** will demonstrate the surgical techniques step by step and show several videos.

6 Iris Surgery

Ulrich Spandau

An iridoplasty has become surgically much easier with the introduction of a foldable iris prosthesis from Human Optics (Germany) and of novel iris instruments and suture from Geuder (Germany).

There are two surgical options for iris surgery. The first one is an iris prosthesis (Figs. 6.1 and 6.2) and the second is an iris suture (Fig. 6.3). An iris suture is more preferable than an iris prosthesis because it causes less anterior chamber irritation. The iridoplasty with an iris suture has been made possible for VR surgeons through the advent of novel iris instruments (Fig. 6.3, Geuder, Germany) and a suture with a short needle (Onatec, Germany) (Fig. 6.4). A traumatic mydriasis can be operated easily and a video for this technique is presented.

There are several important features which determine the surgical planning:

1. (Partial) iris defect (Figs. 6.5 and 6.6)?
2. Old traumatic mydriasis (Figs. 6.7 and 6.8)?
3. Aniridia and aphakia (Figs. 6.9, 6.10 and 6.11)?
4. Recent traumatic mydriasis (Figs. 6.12 and 6.13)?

Eyes with aniridia and aphakia secondary to trauma can be provided with an iris prosthesis and with/without an IOL prosthesis. The company Human Optics (Germany) produces a foldable iris prosthesis, which is hand painted (Fig. 6.1). It has a diameter of 12 mm and needs to be customized to the eye with a trephine (Opthec).

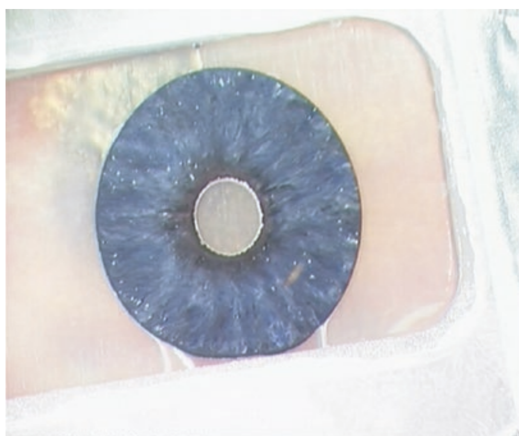

Fig. 6.1 A foldable and hand painted iris prosthesis from Human Optics (Germany). The material is Goretex. The body is 12 mm in diameter

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Prosthesis size for Human optic iris prosthesis:

Sulcus implantation: 10.0 mm
In the bag implantation: 9.0 mm

The companies Morcher (Germany) and Ophtec (The Netherlands) offer a combined iris and IOL prosthesis made from PMMA and are therefore not foldable (Fig. 6.11). Whereas Morcher produces a hand painted iris prosthesis offers Ophtec a range of four colours. The Morcher and Ophtec iris - IOL prosthesis require a 10.0 mm broad main incision.

Fig. 6.2 A non foldable and not hand painted iris + IOL prosthesis from Ophtec (Netherlands). The material is PMMA. The body is 12 mm in diameter

The foldable iris prosthesis from Human Optics can be implanted with an IOL injector into the sulcus (Figs. 6.14, 6.15, 6.16, 6.17, 6.18, 6.19, and 6.20). For eyes with aniridia and aphakia the iris prosthesis from Human Optics can be combined with a 3-piece IOL: The iris prosthesis is fixated into the haptics of a 3-piece IOL (MA60AC, Alcon). I call this a combo iris and IOL prosthesis. It is implanted through a 2.4 mm main incision with an IOL injector (Alcon).

Our surgical management is as follows:

In case of an aniridia and an old traumatic mydriasis we prefer the foldable iris prosthesis (Human Optics®). You can check if a traumatic mydriasis is feasible for surgery by pulling on the old iris with an intravitreal forceps. If it bleeds and cannot be constricted then a prosthesis is the only option.

In case of a fresh traumatic mydriasis, I recommend an iridoplasty with iris instruments from Geuder (Germany) and a special suture from Onatec®, Germany (Figs. 6.3 and 6.4). If an aphakia is also present I would perform an iridoplasty and implant at the same time a retropupillar iris claw-IOL (Figs. 6.21, 6.22, 6.23, and 6.24).

In case of an aniridia with aphakia, I prefer a combined iris and IOL prosthesis (Figs. 6.14, 6.15, 6.16, 6.17, 6.18, 6.19, and 6.20). The foldable iris

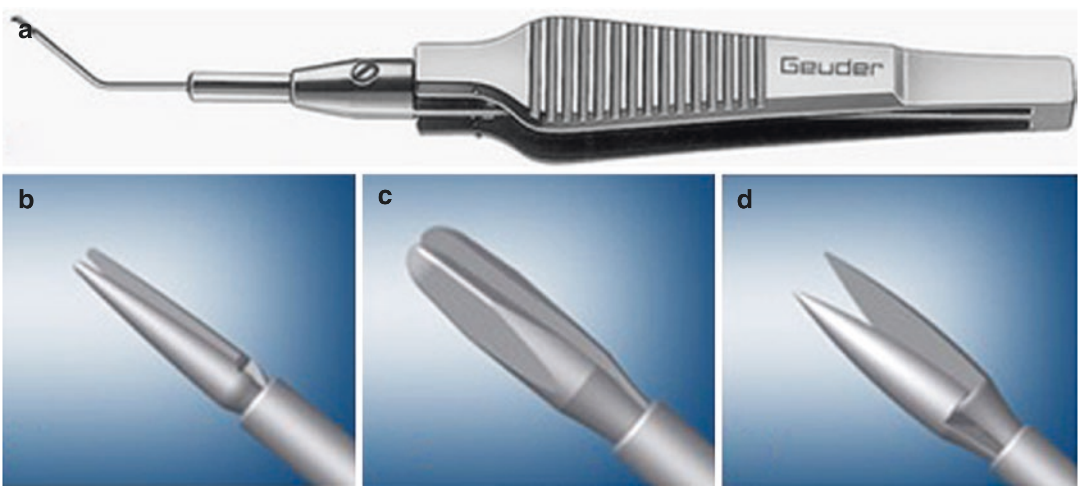

Fig. 6.3 (**a**–**d**) Hattenbach iris instruments from Geuder (Germany) (**a**). It includes a needle holder (**b**), an iris holder (**c**) and scissors (**d**). The instruments are very easy to use

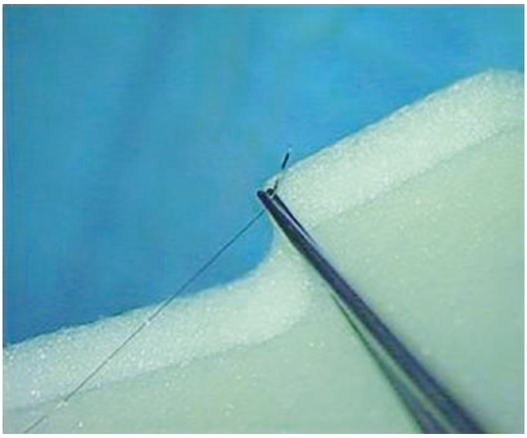

Fig. 6.4 A special suture with short needle for iris sutures (Onatec, Geuder, Germany)

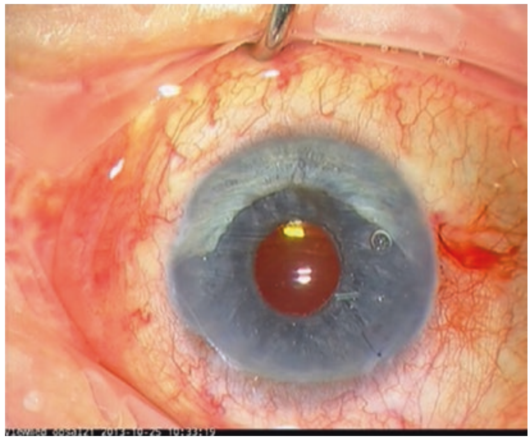

Fig. 6.6 After implantation of a hand painted Human Optics iris prosthesis into the sulcus

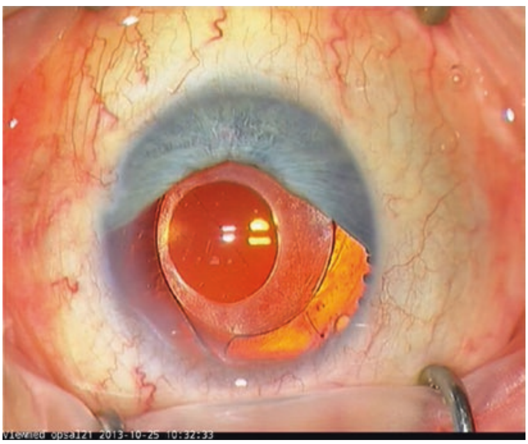

Fig. 6.5 A sector iris defect after complicated phacoemulsification

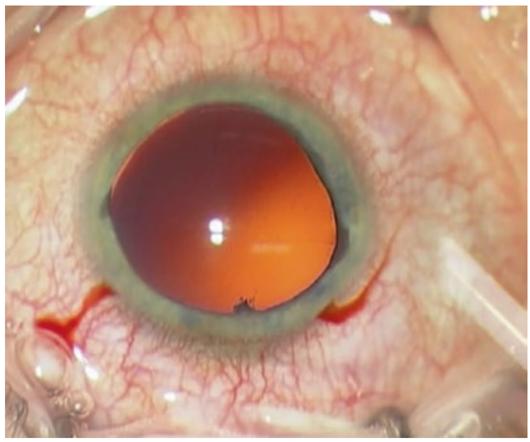

Fig. 6.7 An eye with an old traumatic mydriasis and natural lens

prosthesis is implanted together with a 3-piece IOL (Alcon, AMO). In case of aniridia with a phakic lens, I would implant the foldable iris with the IOL inside the bag.

Implantation site:

The Ophtec iris-IOL can be scleral fixated with a 9-0 polypropylene suture.

The artificial iris (Human Optics) can be implanted into the lens capsule or in the sulcus. The combo IOL-iris prosthesis can be implanted in the bag and be scleral fixated with 10-0 polypropylene suture. An alternative is a Scharioth intrascleral fixation with the 3-piece IOL.

Complications of the above mentioned surgical methods:

1. Iridoplasty for traumatic mydriasis: No complications.
2. Iridoplasty for sector defects: May cause an anterior chamber inflammation. A perioperative subconjunctival triamcinolone injection is recommended.
3. The foldable iris prosthesis in the sulcus position may cause a low grade chronic inflammation and discomfort if the diameter is too large. A diameter of 10 mm and a trephine (Opthec) is recommended.

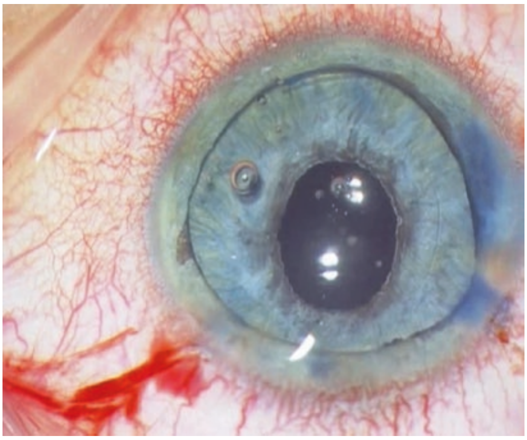

Fig. 6.8 After implantation of a hand painted Human Optics iris prosthesis together with a 3-piece IOL into the lens capsule

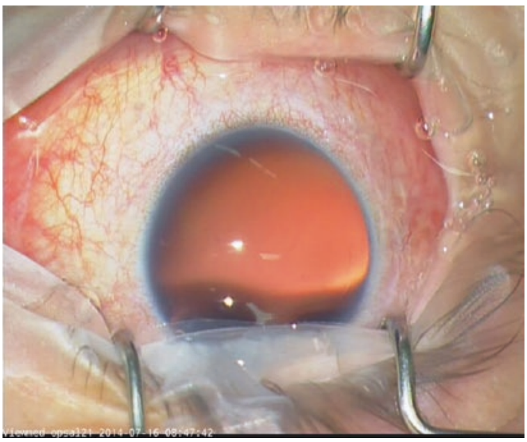

Fig. 6.9 An aniridia and aphakia after a blunt perforation with an i-pad

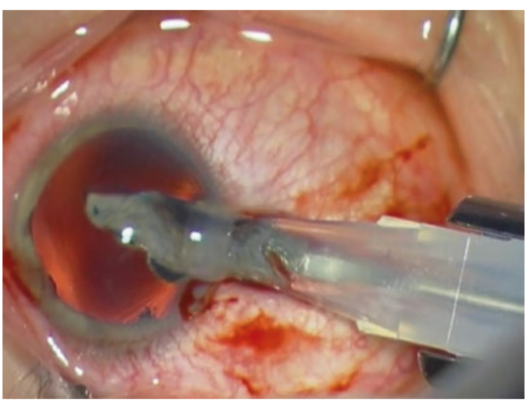

Fig. 6.10 Scleral fixation of a combined Human Optics iris prosthesis + 3-piece IOL

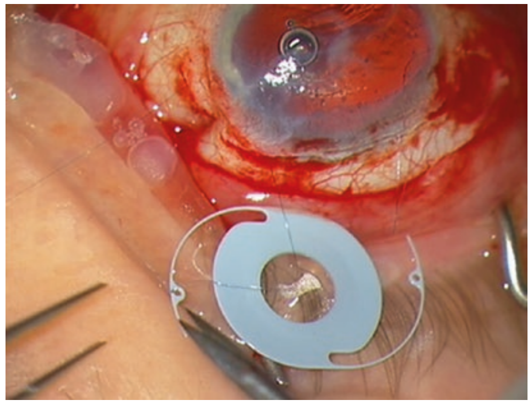

Fig. 6.11 Scleral fixation of a hard Opthec iris-IOL prosthesis (12 mm diameter)

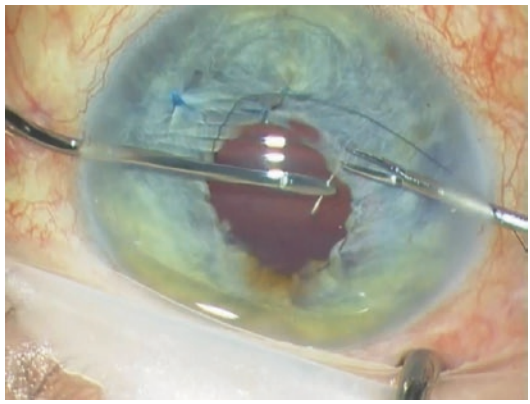

Fig. 6.12 Intraoperative view on an eye with a recent traumatic mydriasis and aphakia after blunt trauma. The Hattenbach iris instruments in action

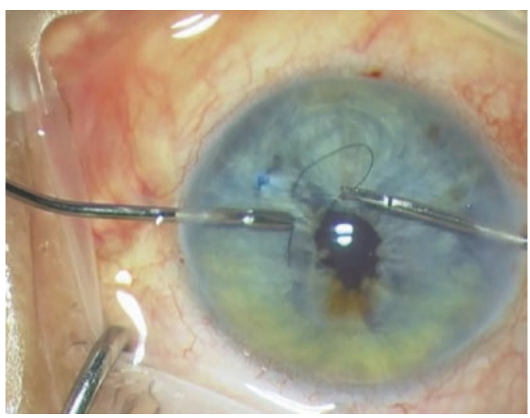

Fig. 6.13 After performing a purse string suture a retropupillar iris-claw IOL is implanted. Postoperative VA=1.0

Implantation of a Foldable Iris Prosthesis (Human Optics®)

Video 6.1: Foldable iris and IOL prosthesis (very short version).

Video 6.2: Combo IOL-iris prosthesis (long version).

Video 6.3: Combo IOL iris prosthesis in lens capsule (short version).

Instruments

1. 10 mm corneal trephine (Opthec)
2. 23G or 25G endgripping forceps
3. IOL injector

Material

Iris prosthesis (Human Optics)
MA60AC IOL (Alcon)

Individual steps

1. **Preparation of an iris-IOL prosthesis**
2. **Insertion of iris-IOL prosthesis into a cartridge**
3. **Implantation of iris-IOL prosthesis**
4. **Fixation of iris prosthesis**

The surgery step-by-step: Figs. 6.14, 6.15, 6.16, 6.17, 6.18, 6.19, and 6.20

1. **Preparation of an iris-IOL prosthesis**

The size of the iris prosthesis depends on an implantation in the sulcus or in the capsular bag. In case of a capsular bag implantation we use a 9.0 mm corneal trephine. In case of a sulcus implantation we use a 10.0 mm corneal trephine (Fig. 6.14). Place the 3-piece IOL on the backside of the foldable iris and place two incisions at each haptic with a 15 deg. knife (Alcon). Tunnel the 25G endgripping forceps through the two incisions, grab an end of a haptic and pull the haptic through the incisions (Figs. 6.15 and 6.16). Repeat the manoeuvre with the other haptic.

2. **Insertion of iris-IOL prosthesis into a cartridge**

Fig. 6.14 Cutting the Human Optics iris prosthesis (12 mm body) with a 10 mm trephine for sulcus implantation

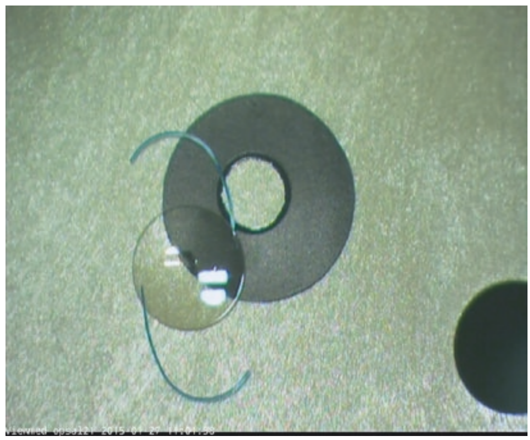

Fig. 6.15 A 3-piece IOL (Alcon, AMO) will be combined with the foldable prosthesis

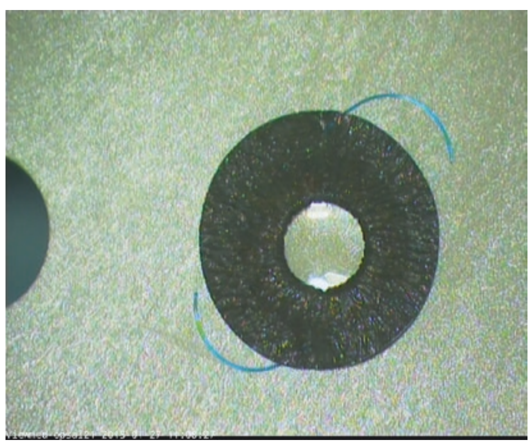

Fig. 6.16 The haptics of the 3-piece IOL were inserted into the iris prosthesis

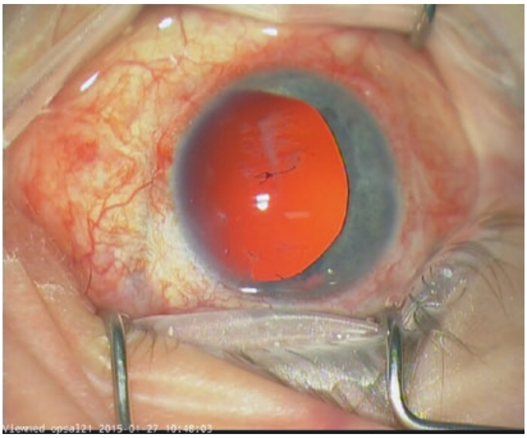

Fig. 6.17 The preoperative status after an explosive trauma. A healed corneal perforation, partial aniridia and aphakia

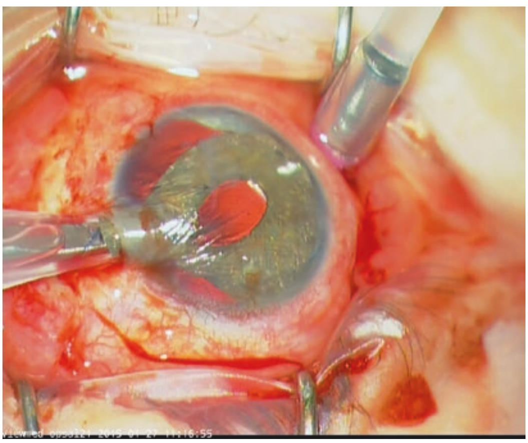

Fig. 6.18 Implantation of the combined iris prosthesis with 3-piece IOL with a regular IOL injector

3. **Implantation of iris-IOL prosthesis**

Fold or roll the combo prosthesis and insert it into an IOL cartridge (Alcon) and finally into an injector. Continue with a 2.4 mm main incision and implant then the combo iris-prosthesis into the anterior chamber (Fig. 6.18).

4. **Fixation of iris prosthesis**

Rotate the combo iris-IOL prosthesis into the lens capsule. If a lens capsule is not present a scleral fixation has to be performed: (1)

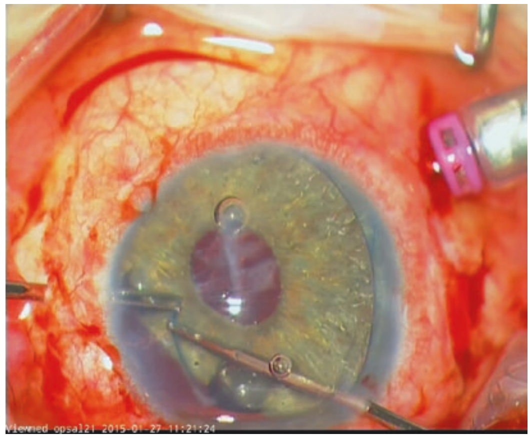

Fig. 6.19 Scleral fixation of the IOL

Intrascleral Schartioth method or (2) scleral fixation with sutures (Figs. 6.19 and 6.20). For details read the book "Complications during and after cataract surgery" from Ulrich Spandau and Gabor Scharioth.

Iridoplasty and Iris-claw IOL Implantation

Video 6.4: Iridoplasty for traumatic mydriasis.

Video 6.5: Iridoplasty for traumatic mydriasis + iris claw IOL.

Instruments

1. Iris instruments (Geuder)
2. 23G or 25G intravitreal scissors

Material

1. Onalene suture (Geuder)

Individual steps

1. **Anterior chamber maintainer or pars plana infusion**
2. **Four paracentesis at 12, 3, 6 and 9 o'clock**
3. **Insert the Onalene suture into the anterior chamber with a Sinskey hook**
4. **Perform a 360° suture around the pupillary margin (purse string suture)**

5. **Retropupillary implantation of the iris-claw IOL**
6. **Tying of the Onalene suture**

The surgery step-by-step: Figs. 6.21, 6.22, 6.23, and 6.24

1. **Anterior chamber maintainer or pars plana infusion**

Eyes with aphakia tend to be hypotony under surgery because the lens-iris diaphragma is impaired. In order to avoid intraoperative hypotony I recommend the use of an anterior chamber maintainer or even better a pars plana infusion. The anterior chamber maintainer may disturb the suturing within the anterior chamber.

2. **Four paracentesis at 12, 3, 6 and 9 o'clock**
3. **Insert the Onalene suture into the anterior chamber**

Perform a paracentesis at 12, 3, 6 and 9 o'clock. Then push the suture with a Sinskey hook (push-pull instrument) into the anterior chamber (Fig. 6.22).

4. **Perform a 360° suture around the pupillary margin (purse string suture)**

Place the needle behind the iris, pierce the tissue at the pupillary margin, grasp the needle with the second forceps and pull the needle completely through. Continue 360°. Before tying the suture we must implant the IOL (Fig. 6.23). Alternatively you could tie the suture now and implant the iris-claw IOL antepupillary.

5. **Retropupillary implantation of the iris-claw IOL**
6. **Tying of the Onalene suture**

Perform a 6 mm broad incision at the limbus or at the sclera. Place the IOL on the iris and rotate the claws at the 3 and 9 o'clock position. Hold the IOL in an upside-down position with the IOL forceps (AMO), place the IOL behind the iris. Now the assistant must pull on both

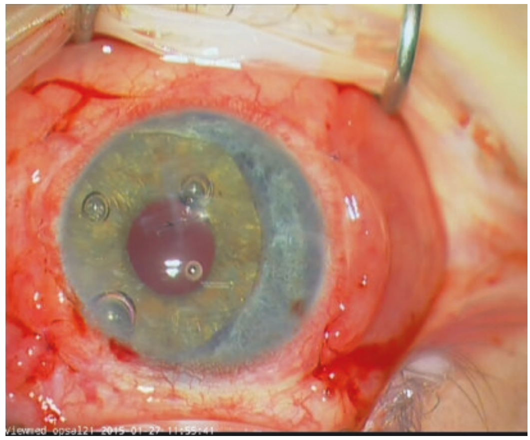

Fig. 6.20 Immediate postoperative status. The 3-month postoperative VA=0.4

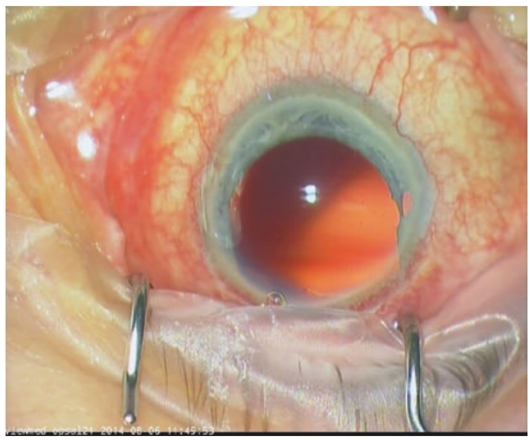

Fig. 6.21 A recent traumatic mydriasis and aphakia after a blunt trauma with a plastic ball

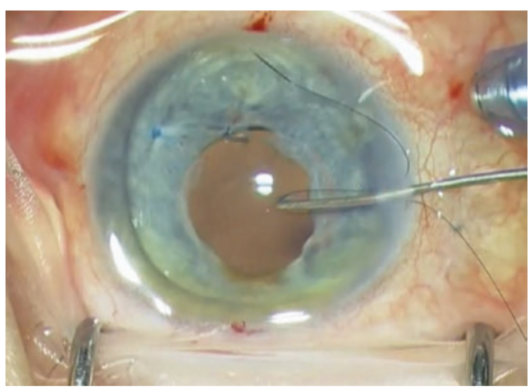

Fig. 6.22 Insert the suture into the anterior chamber with a Sinskey hook

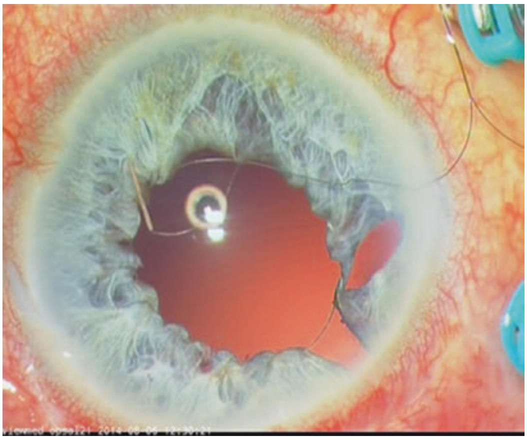

Fig. 6.23 Purse string suture with Hattenbach iris instruments

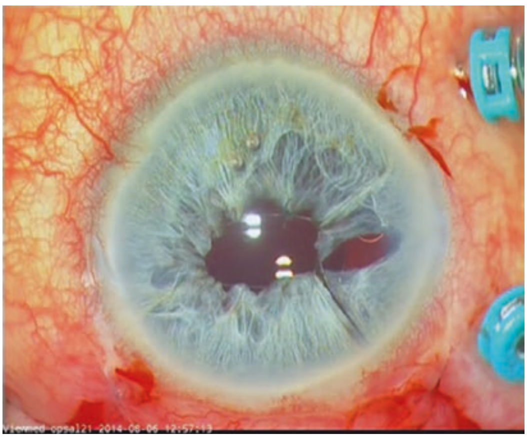

Fig. 6.24 After implantation of an Artisan IOL and closing the knot of the purse string suture. The 1- week postoperative VA=0.9

ends of the purse string suture so that the pupil is constricted. Using an iris spatula from Sekundo (Geuder) enclavate the iris tissue within the iris claws. Tie finally the purse string suture (Fig. 6.24).

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Part V

Cataract: Femto-Cataract, Laser Phaco, Congenital Cataract

The most exciting development in cataract surgery is surely the advent of the laser. **Prof. Nagy** from Budapest, Hungary, is the developer of the femto cataract. He will present his technique step-by-step and show the pros and cons of this exciting new surgery. **Dr. Sauder** from Stuttgart, Germany, will demonstrate a novel phaco handpiece which removes the nucleus with laser instead of ultrasound. And finally will **Dr Nyström** from Gothenburg, Sweden, demonstrates congenital cataract surgery with implantation of a Tassignon IOL.

7 Femtosecond Laser Assisted Cataract Surgery: Principles and Results

Zoltan Z. Nagy

Ophthalmology always had a pioneer role in use of lasers (Light Amplification by Stimulated Emission of Radiation). A great variety of lasers have been employed since the first laser appeared within the ophthalmic armamentarium for more than 50 years. The German ophthalmologist Meyer-Schwickerath applied the first laser for photocoagulation in the retina in 1949 [1]. A laser is a special surgical device which emits specific electromagnetic light via stimulated emission. Ophthalmic lasers operate at one specific fixed wavelength, pulse pattern, energy, duration, repetition rate, spot size and causing most of the time thermal effects, but photocoagulation, evaporation and non-thermal effects also important, regarding laser-tissue interaction.

Femtosecond lasers (Fig. 7.1) first applied in refractive surgery to replace mechanical and blade-operated microkeratomes to create corneal flaps during laser in situ keratomileusis (LASIK) [2]. Thereafter the indication has changed and widened to all types of lamellar and penetrating keratoplasties, ring-segment implantation in keratoconus and presbyopia inlay pocket creation [3, 4].

The femtosecond laser beam is sharply focused and generates plasma within the affected corneal tissue. This plasma rapidly expands causing an acoustic shock wave and by this way displacing the surrounding tissue, cavitation bubbles and a cut plane are formed. At tissue level, photodisruption occurs exactly at the laser's focal point without any thermal effect or collateral tissue damage. Due to the photodisruptive effect, the femtolasers are capable of creating very precise cuts within the cornea, lens capsule and crystalline lens (Fig. 7.2) by the principle of tissue separation [5].

The repetition rate of femtosecond lasers has doubled recently from 30 to 60 kHz and recently a 160 kHz femtosecond laser has also became available, which is able to create a corneal flap within 10–12 s. The higher the repetition rate, the less energy is needed to achieve the same tissue effect. Femtosecond lasers used in laser assisted cataract surgery perform with a pulse duration of 400–800 femtosecond (fs) and the energy range is in micro Joules (10^{-6} J). During the surgery of the crystalline lens of the eye, the femtosecond laser energy is usually increased to 8–15 µJ.

The femtosecond laser generated plasma rapidly expands causing an acoustic shock wave which displacing the surrounding tissue. When the plasma cools, cavitation bubbles are being formed [2, 3, 5]. At tissue level, photodisruption occurs without any thermal effect of the collateral tissue.

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-319-47226-3_7) contains supplementary material, which is available to authorized users.

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Fig. 7.1 The Alcon-LenSx femtolaser. The left monitor is for to set the treatment parameters, the right LCD monitor helps the surgeon throughout the femtolaser treatment, underneath the patient interface (PI) which comes into contact with the treated eye

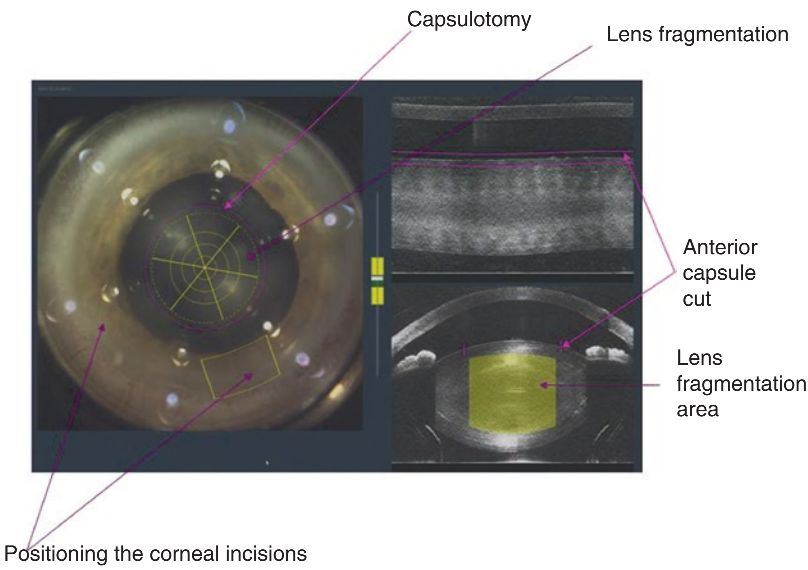

Fig. 7.2 Screen of the Alcon-LenSx femtolaser

Cataract surgery at the moment is the most commonly performed ocular implantation procedure not only within ophthalmology, but within medicine worldwide [6]. It is estimated that approximately 32 million cataract operations will be performed globally by 2020 with a gradual increase year by year, due to aging population, demographic changes, and the change in indications for surgery [9]. Cataract surgery and refractive surgery are being merged, so cataract surgery is not only a purely vision restoration entity, regarding the clarity of the optic media, but became a refractive procedure as well. Ophthalmic surgeons now also change the refractive power of the eye, compensate for astigmatism, spherical and other higher order aberrations of the eye. Further, the restoration of near vision has also become possible with the use of premium artificial lenses, such as multifocal or accommodating intraocular lenses [7, 8].

Patient expectation has also risen, doctors need to take longer chair time with patients explaining the benefits and drawbacks of different surgical approaches and using different intraocular lenses. [10]. To avoid refractive surprises possible solutions include better intraocular lens calculation using more precise formulas and performing a better and more thorough preoperative assessment, especially when the patient had refractive surgery before [11]. Now more consistent surgical results came in the focus of ophthalmic community which is no longer depending on the dexterity of the surgeon. In this field, femtolasers offer new possibilities and potential for surgeons and patients alike. Regarding the new trends in ophthalmology, compound and coupled diagnostic and surgical tools helping surgeons to achieve the final goal: the postoperative refraction should be within ±0.5 Dpt to ±0.25 Dpt as was achieved already in refractive surgery.

The Surgical Technique (Videos 7.1 and 7.2)

Docking Maneuver

The first and one of the most important steps of femtosecond laser assisted cataract surgery is the docking procedure with any types of femtosecond lasers. The Alcon-LenSx femtosecond laser (Fig. 7.1) operates with a curved soft contact lens which is integrated with a sterile limbal suction ring (SoftFit Patient Interface = PI). The tubing uses vacuum with a 16–20 mm Hg suction force to fixate the treated eye. The patient interface should be docked centrally then the rest of the procedure seems easier [12]. In case of decentered docking, incisions might be incomplete, due to paralaxis and geometrically attenuated femtolaser beam. Otherwise it is simple to dock and it provides a large viewing for the surgeon, which allows performing the peripheral corneal incisions and arcuate keratotomy incisions. Due to the low suction force, ocular perfusion and visual perception is usually not disturbed during the femtolaser pretreatment. With the new PI and soft contact lens use, there are no corneal folds, which allows using lower energy and the rate of free floating capsulotomy increased to 98 % [12]. Other femtosecond lasers also operate with a special PI, some of them using coupling fluid to avoid corneal folds. All femtosecond lasers at the moment using moderate suction force to stabilize the eye during femtolaser pretreatment.

The femtolaser has an in-built HD (high definition) optical coherence tomography (HD-OCT) system and a live video with a separate screen to assist the surgeon and to provide total control for the surgeon during the docking procedure and surgical pattern determination [12]. The OCT uses the same optical path as the laser beam. Therefore the surgeon knows by micrometer precision where the laser beam will incise within the ophthalmic tissues. The high-definition OCT (HD-OCT) covers the complete anterior segment of the eye up to the posterior capsule with dilated pupil and is also able to assess the clinical density of the crystalline lens. The surgical pattern is offered automatically and performed by the LenSx femtosecond laser. However, the surgeon should check and alter treatment parameters if necessary prior starting the treatment. The femtosecond laser produces approximately a 100 μm acoustic shock wave (very small); therefore a minimum of 500 μm safety distance from the posterior capsule is recommended (Fig. 7.2).

Due to the technical development a new preoperative assessment tool has been created, which is called the Verion system. It allows a complete preoperative assessment and postoperative follow-ups as well. Meanwhile with data transfer it helps the surgeon in the OR to perform the surgery with the greatest exactness. The Verion pre-operative assessment system identifies the conjunctival, scleral vessels and iris characteristics. In the OR all structures are recognized automatically and information is provided where to perform corneal incisions, shows the diameter and localization of the capsulotomy and helps implanting the intraocular lenses in the best available position, which is especially useful during toric lens implantation.

The first human femtolaser assisted cataract surgery was performed in 2008 by Zoltan Z. Nagy at Semmelweis University in Budapest, Hungary [5]. Since then the United States Food and Drug Administration (FDA) has granted approval and the European Conformité Europėene (CE) mark

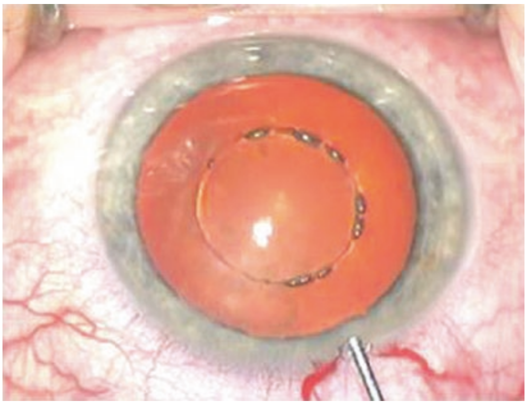

Fig. 7.3 Femto-capsulotomy sharp edge incision performed by the femtosecond laser before phacoemulsification

has granted for femtosecond lasers, and femtolasers became available for the public. There are currently four international companies producing and providing this new technology for cataract surgery. The number of peer-reviewed publications is increasing on femtosecond laser assisted cataract surgery and it is foreseen that within a decade the method could be spread generally in the largest ophthalmic centers in the world.

Indications

The main indications of the femtolaser during cataract surgery are:

- Anterior capsulotomy (4.5–7.0 mm) (Fig. 7.3.)
- Laser fragmentation and liquefaction of hard and soft lenses respectively, hybrid pattern: central liquefaction and fragmentation using a cake or cross pattern (six cuts at least)
- Single plane or multiplane corneal incisions with any geometry
- Arcuate corneal incisions to control pre-operative corneal astigmatism

Contraindications

- Small, non-dilating pupil (the only and relative contraindication)

The small, non-dilating pupil less than 6 mm in diameter is recognized as a relative contraindication to femtolaser cataract surgery (lens fragmentation). If the laser beam hits the iris it may cause more miosis and freeing inflammatory mediators within the iris. It is possible to perform an anterior capsulotomy with a 5.0 mm pupil, but there is a high risk of iris injury. Malyugin rings or iris hooks offer a good solution in such cases [13, 14].

The order of the three main steps of femtosecond laser assisted cataract surgery is as follows: first the anterior capsulotomy should be created, secondly the lens fragmentation and or liquefaction and thirdly the corneal incisions. The anterior capsulotomy is performed before the lens fragmentation/liquefaction because the lens fragmentation/liquefaction may create a gas bubble, which may elevate the anterior capsule. In that case the laser beam will not cut in the same plane as it was planned during the preoperative OCT assessment. The corneal incisions are performed lastly and they are performed from the inside to outside. Conjunctiva should be avoided. In the latter case the penetration with a special spatula can be quite difficult if not impossible.

Clinical Results

Capsulotomy Studies

During the first study the accuracy of the diameter of the anterior capsulotomies have been evaluated and compared to standard manual capsulotomies targeting also the same diameter of 5 mm and found that using the manual technique the diameter was 5.88 (±0.73) but it was 5.02 (±0.04) mm using the Alcon LenSx femtosecond laser. During the surgery of human crystalline lenses, the Alcon LenSx FSL was able to perform all capsulotomies within ±0.25 mm accuracy, whereas with the manual technique it was only achieved in 10 % of the eyes [15].

The in-the bag position with an 0.25–0.5 mm coverage of the posterior chamber lens by the anterior capsule, so the effective lens position (ELPo) is a very important parameter in predictability of postoperative achieved refraction against the planned one. Therefore exact IOL calculation especially with multifocal IOLs [10, 21]

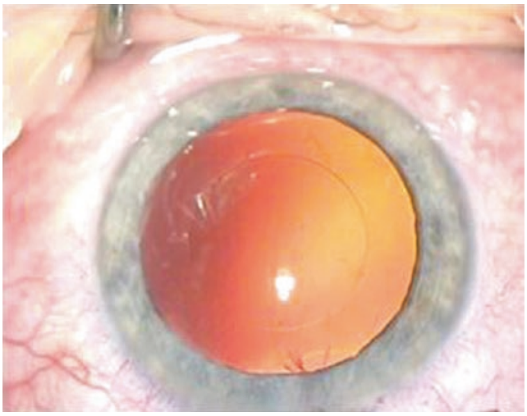

Fig. 7.4 Femto-capsulotomy after removal of the crystalline lens and before implantation of the posterior chamber lens

and the accuracy of the size and position of rhexis is very important regarding ELPo [14, 15] A recent study by Packer et al. reported that planning and achieving the capsulotomy centred on the optical axis of the lens with a diameter of 5.25 mm optimizes the consistency of final ELPo-s [20].

The size and central location of capsulorhexis is one of the most important factors to achieve the targeted accurate final post-operative refraction (Figs 7.3 and 7.4). In the literature there not too much about the accuracy of the standard manual technique because for more than two decades it has been the only method available, little attention has been paid to the effect of capsulotomy diameter and localization on the refractive outcome. A larger or smaller than intended rhexis may cause anterior or posterior shift of the IOL, respectively or IOL tilt [15–17]. In that cases myopic or hyperopic shift or increase in the higher order aberrations and possibly in the final ocular astigmatism may be the consequences. Irregular capsulotomies cannot provide enough defence against remaining epithelial cells so the incidence of posterior capsular opacification also may increase.

In a study of our team, it was found that Femto Second Laser (FSL) capsulotomies were not stronger compared to manual capsulotomies, but due to perfect circularity and central location, the predictability of tearing was much better than in manual capsulotomies [18, 19]. A capsule strength study found that capsulotomies performed by the OptiMedica FSL required two to three times more force to tear compared with the manual capsulotomies [17, 20].

So the real strength of FSL created capsulotomies is still debated in the literature and it is depending what method was used for force testing, but it is questionable that a less regular edge capsulotomy tested by the electron microscopy would be 3 times stronger than manual ones. Femtosecond laser creates small circular shape irregularities ("saw teeth shape") within the capsule, the lower the energy, the more regular is the edge of the capsulotomies and the stronger the capsule against tearing forces [18].

Circularity of the Anterior Capsulotomy and PCL Centration

Authors performed two studies at Semmelweis University in Budapest in an assessed the accuracy of the circularity of the femtosecond laser created rhexis with the Alcon LenSx and the effect on IOL centration postoperatively. They found that the LenSx performed anterior capsulotomy was more regular and circular shaped and provided better centration and capsule/IOL overlap compared with the manual capsulorhexis. Vertical and horizontal IOL decentration following the standard manually created rhexis was found to be statistically higher than the LenSx [15] even if capsulorhexis was performed by the same experienced surgeon.

In another anterior comparative study, anterior capsulotomy was created by the Alcon LenSx femtosecond laser (Figs. 7.3 and 7.4). The circularity was statistically significantly better in the FSL group ($p = 0.032$) and there was significantly less incomplete overlap of capsulotomies with the manual rhexis (28 % of eyes versus 11 %; $p = 0.033$). In highly myopic eyes the capsulotomy tended to be larger in the manual group than in normal eyes. The possible cause is the larger size of myopic eyes, the larger dilated pupil, which may deceive the surgeon assessing the relation to anatomy [16]. The letter one is very important in

ELPo and predictability, so in high myopic eyes the size and centration of capsulotomies have a higher importance than in eyes with normal axial length and less or no preoperative refractive error.

Lens Fragmentation and Phacoemulsification Energy Studies

The various femtosecond laser platforms offer different types of lens fragmentation. With soft lenses, LOCS grading less than 2.0, a central 0.25 mm central liquefaction is typically used. This technique is especially important in clear lens extraction, in patients with high myopia or high hyperopia or in presbyopic subjects who are seeking a refractive solution for the refractive error and not for cataract. During lens liquefaction concentric rings (cylindrical pattern) are created within the nucleus of the crystalline lens, rings elevate from the bottom toward the anterior part of the crystalline lens. With LOCS grading greater than 2.0, lens fragmentation is typically recommended and used. This can be a cross pattern (two perpendicular incisions within the lens), or can be customized with an increased number of cuts. Typically six cuts are performed and called "cake" or "pizza" pattern by the surgeons on the LenSx platform. The surgeon might decide to choose a hybrid pattern which means a central 3.0 mm diameter of liquefaction and a six lines fragmentation especially at the peripheral part of the crystalline lens [6]. This allows a quick nuclear removal and a help to fragment the remaining part of the crystalline lens. The final aim is to increase the safety of the method. The fragmentation length area should not be greater than 1–2.0 mm of the capsulorhexis diameter, due to the concave shape of the back of the lens surface. With longer fragmentation lines, the risk of trauma to the posterior capsule might be above acceptable risks.

Cubicle pattern was introduced first by another platform (Catalys), by now it is available in most types of the femtosecond lasers. The author found that using the cubicle pattern, two main planes are still required in order to chop the crystalline lens and to avoid the epinuclear 'bowl' phenomenon that can make the rest of the surgery really difficult to remove due to limited accessibility either to phaco or to irrigation-aspiration handpieces [13].

The use of the cross pattern and 'quick chop' surgical technique with the LenSx femtosecond laser compared to standard phacoemulsification resulted in a 43 % reduction in cumulative dissipative energy (CDE) and a 51 % reduction in effective phacoemulsification time (EPT) using the Infiniti (Alcon, Forth Worth, Texas, USA) phacoemulsification device already at the early phase of femtosecond laser use [5]. Since a decrease of more than 90 % is reported in the literature using FSL technology. Of course this result is depending what type of cataract is being pre-treated by the FSL.

Corneal and Limbal Incisions

Manually created incisions with a blade usually require stromal hydration at the conclusion of cataract surgery due to irregular, sometimes imprecise tunnel structure. If the wound is smaller than required a tear during phacoemulsification or lens implantation might be the consequence, therefore wound hydration is a must. If wound leaks during the postoperative period a lower intraocular pressure might cause the manual wound to open with free entering of bacteria from the conjunctival sac, leading possibly to endophthalmitis [22]. Precise wound position, geometry and architecture are very important in controlling postoperative infection and also to minimize surgically induced astigmatism (SIA) [22, 23]. FSL offers a new horizon due to precise wound geometry and architecture resulting in a better wound closure and no need for stromal hydration at the end of the surgery [22]. The consistency of wound structure is of utmost importance also important, especially implanting toric and multifocal IOLs [22]. Femtosecond laser created corneal incisions should be as peripheral as possible. Conjunctiva must be avoided, because if laser incision hits the conjunctiva the wound usually cannot be opened with the special blunt spatula. The reason is different laser absorption in conjunctiva and possible hemorrhage from peripheral conjunctival vessels may cause loss of laser absorption. In order to control preoperative corneal astigmatism corneal incisions can be arcuate or limbal relaxing and case reports with the LenSx and Catalys OptiMedica FSLs indicate successful correction of large amounts of corneal astigmatism [24].

The LenSx uses an image-guided capability enabling the control of corneal thickness, incision length, width, depth shape, and location. The surgeon may determine preoperatively the depth up to 90 % of thickness, the length and position of the corneal arcuate incisions. After planning the procedure is completely computer-controlled, precise and predictable. It is possible to open the incision immediately following the FSL pre-treatment or the surgeon can wait until the next post-operative day. With topography control, opening of the incisions might be customized at the slit lamp. This allows a better control of decreasing preoperative corneal astigmatism, according to the real need, which in turn increases predictability [22].

Refractive Outcomes, Fine Vision Tuning

A study from Semmelweis University, Budapest, compared internal aberrations and quality of vision in eyes treated with the LenSx FSL and standard manual phacoemulsification. The study was performed by the Nidek Optical Path Difference (OPD) scanner (NIDEK Inc., Japan) [8]. It was revealed that the anterior capsulotomy with the LenSx induced significantly less internal aberrations. Other outcome comparisons included: post-operative visual acuity (uncorrected and best corrected spectacle), residual refraction, ocular and internal aberrations, Strehl ratio and the modulation transfer function (MTF). No statistically significant differences were found between the post-operative refraction, and distant visual acuity (uncorrected and corrected), regarding standard manual phacoemulsification and femtosecond laser assisted cataract surgery (FLACS). On the other hand, the femtosecond treated eyes had lower values of intraocular vertical tilt (Z_1^{-1}) and coma aberrations (Z_3^{-1}), higher Strehl ratios and higher MTF values at all measured cycles per degree ($p < 0.05$) [8]. Other studies in the literature have reported no difference in post-operative refractive error between FSL and standard cataract surgery [25, 26].

Szigeti and colleagues found less IOL tilt and decentration with a FSL created anterior capsulorhexis of 5.5 mm compared with 6 mm [7] in case of implanting accommodative type of lenses (Crystalens). In this type of lens, the capsulotomy diameter should be above 5.0 mm in order to allow anterior and posterior movement of the implanted posterior chamber lenses. Subjective comparative studies on outcomes between FSL cataract surgery and standard manual cataract surgery regarding quality of vision and quality of life [10] are still scarce and welcomed.

Safety Issues

Effects on the Corneal Endothelium

It is estimated that there is 8.5 % endothelial loss with standard cataract surgery [27]. Abell and colleagues found no difference in endothelial cell loss between the Catalys OptiMedica FSL and standard cataract surgery 3 weeks post-operatively. Abell performed femtosecond laser assisted cataract surgery in a group of 405 eyes; among them 118 had automated laser corneal incisions and 287 had manual corneal incisions. Interestingly, endothelial cell loss was significantly less in eyes with manually created corneal incisions [28].

Takács and colleagues compared the corneal thickness, corneal volume stress index, and endothelial density following FSL with the LenSx and standard cataract surgery. They reported better outcomes with the LenSx in the early post-operative period in terms of significantly lower corneal thickness compared to the manual group; and the difference disappeared by the second postoperative week and 1 month. Presumed causes for this finding account for the less phacoemulsification time and corneal edema associated with the FSL technique [27]. Therefore FSL assisted cataract surgery might be an option in eyes with reduced endothelial number, e.g.: Fuchs disease, previous ocular surgery, glaucoma, etc.

Effects on the Macula

In the most recent studies macular problems following FSL surgery seem no safety issue. In a study comparing changes in macular thickness following FSL with the LenSx versus standard cataract surgery, there was less gain in macular thickness in the FSL group at 1 week postoperatively and there was no difference after 1 month [29]. Nagy et al. also compared thickness changes in the retinal layers in the macula with optical coherence tomography (OCT) after femtosecond laser-assisted phacoemulsification (study group) and conventional manual phacoemulsification (control group). After cataract surgery, macular edema was detectable mainly in the outer nuclear layer in both groups but was significantly less using the femtosecond laser technology, presumably due to shorter phacoemulsification time and less ultrasound energy. Uveitis patients may therefore also benefit from FSL cataract surgery. Less cystoid macular edema (CME) might be expected due to above mentioned facts [30]. Levitz et al. reported also no difference in macular edema between groups of patients having FSL cataract surgery compared to standard manual phacoemulsification [31].

Complications

Complications are rare with the FSL. The most common issues encountered are:

Pupillary Constriction

Pupillary dilation is an important issue during preoperative care in FSL surgery. The pupil diameter should be at least 6 mm to avoid iris injury. In case of poorly dilated pupil, bleeding and inadvertent miosis may occur. At the early stage authors experienced miosis in 1/3 of the femtosecond laser pretreated eyes, the reason behind was the elevation of prostaglandin (PG) level in the anterior chamber (within the aqueous). By now it is cleared based on lab test and peer-reviewed literature data, that the PG level might elevate de novo during FSL surgery [13, 32]. Preoperatively additional dilating drops and non-steroidal anti-inflammatory drugs (NSAIDS) should be used to prevent disabling miosis [32]. In case of small, non- dilating or adhered pupil, Malyugin ring or iris hooks offer a good solution [13, 14].

Capsular Blockage Syndrome

Roberts and colleagues were the first to report capsular block syndrome, occurring during the first cases of FSL surgery [33]. A capsular block syndrome usually occurs during hydrodissection if the fluid is injected with high volume and speed under the anterior capsule and intranuclear/−lenticular gas bubbles are pressed towards the posterior capsule. The gas bubbles may rupture the posterior capsule followed subsequently by drop of the nucleus into the vitreous cavity. The ‘rock and roll’ technique described by Nagy reduces the risk of this possible complication [13]. The technique involves slow and titred injection of hydrodissection fluid and careful moving of the nucleus which helps to release intra-lenticular gas bubbles. By this way the intralenticular gas leaves the eye toward the anterior chamber and then through the corneal wound. The rock refers to gentle down and upward force to the lens and the roll refers to the gentle moving around of the crystalline lens. This is the most important safety maneuver during the first part following femtosecond laser assisted pretreatment.

Corneal Incisions

With a thorough preoperative planning and the proper insertion of PI, the surgeon is able to ensure the optimal anatomical situation to perform a central and even free-floating capsulotomy, as peripheral as possible corneal wounds and a proper liquefaction/even fragmentation within the crystalline lens. Precise docking has a paramount importance avoiding lens tilt, centrally localized corneal wounds, creating higher surgically induced astigmatism which was expected and uneven cuts within the crystalline lens [22].

Other complications listed in the literature include anterior capsule tear and clinically significant increases in intraocular pressure (with the Victus platform) [34]. In a very large study by Abell et al. evaluating 4080 eyes, 1852 had FSL assisted cataract surgery with the Catalys Laser System, an incomplete capsulotomy was found to occur in 21 eyes. An anterior capsulotomy tag occurred in 30 eyes compared to one with non-FSL surgery (P = 0.001). Posterior capsular tear occurred in eight eyes compared to four with non-FSL surgery, which was not statistically significant. Usually most of the complications occurred during the first 100 cases. Certainly there is a learning curve for surgeons. FSL technology is different from standard manual phacoemulsification. Surgeons should respect this fact and should start surgery with a slower technique compared to manual phacoemulsification. Corneal haze occurred in 12 eyes compared to one with non-FSL surgery (P = 0.0009), the reason behind this is unknown. An unstable pupil was experienced by the surgeons in 30 eyes compared to 14 with non-FSL surgery (P = 0.003) [26]. The latter is extremely important in eyes with floppy iris syndrome. More pupil dilation and preoperative non-steroid anti-inflammatory drops one day earlier may help to avoid unwanted pupillary constriction during surgery.

Special Indications

FSL cataract surgery has been successfully used in ocular trauma [35], phacomorphic glaucoma [14], following penetrating keratoplasty [36], keratoconus, Marfan syndrome [37], in a nanophthalmic eye [38], in Alport syndrome [39] and pediatric cataract surgery [40], white intumescent cataract. The indications of FSL assisted cataract surgery still widens and more indications are to be expected in the future [41]. Special focus should be placed on the pediatric cataract. The anterior and posterior capsulotomies are prone to have a larger diameter than planned due to the elastic lens capsule. FSL helps avoiding inadvertently larger capsulotomies in infants and young children. There should be a solution to avoid the need to use double PI-s with unnecessary doubled costs in pediatric cases.

Conclusion

The FSL at present is utilized in four main areas: corneal incisions, anterior capsulotomy, lens fragmentation and arcuate corneal incisions to control preoperative corneal astigmatism. Customized corneal wounds with any geometry, size and location, desired centration of capsulotomy, guaranteed size of capsulotomy diameter, pre-fragmented or liquefied lens nucleus offers increased precision and predictability and higher consistency in postoperative refractive results. FSL technology is still an expensive technology with additional costs compared to standard phacoemulsification. Peer-reviewed studies are still needed, with more realistic pricing and then a quicker spread of this technology is expected.

Material and Companies Adress

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https://www.myalcon.com/products/surgical/lensx-laser/index.shtml

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8 Nano Laser Photofragmentation

S. Mödl, E. Ruf, and Gangolf Sauder

The use of lasers for the fragmentation of the lens in cataract surgery is an interesting alternative to traditional ultrasonic phacoemulsification. Since the beginning of phacoemulsification it has been a constant ambition to reduce the operative trauma and collateral damage of intraocular tissue during phacoemulsification. Parameters to be changed are operating time, total intraocular energy used, incision size, tissue heating, corneal endothelial cell loss and induced corneal astigmatism. During the last years different laser systems have been developed to minimize thermal and mechanical damage of the intraocular tissue [1–3].

One possibility to replace phacoenergy by laser energy is the usage of Nd:YAG lasers. Laser technologies like the Nd:YAG laser have been studied for use in the removal of cataractous lens tissue for nearly two decades [4]. One disadvantage of this procedure was that laser energy could be used only partly for the disruption of the lens tissue and only very soft nuclei could be emulsified efficiently. This technique has been continuously improved. Studies have demonstrated the ability of a Nd:YAG laser system to safely and effectively emulsify the lens nucleus [5]. The cetus nano laser (A.R.C. Laser company) is a pulsed Nd:YAG laser with a wavelength of 1064 nm. The laser light is carried by a 300 μm fiber and hits a titanium target inside the tip, thus generating a plasma followed by a circumscript cavitation just around the opening (Fig. 8.1). The laser induced plasma and shock wave disrupt the nuclear material and thus induce a photofragmentation of the crystalline lens into particles, which then can be aspirated through the same needle. Similar to conventional phacoemulsification irrigation can be done via the same handpiece (Fig. 8.2).

Using this technique no laser light is being emitted into the eye because the lens material is emulsified indirectly. The nano laser is effective

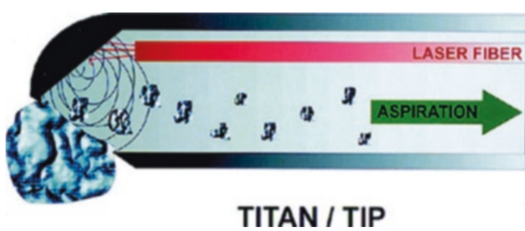

Fig. 8.1 The titan tip of a nano laser (ARC, Germany). The laser induces a plasma and shock wave and disrupts the nucleus. The nuclear material is aspirated through the same needle

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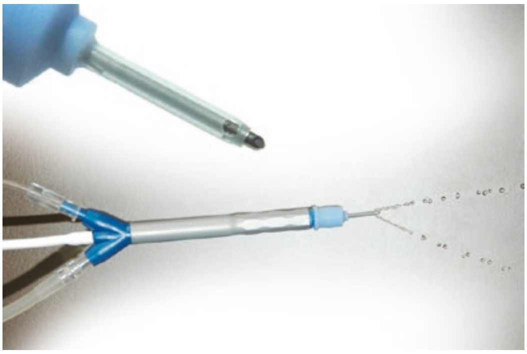

Fig. 8.2 Similar to phacoemulsification the irrigation is done with the same handpiece

for lenses with grade 1–4 nuclear sclerosis (LOCS-classification).

Nano laser photofragmentation and ultrasonic phacoemulsification are two physically completely different techniques, resulting in different conditions during surgery.

The holdability of the lens particles in the phaco procedure is superior to the nano laser because the laser induced cavitation out of the port and the aspiration in the opposite direction are always competing with itself. The holdability has been improved by shortening the nano laser pulses. The deep impaling necessary for an efficient chopping technique is not possible because the laser handpiece is missing the phaco oscillations.

In clinical practice two different techniques for the removal of lens tissue proved to be effective.

Softer nuclei (LOCS 1–2) can be removed with a so called bowling technique. The lens nucleus is photo fragmented by slightly rotating the tip down posteriorly from the middle of the surface. The tip is positioned with the port bevel down to protect the corneal endothelium. The epinucleus and cortex need to be untouched in order to protect the posterior capsule. For harder cataracts a lower frequency of laser pulses should be used. After the removal of the nucleus the epinucleus and cortex can be aspirated with the standard I/A.

Technical data	
	Nano Laser Cetus (A.R.C. Laser company)
Handpiece	Quartz fiber (300 μm)
Single pulse energy	0–10 mJ
frequency	0–20 Hz
Single pulse duration	8 nsec
Vacuum	250–350 mmHg

Harder cataracts (LOCS 3–4) can be more efficiently emulsified by a "groove & crack" technique. Again with port bevel down a small hole or a little grove is created in the lens center up to approximately 50 % of the lens thickness. Then the lens nucleus can be cracked with a second instrument, for example an iris hook or a Neuhann chopper. With aspiration half of the lens can be elevated in the iris level to fragment the half completely. If possible the same technique can be used to produce four quadrants. After removal of the nucleus the cortex and epinucleus are aspirated.

The complete nano laser cataract surgery is performed with single use instruments and thus features a very high hygienic standard.

The theoretically expectation and advantage of the laser photofragmentation over phacoemulsification are the lesser induction of shockwaves resulting in a gentler effect on corneal endothelium and intraocular tissue.

A major difference of the laser photofragmentation is the operation time which implies a higher consumption of jetting liquid and which would theoretically lead to a higher corneal endothelial cell loss.

First own investigations demonstrated a 20 % higher fluid consumption with the laser procedure compared to conventional phacoemulsification and a longer effective laser–/phacotime. Concerning endothelial cell count and corneal thickness no significant differences were found. Intraocular energy release was significantly lower using the laser technology which might have a protective effect on the corneal endothelium. No differences could be shown for postoperative corrected visual acuity.

Conclusion

In addition to phacoemulsification as the gold standard nano laser photolysis is an efficient and safe procedure in cataract surgery. Main advantages are the lowest possible intraocular energy and heat release and minimal mechanical complications. A further advantage is that the complete cataract surgery is performed with single use instruments. Disadvantages are the longer operation time and the harder manipulation of the lens nucleus due to different physical characteristics of the laser photolysis compared to phacoemulsification.

Nano laser photofragmentation is a promising new procedure for cataractous lens removal. Further studies are required to see if this new technique is to be an improvement over current techniques.

FAQ

1. *What are the advantages of laser compared to ultrasound regarding phacoemulsification?*
   The main advantages of the Nano laser compared to ultrasound are much lower required energy levels, no thermal or mechanical side effects and the possibility to perform the whole procedure with single use instrument
2. *How high is the risk of the input of laser energy for the eye?*
   As no laser radiation is being emitted directly into the eye there is no risk of any laser induced damage to the intraocular tissue
3. *How long is the learning curve?*
   The learning curve is short. An experienced phaco surgeon needs only a few weeks to adapt to this new technique.
4. *What are the main surgical differences when changing from phaco to laser?*
   There are two major differences an experienced phaco surgeon has to adapt to when switching to Nano laser photo fragmentation. First the holdability of the lens particles is reduced using the laser technique compared to phacoemulsification. Second the deep impaling needed for an efficient chopping procedure is not possible with the Nano laser. Because of these different characteristics different surgical techniques as described above are required.
5. *How high is the risk to rupture the posterior capsule?*
   The risk to rupture the posterior capsule is low due to the operating method of the laser. If the laser is pointed at the posterior capsule no rupture occurs unless the capsule is aspirated at the same time. In such a case a circular hole in the posterior capsule occurs similar to a posterior capsulorhexis.
6. *If we assume a surgical time of 10 min with phacoemulsification for a LOCS 3 nucleus; how long does it take with the laser handpiece?*
   In our whole study group (30 nano laser patients and 30 phacoemulsification patients) a surgical time of 10 min was never needed.

Material and Companies Adress

A.R.C. Laser GmbH
Bessemerstraße 14
90411 Nürnberg
Germany
http://www.arclaser.de/en/

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9 Congenital Cataract Surgery

Alf Nyström, Lothar Schneider, and Ulrich Spandau

Indication for Surgery

To develop vision in an eye, a child must have an image on the retina. This can be checked with retinoscopy in a non-dilated child. Note that newborns often have very small pupils which are much bigger only a few weeks later.

A child with a non-dilated retinoscopy reflex has a good enough image which can be left without surgery regardless in which area the lens is opacified. If a child has a readable retinoscopy reflex then follow up with retinoscopy and a vision test (Fig. 9.1). If visual acuity under repeated examinations does not rise or even drops then the child should undergo surgery. Within the first 3 months of life at least two examinations should be performed, and then every second month within the first year and every third month within the second year of life.

If the child does not have a readable retinoscopy reflex and haze covers the pupil, the child should then undergo surgery; otherwise severe amblyopia will develop.

It is advantageous to carry out surgery after the age of 1 month in order to reduce the risk of secondary glaucoma and not later than 7–8 weeks to reduce the risk of grave amblyopia. After 3 months, the child often has a nystagmus if surgery has not been carried out, and reduces the chance of good visual acuity levels.

If the child does not have a readable retinoscopy reflex but the opacity does not completely cover the pupil, then the retinoscopy reflex is

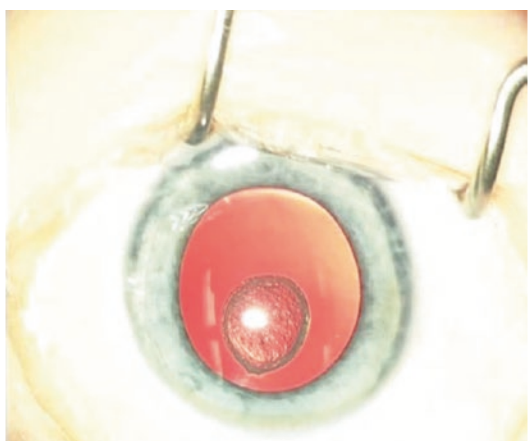

Fig. 9.1 A lens with inferior opacification and retinoscopy reflex

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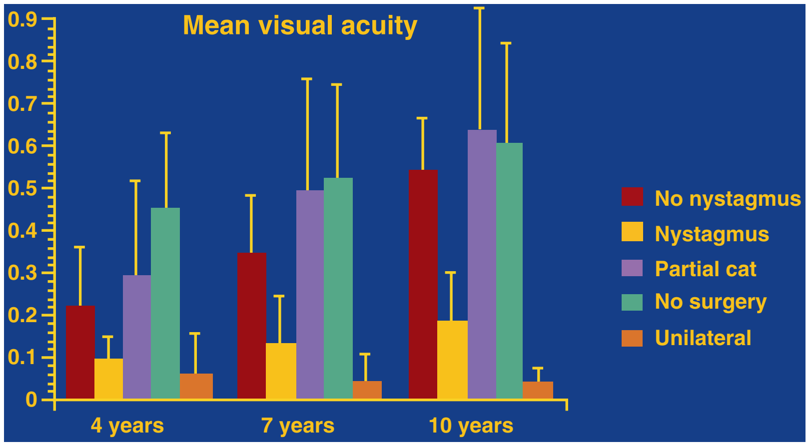

Fig. 9.2 Development of visual acuity of children with congenital cataract. Observe the poor VA for eyes with nystagmus and the increasing VA for eyes with no surgery

adjusted by adding different glasses. Not infrequently, cataract eyes are short and thus greatly hyperopic, but also grave myopia occurs due to a small anterior segment or spherical lens shape. It does not require so many diopters ametropia for the retinoscopy reflex to deteriorate.

If you achieve a retinoscopy reflex with glass then you should refrain from surgery and following the above actions.

Why should you not operate a partial cataract?

The child's visual development is faster if it is phakic than if it is pseudophakic or aphakic (Fig. 9.2).

Unilateral cataracts should probably be operated slightly earlier. Unilateral cataracts are seldom caused by a syndrome and the risk for glaucoma is less (this does not apply for very small eyes).

Intraocular Lens

Video 9.1: 3D animation Bag in the lens.

The Morcher 89 A IOL (Tassignon IOL, Fig. 9.3) is hydrophilic and called a BIL (Bag in the lens IOL) because the anterior and posterior lens capsules are clamped inside the IOL (Fig. 9.3). There are two sizes of IOL, one for adults and one for children. In the most cases an adult IOL (89 A) is used even in children eyes. In case of small eye and poorly dilated pupil the model 89D is preferred (Fig. 9.4).

The advantages of the Morcher 89 A IOL is that no posterior capsular opacification forms, the view to the fundus is excellent. The IOL causes much less inflammation than a usual three-piece IOL. Finally, in case of severe ametropia the IOL can be explanted against a new Tassignon IOL.

Morcher IOL type	Total diameter	Optic diameter
Type 89 A	7.5 mm	5.0 mm
Type 89D	6.5 mm	4.5 mm

Figure 9.4: There are two different sizes of "Tassignon" IOL.

Die IOL has an anterior and posterior haptic (Fig. 9.3). Between both haptics is a lens groove. Both rhexis sheets are located in this groove. Both haptics are located at a 90° angle to each other. The IOL is implanted so that the posterior haptic points towards 6 o'clock.

Target Refraction of IOL

In order to find out the target refraction the normal ocular axial growth curve from Sampaolesi is required (Fig. 9.4) [1]:

Example Congenital cataract in a 4 month old child, The AXL is measured with 20 mm. The Normal ocular axial growth curve from Sampaolesi (Fig. 9.4) shows now that the AXL will be 23 mm at the age of 80 months (6.5 years). The difference between 23 mm–20 mm=3 mm.

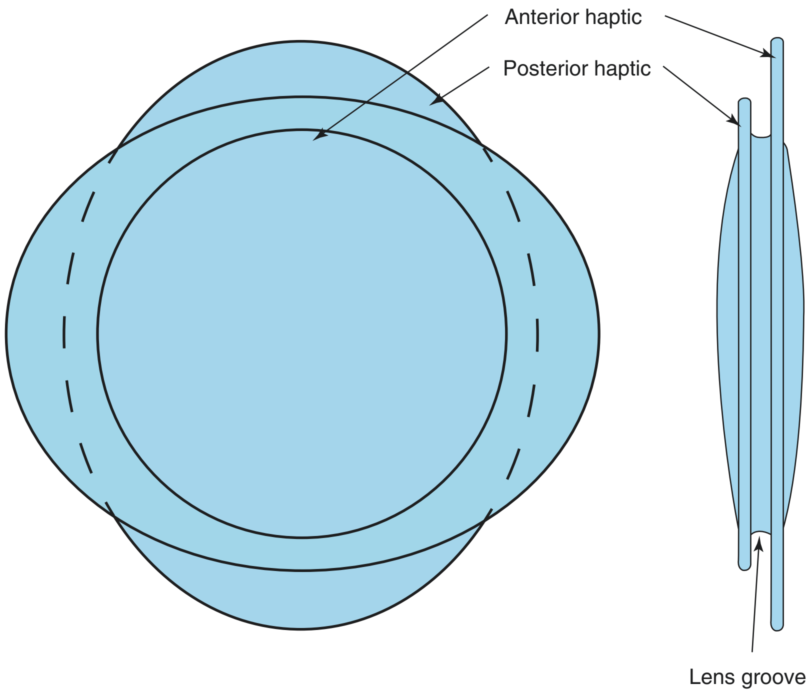

Fig. 9.3 The 89 A MORCHER hydrophilic IOL. The IOL has an anterior and posterior haptic and a groove between both haptics (Photocourtesy Morcher)

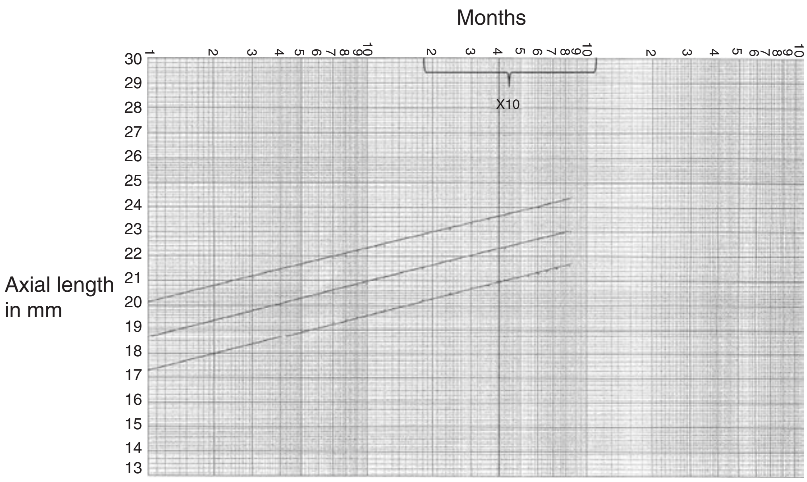

Fig. 9.4 The normal ocular axial growth curve from Sampaolesi. The scale is logarithmic. Note that on the months scale the months on the left are 2–10 months and in the middle 20–100 months

Three millimeter equals 9D (1 D=3 mm). The target refraction is therefore +9D.

Remark Short eyes tend to grow less (require approximately 2D less target refraction); long eyes tend to grow more (approximately 2D more target refraction); Down syndrome eyes tend to grow significantly more (approximately 4D more target refraction) (unpublished results).

Surgical Protocol

Video 9.2: Child's eye.

Surgical protocol according to Prof Tassignon [2] (Fig. 9.5)

- Opening of the limbus with a knife 2.8 mm (eventually 2.5 mm) [1]

Fig. 9.5 Surgical tray for congenital cataract (Photocourtesy Morcher)

- Injection of 1.0 ml adrenalin solution (see procedure medication) [2]
- Injection of Healon GV for corneal protection [3]
- Insertion of the caliper ring type 5 NO Tassignon [4] using the ring caliper inserter (sk-7017 EyeTech) [5]
- Opening of the anterior capsule with the capsulorhexis forceps [6] (Ikeda 30° forceps) (Rr. 2268 EyeTech)
- Removing the caliper ring
- Injection of BSS between the lens and the capsule, hydrodissection [7]
- Phaco-emulsion of the lens content [8]
- Removing lens remnants with the I/A mode [9]
- Cleaning the capsule with BSS using the Helsinki needle (1273E Steriseal)
- Injection of Healon GV on top of the anterior capsule [3] (never fill the capsular bag!)
- Puncturing of the posterior capsule by using the tuberculin needle or 36G needle [10]
- Injection of Healon through the puncture hole within the space of Berger until the size of the blister is slightly larger than the anterior capsulorhexis [11]
- Attention not to overfill the space of Berger
- Performing the capsulorhexis with the Ikeda forceps [6]
- Insertion of the lens with the injector (Medicel Lp 604,410)
- Injection of miostat [12]
- Removing of the Healon with the I/A mode
- Refilling the anterior chamber with BSS and hydration of the corneal wound [9]
- Control of the water tightness of the wound
- Injection of zinacef solution (see procedure medication) [13]

P.S. In pediatric cataracts the procedure is slightly different

- Ring caliper 4.5 mm is used
- Two sight ports of 1.0 mm are used for lens removal
- Injection of Healon into the space of Berger by means of a 41 G needle (Dorc 1270.0.100)

Instrumentation list [2]

No.	Description	Comments	Ref. no.	Manufacturer
1	"Bag-in-the-lens" foldable IOL	28 % hydrophylic acrylic	89 A–D-E-F	MORCHER®
2	Ring caliper (4.5 – 5.0 – 6.0)	To caliper the position of the anterior capsulorhexis	Type 4 L Type 5 NO	MORCHER®
3	Tassignon caliper ring positioner	To position the ring caliper in the eye	sh-7017	EyeTech
4	Lkeda angled 30° capsulorhexis 23.0 g forceps	To perform anterior and posterior capsulorhexis	Fr 2268	EyeTech

No.	Description	Comments	Ref. no.	Manufacturer
5	Straight scissors in curved shaft	To adjust the capsulorhexis if needed	Fr 2295c	EyeTech
6	Naviject injector atraumatic/ naviglide cartridge 2.5-IP injector set foldable cartridge 2.8-IP injector set foldable	Up to +20.0 diopters For all diopters	Lp 604,420 Lp 604,410	Medicel
7	Rycroft/ Helsinki hydrodissection needle 27G	To inject dispersive viscoelastic behind the posterior capsule	1273E	Steriseal Oasis
8	41G needle (same type from two different manufacturers)	Idem than 7 but to be used in babies and children	E7370 1270.0.100	Bausch & Lomb Dorc
9	Corydon cannula	Curved hydrodissection cannula		Beaver Visitec Moria

Surgical protocol in detail according to the University of Gothenburg, Sweden

Video 9.3: 4 weeks old newborn.
Video 9.4: 2 1/2 years child.
Video 9.5: IOL implantation.

Paracentesis and tunnel (Fig. 9.6) The superior rectus muscle is clamped with a surgical forceps and a holding suture (silk 4.0) is fixated to the muscle. Continue with a small peritomy at 1:30 and then a 20 g paracentesis with Alcon V-lance. Inject Healon GV in the anterior chamber. You can stain the anterior capsule with Vision Blue but the lens capsule stains much less compared to adults. The next step is a peritomy at 12 o’clock, dissect a 3 mm wide sclerocorneal tunnel first with the crescent knife then enter the anterior chamber with an ordinary tunnel knife. Place a 5.0 mm caliper ring (Morcher) with a ring caliper inserter (Eye tech) or a Sinskey hook onto the anterior lens capsule.

Fig. 9.6 A congenital cataract with posterior pole opacification

Anterior capsular rhexis (Fig. 9.7) Puncture the anterior capsule with a cystotome. If the lens capsule is too fibrotic puncture it with a 20G lance (Alcon). Puncture the lens capsule in an area without disturbing reflections so that the capsular rhexis can begin in a controlled fashion. The capsular rhexis is performed with the Ikeda forceps (Eye Tech), always make short strokes/movements with the forceps and observe the whole time how the rhexis behaves. In the inferior periphery the rhexis often has a tendency to move

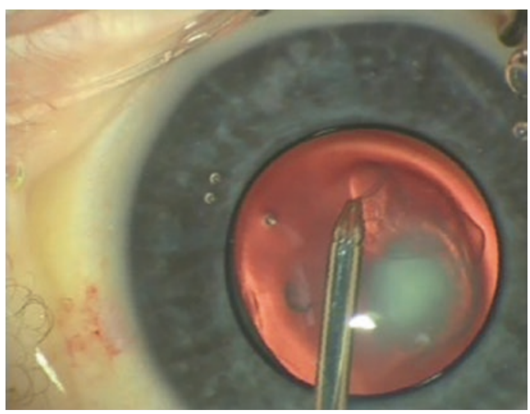

Fig. 9.7 Anterior capsular rhexis with the Ikeda forceps

outwards; just the opposite to the superior periphery where the rhexis has the tendency to move inwards. If necessary recenter the caliper ring. If the lens capsule is too fibrotic and the rhexis cannot be continued then use the curved 20G scissors (Eye Tech). Finally, remove the caliper ring.

Lens removal (Fig. 9.8) First move the straight Helsinki cannula (Steriseal) and then the curved Corydon cannula gently behind the anterior rhexis edge to loosen the lens capsule from the lens; do not perform hydrodissection during this step. Then make a focal hydrodissection at 12 o'clock with Corydon cannula. The wave shall not reach the posterior pole of the lens as the capsule is often defective there. Aspirate the lens with the phaco handpiece or with I/A, then mobilize it and finally disintegrate with light ultrasound. Don't encroach on the periphery too much in the beginning, as the superior part at 12 o'clock can be removed in this way. This part was loosened in the beginning by slight hydrodissection. Then aspirate the cortex with the Corydon and Helsinki cannula. Remark: A stable anterior chamber is important during lens removal. If the anterior chamber collapses a few times then the pupil will become small.

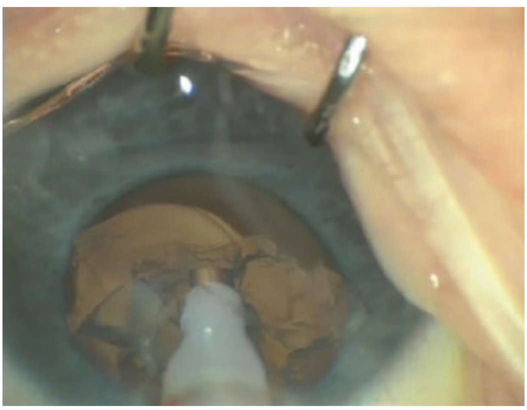

Fig. 9.8 Lens removal with phacoemulsification handpiece (Accurus machine)

Posterior capsular rhexis (Figs. 9.9, 9.10, 9.11, 9.12, 9.13, and 9.14) Fill the anterior chamber with Healon GV. Do not inflate the capsular bag, make it only plane, otherwise the rhexis will not function. Puncture the posterior capsule with a 27 g needle in an area without disturbing reflections. Inject normal Healon with a thin Polytip cannula through that hole into the Berger space; be cautious that no air bubbles are present. The entire area behind the planned posterior rhexis should be filled with Healon. Then make a slow capsular rhexis with the Ikeda forceps. Make short movements as the posterior capsule is very elastic. In the lower half the rhexis often becomes substantially greater than expected. If necessary inject Healon with the Corydon cannula behind the anterior capsule region. The posterior rhexis should have the same size as the anterior rhexis. If it is too small then the enclavation of both rhexis sheets into the Tassignon IOL will be difficult; the rhexis may even tear. Aspirate an excess of Healon from anterior vitreous before continuing to the next step. In case of a vitreous or embryonic tissue prolapse perform an anterior dry vitrectomy. If the eye becomes soft then inject BSS into the vitreous. Repeat this procedure several times.

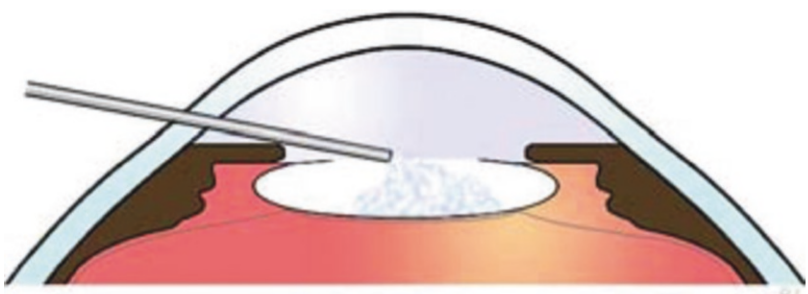

Fig. 9.9 After having emptied the capsular bag of all material (Photocourtesy Morcher)

Fig. 9.10 NEVER refill the capsular bag with OVD!! (Photocourtesy Morcher)

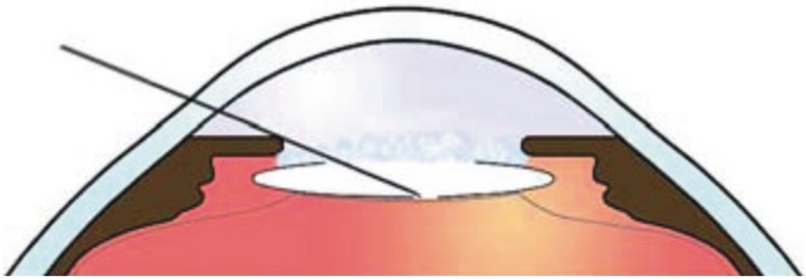

Fig. 9.11 On the contrary ONLY fill the capsular bag on top of the anterior lens capsule and bring the capsule in a horizontal plane (Photocourtesy Morcher)

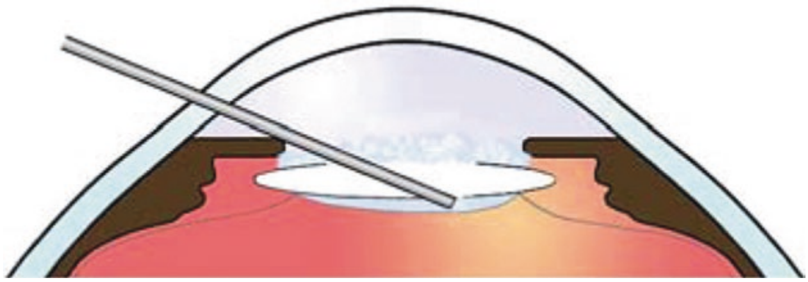

Fig. 9.12 After puncturing the posterior capsule inject the OVD through the hole until the blister is slightly larger than the anterior capsular rhexis (Photocourtesy Morcher)

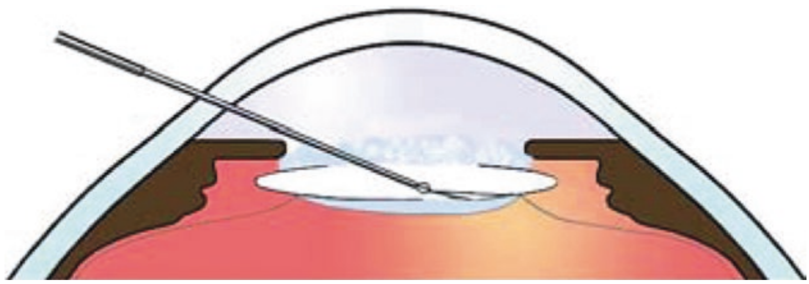

Fig. 9.13 Perform then the posterior capsular rhexis of the same size as the anterior capsular rhexis (Photocourtesy Morcher)

IOL implantation Load the Mediject (Navicel) cartridge with the Morcher IOL and inject the IOL in direction of the corneal endothelium because the IOL drops down more than expected. Centrate the IOL with the IOL rotator before the rhexis. Note that the posterior haptic is located at 12 and 6 o'clock. First clamp the posterior haptic at 6 o'clock behind both rhexis sheets. In the next step press on the left and right sides of the anterior haptic until at least 50 % of both rhexis sheets is clamped inside the groove. In the final and most difficult step the 12 o'clock part of the posterior haptic is clamped inside both rhexis sheets by pushing the IOL towards 6 o'clock and posterior. If you push too much to the posterior then the IOL will luxate into the vitreous cavity. This event is usually prevented by the two lateral haptics which are located in front of the rhexis sheets. Double check again that both rhexis sheets are clamped inside the groove of the optic.

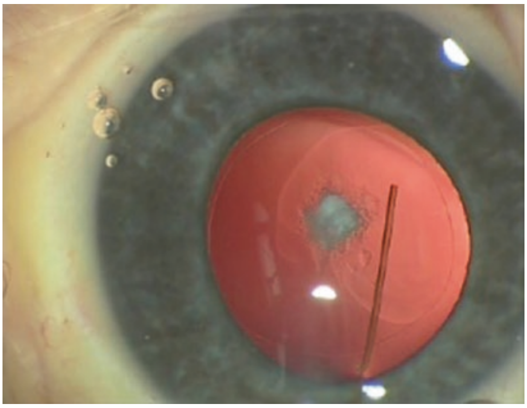

Fig. 9.14 Inject Healon with a thin Polytip cannula behind the posterior capsule inside the Berger space

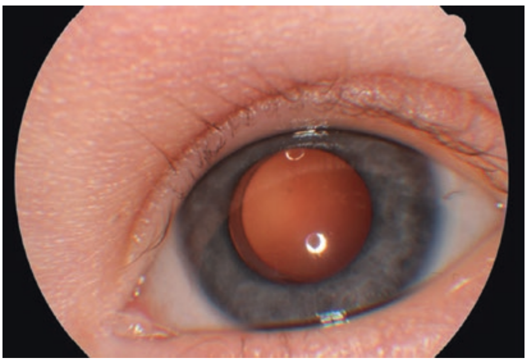

Fig. 9.15 A postoperative photograph. The Tassignon IOL's cause no inflammation compared to 3-piece IOL's and the view to fundus is excellent

Suture of paracentesis and tunnel (Fig. **9.15**) Place a 10-0 Ethilon cross suture with three throws on the main incision. Do not make a knot yet! Close the paracentesis with a single 10-0 Ethilon suture and rotate the knot inside. Remove the Healon from the anterior chamber with BSS irrigation. Don't inject too much BSS into the anterior chamber, as the IOL may be pressed into the vitreous cavity. Remove the Healon completely. Now tighten the cross suture with a knot. The knot is sunk. On the first postoperative day children often have astigmatism of 5–6 dpt but this minimizes quickly. Close the conjunctiva with 10-0 Vicryl. Inject Miochol to avoid an iris capture and finally 0.1 ml Zinacef (Cephalosporin). Remove the holding suture on the rectus muscle, inject Betapred subconjunctivally and place an antibiotic ointment on the cornea.

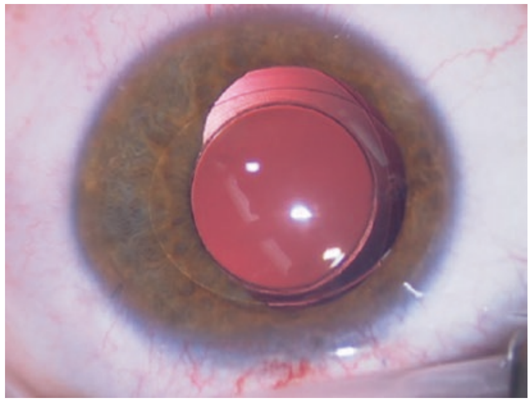

Fig. 9.16 A postoperative complication: Iris capture

Complications

Dropped IOL (happens intraoperatively): Requires a VR surgery to lift the IOL into the anterior chamber

Postoperative iris capture (happens seldom) (Fig. 9.16): The parents are informed that if they observe an oval pupil in the child's eye to come immediately into the hospital. In the most cases a pupillary dilatation (e.g. tropicamide) is sufficient to remove the iris capture. If this is not successful, the IOL is pressed behind the iris under general anesthesia. To prevent a recurrence the eye must be treated with Azopt (Brinzolamid) drop x2. The pathophysiologic effect may be that less aqueous is produced thus reducing the pressure against the IOL.

Posterior capsular opacification (occurs very seldom) (Fig. 9.17): A pars plana anterior vitrectomy is required.

Postoperative Care with Contact Lenses

After surgery, even pseudophakic eyes are always corrected with contact lenses because the target refraction is often strongly hyperopic to prevent grave myopia when the child gets older.

If the child is aphakic the medium refraction postoperatively is about 38D (corneal plane) at 1 month of age and diminishes to about 10 diopters after the first year (28D).

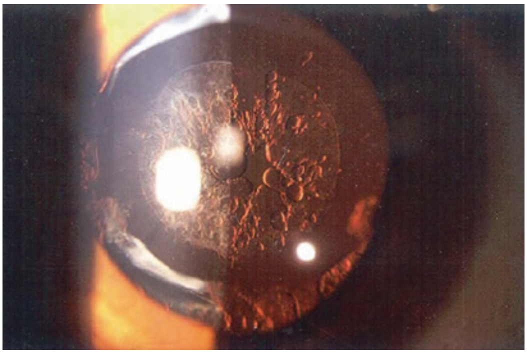

Fig. 9.17 A postoperative complication which occurs very seldom: Posterior capsular opacification

Myopia above the normal and increased corneal diameter above the normal are both strong indicators for glaucoma. The child's refraction often changes 5 diopters towards myopia in less than a month.

Regarding unilateral cataracts amblyopia training is very important. To be sure that the child exercises during waking hours you can occlude the healthy eye every second day. Otherwise training 1 h daily in the waking hours is a very good as the child sleeps more in the beginning.

Materials and Companies

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Part VI

Premium IOL: Macula IOL, Add-On IOL

The amount of implanted special lenses has augmented dramatically in recent years. In this book we will present two special lenses, the macula lens for improved reading ability and the add-on IOL. **Prof Scharioth** from Recklinghausen, Germany, designed a novel macula lens which is implanted as a piggy-back IOL and allows near vision for patients with AMD. **Dr. Sauder** from Stuttgart, Germany, will present the use and implantation of add-on IOL's for spherical, astigmatic and presbyopic correction in pseudophakic eyes.

Scharioth Macula Lens

10

Gabor B. Scharioth

Age-related macular degeneration has a high prevalence in industrialized societies and is the most common cause for loss of reading vision among patients older then 55 years of age [1, 2]. In recent years major advances have been made in the therapy of the neovascular form of age-related macular degeneration [1, 3, 4], but reduced near visual acuity is still a major problem for all forms of age-related macular degeneration. External magnifying low visual aids are known for decades, but uncomfortable use and stigmatization in public limited their acceptance. They might affect the visual field and cannot be worn continuously. Furthermore they might be forgotten at home, lost or damaged.

Evolution of Intraocular Low Vison Aids

Different intraocular lenses or telescopic systems were suggested for intraocular implantation. In 2006 the Italian company Lensspecial introduced the IOL VIP System. One high +power PMMA IOL was implanted in the anterior chamber angle and one high –power PMMA IOL was implanted in-the-bag. This created an intraocular Galilean telescope. The system could be implanted only during cataract surgery. Anterior chamber IOL have been shown to increase the risk of corneal decompensation and secondary glaucoma. Later this system was modified and both lenses were implanted within the capsular bag (IOL VIP revolution, Lenspecial, Italy). The two IOL are stabilized with an additional modified capsular tension ring (SALring). Magnification of this system is limited. In 2010 the Lipshitz Implantable Miniature Telescope (Vision Care Inc.) received FDA approval [5, 6]. This miniature Galilean telescope was implanted during cataract surgery and required a very large main incision of about 11–12 mm. The implant affects the visual field and is very sensible to tilt and decentration. Also diagnostics like funduscopy, fluorescein angiography and OCT might be affected. More recently Lipshitz introduced the OriLens (OptoLight, Israel) [7]. This implant uses reflection within the lens to magnify the image. It is made by PMMA and requires a main incision of about 6 mm. Patients frequently suffer from optical side effects and retina diagnostics are affected. In 2013 London Eye Hospital introduced the iolAMD [8]. This system consists of two hydrophylic acrylic IOL. First lens (−49 D) is implanted intracapsular. Second lens (+63 D and slightly decentered on haptic) is implanted

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into the ciliary sulcus. This creates a Galilean telescope with magnification of about 1.3 and slightly parafoveal focus. Implantation is only possible during cataract surgery and seems to be very sensible to decentration. It seems that magnification of implantable Galilean systems is limited to a maximum of 1.6× and that this might be not sufficient for patients with advanced maculopathy. Furthermore more then 50 % of patients with advanced age related maculopathy are already pseudophakic and could not benefit from such implants.

We therefore developed an implant specially designed for ciliary sulcus implantation in pseudophakic eyes (add-on technology) with sufficient magnification in near (Scharioth Macula Lens A45SML, Medicontur, Hungary) (Fig. 10.1) [9]. The add-on IOL (A4 W from 1stQ, Germany) is in clinical use for several years and has proven ease of implantation technique and low complication rate [10]. We have used a +6.0 D version of this add-on IOL to treat hyperopic shift in vitrectomized eyes with silicone tamponade [11]. It is made from hydrophilic acrylic material and can be implanted through a minimal incision size of 2.2 mm. This lens has an overall diameter of 13 mm and an optical zone of 6.0 mm. The patented design and round polished edges prevent complication (e.g. Uveitis-Glaucoma-Hemorrhage -Syndrome, iris capture syndrome, IOL decentration, interlenticular secondary cataract “red rock syndrome” etc.) known from the previous so called piggy back IOL technique. It was developed to treat residual spherical or astigmatic errors after cataract surgery or perforating keratoplasty. Later a multifocal version became available. We modified this platform and added to a special central optic of 1.5 mm diameter and a power of +10 D. This results in a reduced reading distance of about 15 cm and a magnification of 2× compared to normal reading distance of 35–40 cm. Residual main part of the IOL optic is neutral (0 D). To treat residual spherical error after previous cataract surgery the SML could be ordered with additional power (up to ± 6 D). Visual field and distance vision are not affected. Retinal imaging, incl. SD-OCT is not diminished. First Scharioth Macula Lens was successfully implanted in September 2013 in a single eyed patient with advanced age related maculopathy. The eye was already treated 13 times with intravitreal antiVEGF and BCDVA was 0.12. Near vision improved from Radner 10 preoperative to Radner 4 postoperative. Four weeks postoperative patient was able to read newspaper.

Fig. 10.1 Image of Scharioth Macula Lens (Medicontur Hungary Ltd. Hungary), lens design is based on A4 W add-on IOL (1stQ, Germany), note central optical portion of 1.5 mm diameter with +10.0 diopters, residual optic is optically neutral and has a diameter of 6.0 mm, overall diameter is 13 mm, lens is made from hydrophilic acrylic material and requires a minimum incision size of 2.2 mm if implanted with injector

Surgical Technique (Video 10.1)

Routine major incision of a minimum of 2.2 mm is required. Anterior chamber is filled with viscosurgical device. The Scharioth Macula Lens is placed in the cartridge. Special care is taken that during the folding of the winglets of the cartridge the optic of the lens is folding upwards. This will result in a controlled intraocular unfolding during implantation. While the plunger of the injector is pushed a second instrument is used through the side port incision to guide the leading haptic into the ciliary sulcus (Fig. 10.2). Usually the trailing haptics are placed into the ciliary sulcus in a sec-

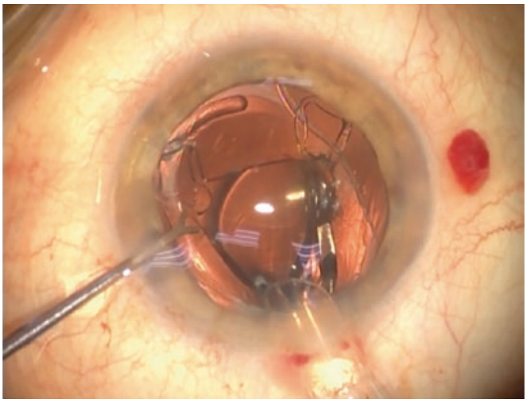

Fig. 10.2 Intraoperative situation during implantation of Scharioth Macula Lens, IOL is unfolding while second instrument is used through side port incision to guide leading haptics into ciliary sulcus

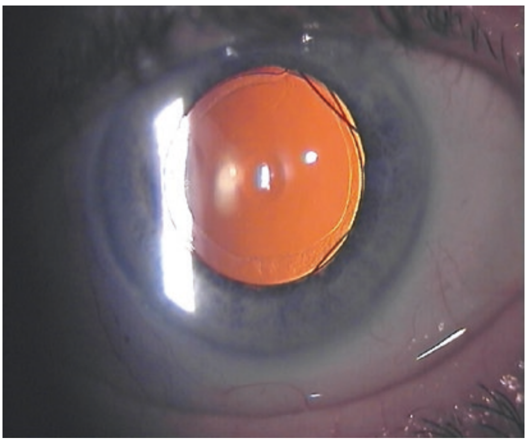

Fig. 10.3 Postoperative photo in retroillumination, well centered in-the-bag PCIOL and SML, note central portion of add-on Scharioth Macula Lens ("rain drop")

ond step. Proper position of the haptics and IOL centration is checked. Finally ophthalmic viscosurgical device is removed. Special care is taken to remove residual OVD between the lenses. We prefer hydroxypropylmethylcellulose to reduce the risk for postoperative intraocular pressure spikes. Additionally one might prescribe acetazolamide per os. Finally incisions are hydrated to prevent leakage (Fig. 10.3).

The implantation can be performed during an uncomplicated cataract surgery after the standard IOL is placed in-the-bag or any time after a previous cataract surgery. If relevant cataract is present we prefer to perform first phacoemulsification and in-the-bag PCIOL implantation. SML implantation can be performed any time after if the patient is unsatisfied with the outcome of cataract surgery alone. In case of a near clear lens we perform a simultaneous surgery with immediate implantation of the Scharioth Macula Lens. In contrast to a secondary implantation years after in-the-bag implantation in this situation the SML has tendency to unfold with the leading haptics into the capsular bag. As the haptics are very soft it should not be difficult to lift the haptic and position it into the ciliary sulcus. In our experience a moderate secondary cataract does affect safeness and visual outcome. But in case of excessive secondary cataract (thick Soemmering) one should consider to remove the material to prevent decentration or tilt. All manipulations should be performed very carefully to prevent zonular damage as this could result in unstable SML positioning.

Preoperative Evaluation and Patient Selection

Patients with advanced maculopathy (e.g. AMD, diabetic maculopathy, myopic maculopathy etc.) and distance visual acuity between 0.3 (0.4) and 0.1 are good candidates. If BCDVA is better then 0.4 patients do not require low vision aid to read. In our experience preoperative testing of BCNVA at 40 cm with +2.5 D vs. 15 cm with +6.0 D gives a valid information about the potential of SML and if BCNVA is better at 15 cm and the patient is motivated he might be a good candidate. Patients with BCDVA worse then 0.1 or no improvement in near test (+2.5 D vs +6.0D) might be also candidates for SML implantation but should be informed that reading vision will not be achieved. In this case a slight improvement might be helpful for daily activities (e.g. looking for coins in a wallet) if the patient is motivated and compliant.

Patients with advanced zonulopathy (e.g. pseudophakodonesis, excessive pseudoexfoliation, large zonular dialysis) are contraindicated. Patients with active maculopathy (e.g. choroidal neovascularisation, intra/subretinal fluid) should first be treated. We suggest SML implantation during a “quiet” phase of the disease. Control of visual acuity and retinal imaging shall be performed as usual. There is no contraindication to intravitreal injections. The add-on IOL implantation is reversible if IOL exchange is needed or improved technologies become available in the future.

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AddOn® Intraocular Lenses

11

Gangolf Sauder and S. Mödl

Introduction

An add-on intraocular lens is designed to be implanted in the ciliary sulcus. In the most cases an add-on IOL is implanted secondary in the sulcus of an already pseudophakic eye. It can also be implanted simultaneously with an endocapsulary implanted lens in the ciliary sulcus.

Although add-on IOLs no longer belong to the very latest developments in ophthalmic surgery, it is worth to look at the developments in recent years. The first add-on IOLs that are available for about 10 years were derived in their design of primary endocapsular implanted intraocular lenses, i.e. usually three-piece design with silicone or PMMA haptics and acrylat optic.

The following patient case shows, which therapeutic options add-on IOL's have:

- 76 y/o engineer with Fuchs corneal disease. The cornea decompensated after phacoemulsification of the right eye. A perforating corneal transplant was performed and resulted in a high astigmatism:
- Refraction:
  RE: −2.0–7.0/42° = 0.9
  LE: +2.5–0.5/90° = 0.9
- Surgery: Implantation of a toric add-on IOL in the sulcus.
- Result: Third postoperative month:
  RE: −1.0–0.75/170 = 0.9–1.0p
  LE: +2.5–0.5/90 = 0.9

Possible indications of add-on IOL's are:

- Astigmatic situations with unstable corneal radii e.g. keratoconus
- ametropia after cataract surgery (instead of IOL exchange)
- lack of near vision in pseudophakic eyes
- ametropia secondary to silicone oil-filled eyes
- ametropia secondary to episcleral cerclage

To use an add-on IOL for the possible indications, the following requirements to the design should be met:

– Highest rotational stability
– High precision of refraction in biometrics
– Stable positioning in ciliary sulcus
– Stable distance to endocapsular IOL
– No induction of pigment dispersion
– Minimal induction of positive or negative dysphotopsia

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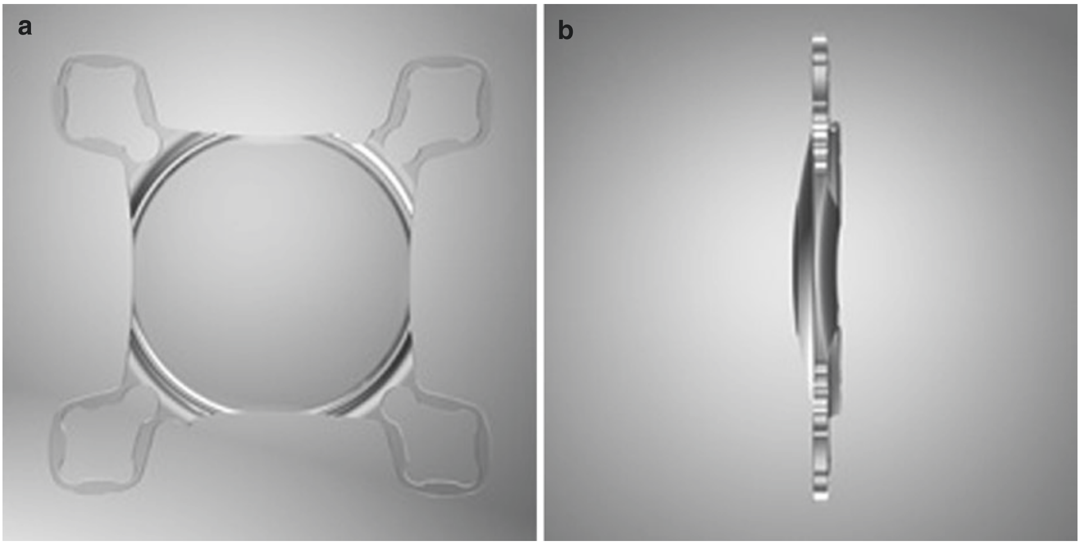

Fig. 11.1 Front- (**a**) and backview (**b**) of the AddOn® IOL (1stQ, Mannheim, Germany)

The most recent AddOn® development by the company 1stQ (Mannheim, Germany) for the first time has adapted the design of the add-on IOL to the requirements of an implantation in the ciliary sulcus (Fig. 11.1). In order to avoid contact of the optics of the add-on IOL in the ciliary sulcus with the basis IOL in the lens capsule, the overall diameter was created with a convex-concave optic design.

The IOL of AddOn® 1stQ (Fig. 11.1) consists of a square basic geometry and a 6.0 mm optics. The square geometry prevents an iris capture. The hydrophilic acrylic IOL has a convex-concave optical design, which has an edge in all four quadrants of the optic rear surface, which ensures a steady distance to the base lens. The distance from the base lens is on average 0.64 mm [1]. This important design feature prevents a touch of both intraocular lenses, which might change the refraction such as diminishing the toric effect (Figs. 11.2, 11.3, and 11.4). On the other hand a stable refraction and refractive predictability is guaranteed (Fig. 11.5).

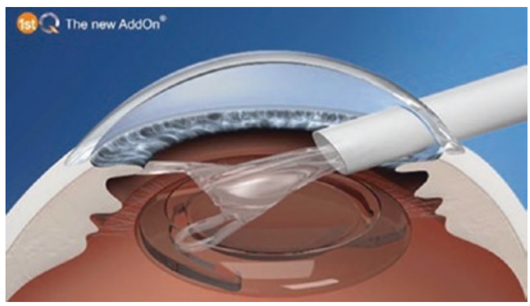

Fig. 11.2 The addON IOL is implanted into a pseudophakic eye. Fotocourtesy 1stQ (Germany)

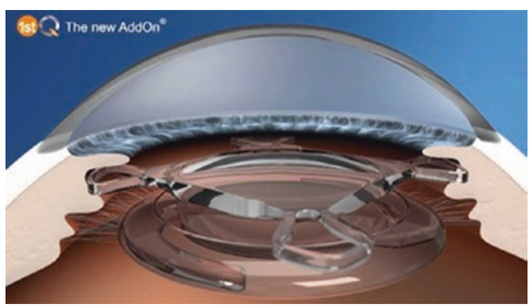

Fig. 11.3 The addON IOL is located in the ciliary sulcus. Fotocourtesy 1stQ (Germany)

The main feature of AddOn® IOL's is the four diamond-shaped haptics on the four corners of the square basic shape (Fig. 11.1). They provide a neutral adaptation of the IOL to the anatomical conditions of the ciliary sulcus by absorbing forces acting from the outside on the haptics without transferring these to a decentering or rotational component. This feature ensures a high stability in the ciliary sulcus and is especially important for toric and multifocal AddOn® intraocular lenses.

The main indications of AddOn® IOL are:

1. Spheric intraocular lens AddOn®

   Already pseudophakic eyes can be effectively "retrofitted" even years after the cataract operation with an AddOn® IOL. Postoperative ametropia can be corrected with a possibly complicated lens exchange or more elegant with an AddOn® IOL. In addition, an ametropia in eye with permanent silicone oil tamponade or with a cerclage can be easily corrected with an AddOn® IOL. This applies in principle all under one to three mentioned variants. Toric and spherical post-corrections are not critical, easy to perform and have a high refractive accuracy.

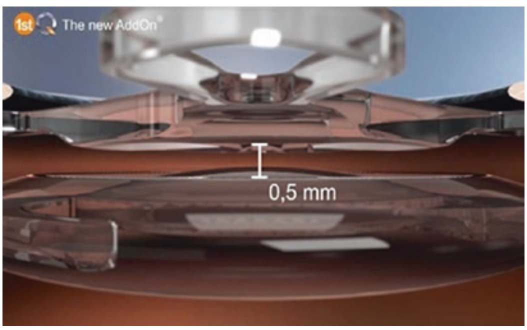

Fig. 11.4 There is a secure distance of 0.5 mm between the addON IOL and the endocapsular IOL. Fotocourtesy 1stQ (Germany)

2. Toric intraocular lens AddOn®

   An excellent indication for a toric addOn IOL is the correction of corneal astigmatism after penetrating keratoplasty or stable keratoconus in eyes with pseudophakia. The toric AddOn® IOK is implanted into the ciliary sulcus. Even if changes in the corneal geometry occur to a later time point then a repositioning (rotation) of the toric AddOn IOL is simple and feasible. If necessary, the AddOn IOL can be explanted so that the implantation of an AddOn IOL is always reversible.

   If future prospective studies prove that toric AddOn® IOL are as rotationally stable or even better than a endocapsulary IOL then an AddOn IOL approach for corneal astigmatism should be considered.
3. Multifocal intraocular AddOn®

   Within a prospective study it could be demonstrated that a multifocal AddOn® IOL is equal to an endocapsular toric IOL in regard to contrast sensitivity, halos and glare and even superior in subjective patient satisfaction [2]. The multifocal Array of AddOn® IOL is being investigated as part of a multicenter study. The main advantage of the addON IOL approach is of course its reversibility.
4. A more recent approach is the implantation of add-on IOL's lenses to correct undesirable dysphotopsias [3]. With an additional IOL implantation in the ciliary sulcus visual phenomenon like a shadow, or halos disappear. Larger and

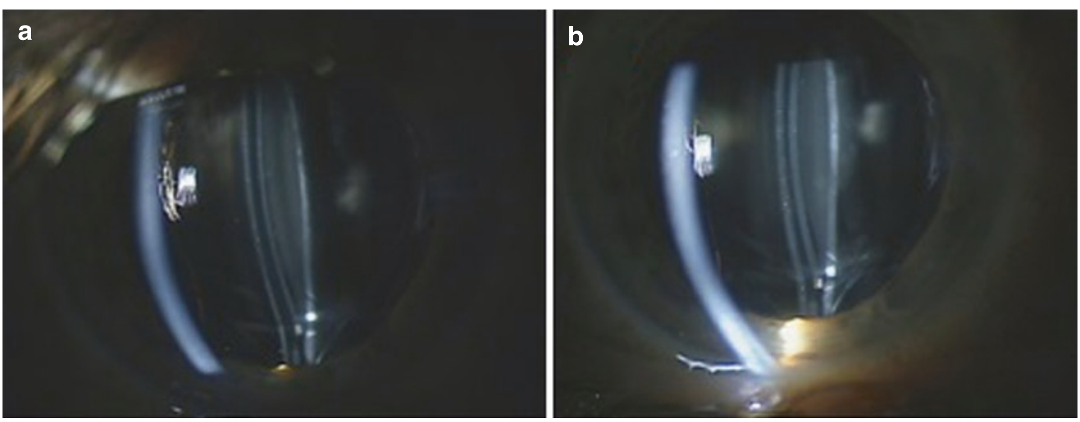

Fig. 11.5 Slit lamp view of an AddOn® IOL in the ciliary sulcus with a constant distance between the add-on IOL and the endocapsular IOL

more extensive studies are required to investigate the precise nature of negative and positive dysphotopsias and their correction.

The calculation of the required AddOn® IOL power is essentially based on the subjective refraction. The situation is different in pseudophakic patients who wish a multifocal IOL AddOn® to improve reading vision. Here the preoperative information is paramount that a higher spectacle independence and better near vision is achieved for the price of a subjective and often also objective loss of distance vision.

The Surgical Technique (Videos 11.1 and 11.2)

Important points **before** implantation:

- Identification of the front and back surface of the IOL
- use blunt forceps for manipulation
- note orientation teeth on the IOL
- Exact positioning in shooter:
  - Complete filling with viscoelastics in the cartridge
  - Exact positioning of haptics in cartridge channel
  - note that the haptics are not jammed inside the cartridge channel
  - No temporary advancing of the IOL in the shooter

Important points **during** implantation:

- Clear cornea incision of 2.2 mm
- Inject highly viscous viscoelastic into the anterior chamber
- inject visco under the iris to simplify the implantation
- advance the IOL slowly inside shooter
- when the IOL unfolds in the anterior chamber, make a short stop with advancing of the IOL to allow the two front haptics unfold fully
- rotate the IOL 90° to ensure the haptics to unfold safely in the sulcus
- in case of simultaneous implantation of a regular IOL check that the add-on IOL does not sit endocapsulary
- inject Miochol ™ to induce miosis
- No iridectomy

Adverse Effects of AddON IOL's [2]

- No IOP elevation
- No pigment dispersion
- Minimal endothelial cell loss

In conclusion AddOn® IOL's represent a useful addition to the operational spectrum of refractive cataract surgery, be it as a primary implantation of two lenses for presbyopia or to correct corneal astigmatism. Easy atraumatic implantation and easy reversibility or post-rotation are certain advantages of the AddOn® system. The high rotational stability of the toric IOL AddOn® could also bring advantages over endocapsulary implanted toric IOLs.

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Part VII

Secondary IOL Implantation: Scleral Fixated IOL and Glued IOL

Glued IOL and the intrascleral IOL are the most common techniques for secondary IOL implantations. **Prof Scharioth** from Recklinghausen, Germany, will present his famous technique of intrascleral IOL fixation and the modified glued IOL technique.

12 Sutureless Intrascleral Haptic Fixation

Gabor B. Scharioth

A vitreoretinal surgeon could be faced with three main scenarios. The patient could be aphakic after complicated phacoemulsification, trauma, vitreoretinal surgery or years after intracapsular cataract extraction. Second, the patient is pseudophakic with dislocated intraocular lens or even dislocated capsular bag-intraocular lens-complex, sometimes with capsular tension ring in place. Even more complicated if previous secondary implantation with intraocular (transiridal or transscleral) suturing was performed. Last the vitreoretinal surgeon could recognize the dislocation during intraocular surgery (preexisting or caused by the surgeon himself) complicating the surgery and may require intraoperative repair.

Fixation of intraocular lenses in case of insufficient or no capsular support is challenging and requires a large augmentarium of techniques to solve different situations (Figs. 12.1 and 12.2) [1–22].

Since the introduction of intraocular lenses in cataract surgery by Sir Harold Ridley this became standard of care in late 80ies. Whenever possible, in-the-bag implantation with overlapping continuous curvilinear capsulorhexis is preferable. But various IOL models and fixation sites and techniques are recommended for difficult situations.

Anterior chamber lenses were used for many years because of relatively easy implantation technique even in the total absence of capsular support. But the fixation in the anterior chamber angle may cause glaucoma and chronic irritation to iris. Furthermore long term endothelial cell loss with corneal decompensation is reported for angle fixated intraocular lenses as well as for iris claw lenses fixed to anterior surface, a technique

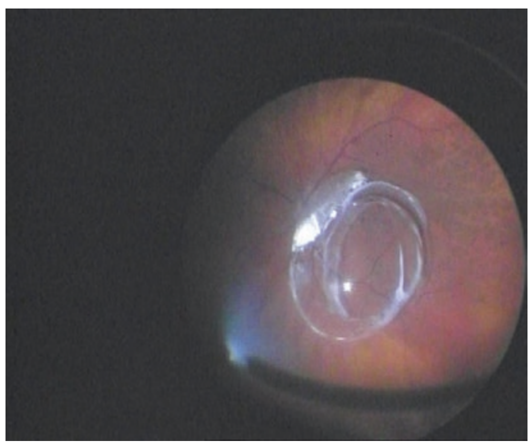

Fig. 12.1 Intraoperative appearance of completely luxated capsular bag – intraocular lens – capsular tension ring – complex ten years after uneventful phacoemulsification and in-the-bag PCIOL implantation in an eye with pseudoexfoliation syndrome

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-319-47226-3_12) contains supplementary material, which is available to authorized users.

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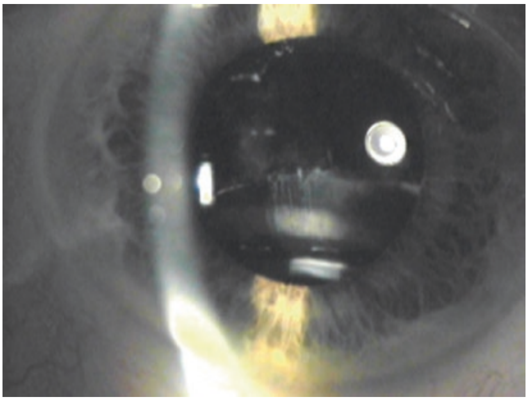

Fig. 12.2 Inferior dislocated capsular bag – intraocular lens – complex (Sunset syndrome) 8 years after uneventful phacoemulsification and in-the-bag PCIOL implantation in an eye with pseudoexfoliation syndrome

introduced by Jan. Worst almost thirty years ago. Both require relatively large incisions up to 6.5 mm. For iris claw lenses Uveitis-Glaucoma-Hemorrhage Syndrome is reported and late dislocations may occur. Anyway if someone would use this type of lens we recommend the retropupillary reverse implantation technique [21]. This is much more convenient because it prevents contact to corneal endothelium intraoperatively i.e. during fluid-air-exchange during a pars plana vitrectomy and postoperatively due to eye rubbing, blinking etc. Iris fixated IOL tend to cause IOL wobbeling with optical side effects and unstable vision. Some surgeons prefer iris-sutured intraocular lenses. This could cause pupil ovalisation and iris chaffing with uveitis and/or pigment dispersion and secondary complications like chronic inflammation and secondary glaucoma. Anyway these techniques need sufficient iris stroma for fixation and cannot be used in aniridic patients.

We are convinced that the best place for fixation of intraocular lens in the absence of sufficient zonular/capsular support is the sclera. It is the strongest intraocular tissue, mainly avascular and does not tend to inflammation. Vitreoretinal surgeons know for decades that implants and explants for retinal procedures are well tolerated over a long period. In moderately damaged zonular apparatus we are using for many years capsular bag refixation techniques with modified capsular tension rings (s.c. Cionni ring) or Ahmed segments (both Morcher, Germany). These implants are positioned in the capsular bag and have an extra eyelet which is positioned on the anterior surface of the anterior capsule and fixed with a 10 × 0 or 9 × 0 Prolene suture transsclerally into the ciliary sulcus. This technique is difficult and needs an intact capsulorhexis. Furthermore capsular bag cleaning is diminished. This tends to cause early secondary cataract and capsular fibrosis with rhexis phimosis. For more severe luxated capsular bags or for fixation of intraocular lenses in the absence of sufficient support the haptic of the intraocular lens could be knotted to a 10 × 0 or 9 × 0 Prolene suture and fixed to the scleral wall. Many variations of transscleral suture fixation are reported and these techniques are used worldwide because small incision techniques can be used, intraocular lens is positioned more physiologically in the posterior chamber and standard lenses could be used. In case of dislocated intraocular lens this could be refixated by intraoperative haptic externalization for knot fixation to the haptic and transsclerally suturefixation without need for intraocular lens explantation. A fibrosed capsular bag esp. if with capsular tension ring in place can easily refixated with double armed 10 × 0 or 9 × 0 Prolene suture to the ciliary sulcus. The first needle is passed through the capsule catching the haptic and/or capsular tension ring and passed through the sclera while the second needle is just placed above the bag through the sclera. The so created suture loop will hold the bag after knotting to the sclera. Usually more than one sclerafixation is necessary to stabilize the whole bag. Recently Richard Hoffmann reported a technique for transcleral suturefixation without opening of conjunctiva [22]. Here the pockets for suture knots are prepared from the limbus intrascleral towards the sclera, a double armed suture is used and stitched 1.5 mm postlimbal through the scleral pockets and conjunctiva, needles are cut off and the sutures are catched with a hook from the limbus. Then the suture is knotted and the ends are buried into the scleral pocket.

However centration of suturefixated intraocular lenses is difficult and lens tilt is a common problem. This will result in internal astigmatism and inconvenient refractive outcome. Fixation into the ciliary sulcus without capsular and zonular support is difficult and malpositioning may result in chronic irritation to ciliary body and/or iris with secondary complications. Good long term stability is reported but late dislocations due to suture biodegradation may occur and require reinterventions [23–27]. There is a long learning curve for suturefixation techniques and outcome is very much depending on surgeons experience. Furthermore there could be a need for special intraocular lens, which may not be available everywhere and prompt, need extra costs and logistics, adapted biometry etc.

For these reasons we were searching for technique for intraocular lens fixation in the absence of sufficient capsular support which uses a standard foldable intraocular lens, sclerafixation, is independent from iris changes and the amount of zonular/capsular damage, sutureless, reduces the contact to uveal tissue and could be standardized.

In 2006 we performed the first intrascleral haptic fixation of a standard three piece intraocular lens and reported the surgical technique in 2007 [28].

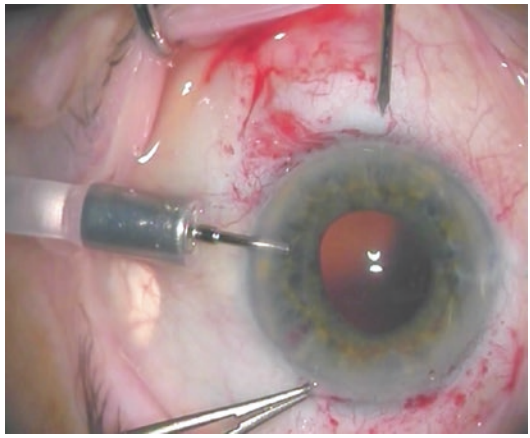

Fig. 12.3 After peritotomy, anterior chamber maintainer (25G infusion line) placed in a micro side port, 23G or 24G sharp cannula is used to create a straight ciliary sulcus sclerotomy 1.5 to 2.0 mm postlimbal

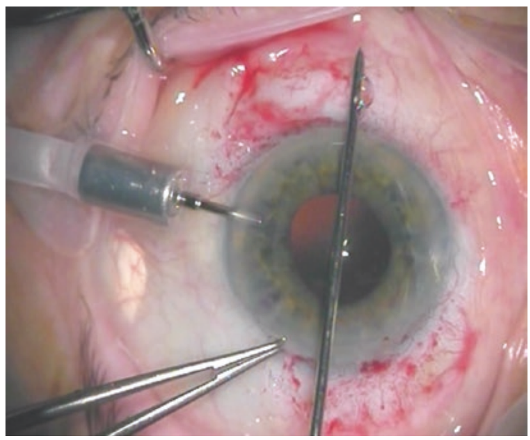

Fig. 12.4 Second sclerotomy shall be placed exactly 180°, alternatively a corneal marker could be used

The Surgical Technique (Videos 12.1 and 12.2)

This sutureless technique for fixation of a posterior chamber intraocular lens is using permanent incarceration of the haptics in a scleral tunnel parallel to the limbus. After peritomy the eye is stabilized either by pars plana infusion (i.e. 25G) or by anterior chamber maintainer. We try to prevent any diathermy of episcleral vessels to reduce the risk for scleral atrophy. Two straight sclerotomies ab externo are prepared with a sharp 23G cannula or 23G MVR blade about 1.5 mm postlimbal exactly 180° from each other and directed towards the center of the globe. Then new cannulas are used to create a limbus-parallel tunnel at about 50 % of scleral thickness, starting from inside the ciliary sulcus sclerotomies and ending with externalisation of the cannula after 2.0 to 3.0 mm. A standard 3-piece IOL with a haptic design fitting to the diameter of ciliary sulcus is implanted with an injector, and the tailing haptic is fixated in the corneal incision. The leading haptic is then grasped at its tip with a special straight 25G forceps (Scharioth IOL fixation forceps 1286.SFD, DORC Int., The Netherlands), pulled through the sclerotomy and left externalized (Figs. 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, 12.12, 12.13, 12.14, 12.15, and 12.16).

With the curved Scharioth forceps then the haptic is grasped at its tip, introduced into the intrascleral tunnel and pushed through. Then the haptic is released, forceps is turned, closed

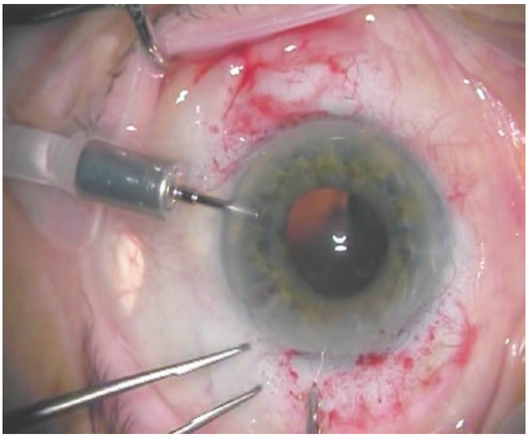

Fig. 12.5 A 23G or 24G sharp cannula is used to create a straight ciliary sulcus sclerotomy 1.5 to 2.0 mm postlimbal exactly opposite to the first

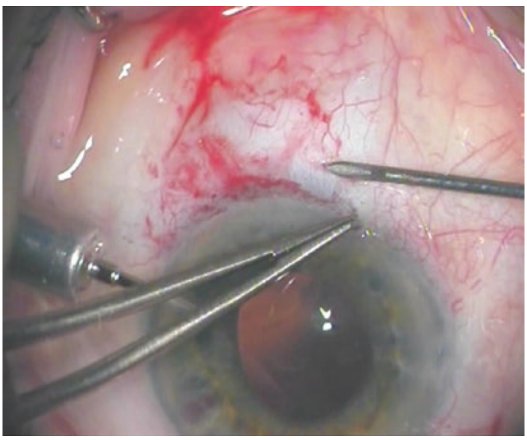

Fig. 12.6 Intrascleral limbusparallel tunnel is created counter clockwise with a 23G or 24G sharp cannula

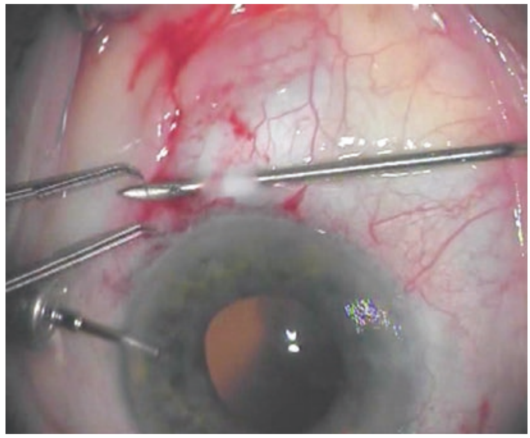

Fig. 12.7 After 2–3 mm the cannula is externalized and withdrawn, same is performed on opposite sclerotomy side

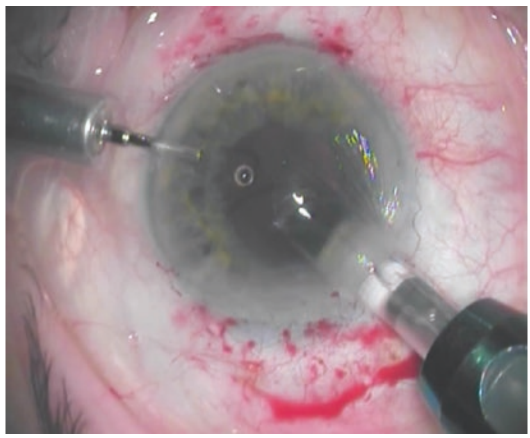

Fig. 12.8 Injector assisted implantation of foldable IOL

and pulled back leaving the haptic in the sclera (pushing technique). Alternatively one can introduce the Scharioth forceps from the distal end of the intrascleral tunnel until it becomes visible in the sclerotomy, then the haptic tip is grasped and pulled in the scleral tunnel (pulling technique). The same maneuvers are performed with the tailing haptic. The ends of the haptic are left in the tunnel to prevent foreign body sensation, erosion of the conjunctiva and to reduce the risk for inflammation. The sclerotomies are checked for leakage and if necessary sutured (Fig. 12.17).

We have used this technique in hundreds of eyes over the past ten years. Our standard IOL were Sensar AR40e (AMO, USA) and Acrysof (Alcon, USA) but any three piece IOL sufficient for sulcus fixation should work. In 2010 we reported our interim results of a European multicenter study. We had 4 haptic dislocations which could be reimplanted and one transient vitreous hemorrhage. These complications occurred all in the first ten cases and in first 4 postoperative weeks [29]. Some young patients with floppy iris showed postoperative recurrent iris capture which disappeared after NdYAG laser iridotomy. If this condition is anticipated we suggest

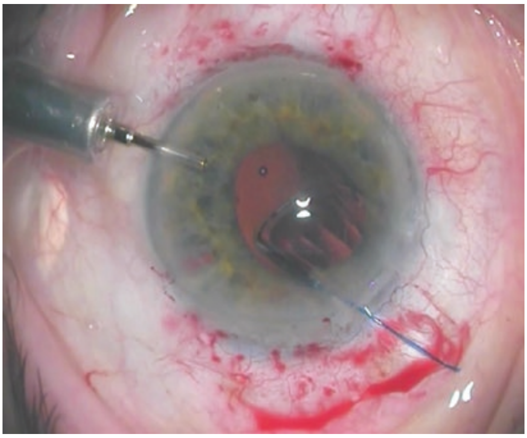

Fig. 12.9 IOL implanted with leading haptic behind iris and trailing haptic fixed inside the corneal incision, continuous irrigation is mandatory to prevent collapse of the eye with haptic slippage from the main incision

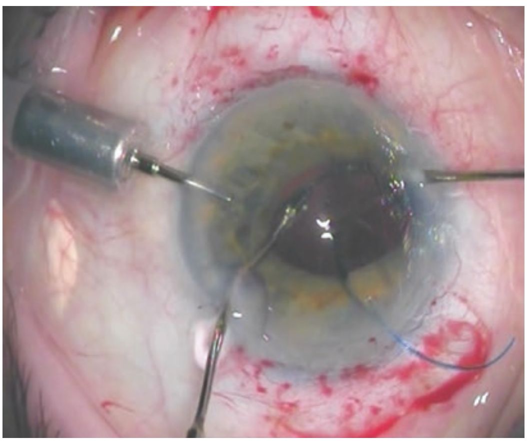

Fig. 12.10 "Hand shake maneuver" using Scharioth forceps, IOL haptic is grasped with right hand first and presented to grasp the haptic with left hand, then right hand forceps is removed from anterior chamber and introduced through opposite ciliary sulcus sclerotomy

intraoperative iridectomy with the vitreous cutter. Also some patients show reverse pupillary block with iris sticking to the IOL surface and very deep anterior chamber. In this case an iridectomy with the vitreous cutter is solving the problem. In our experience anterior chamber depth will immediately return to normal and a repeated inflation of the AC should not cause a recurrent reverse pupillary block.

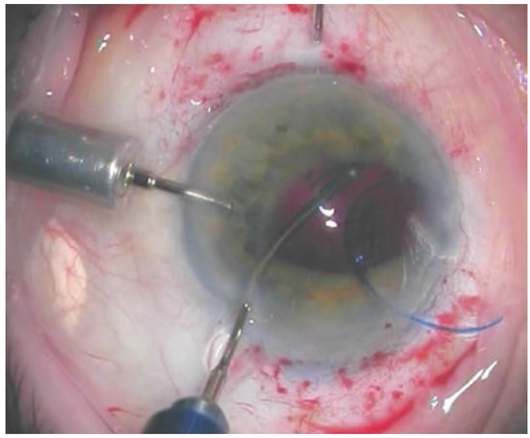

Fig. 12.11 "Hand shake maneuver" using Scharioth forceps, IOL is still hold with left hand forceps, second forceps is grasping the very tip of IOL haptic, then left hand releases haptic and while right hand forceps is withdrawn the haptic is externalized through ciliary sulcus sclerotomy

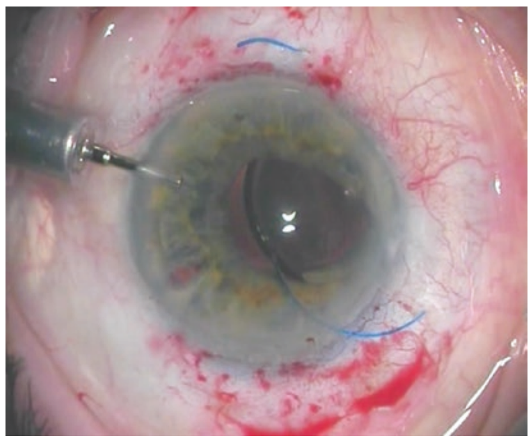

Fig. 12.12 Leading haptic externalized through ciliary sulcus sclerotomy, trailing haptic still in fixated corneal incision

For PCIOL calculation we use the SRK-T formula and the same A-constant as for in-the-bag implantation (Fig. 12.18).

Later a variation of our technique was introduced by Agarwal [30]. After peritomy two half thickness scleral flaps are created postlimbal exactly 180° to each other. Then straight sclerotomies are prepared and the IOL haptics are externalized. Originally Agarwal left the haptics under the scleral flap and closed with fibrin glue (Video 12.3). Over the last years he recommends to

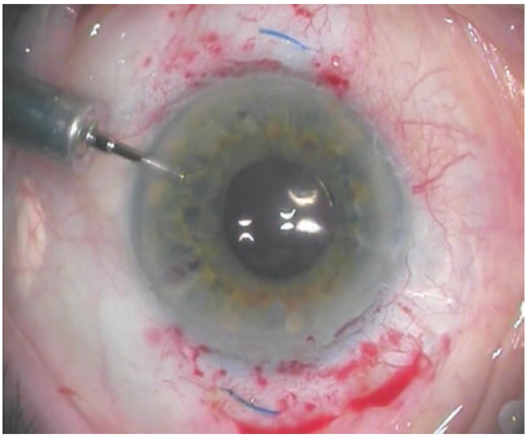

Fig. 12.13 Both haptics externalized after same "hand shake maneuver" is performed with trailing haptic

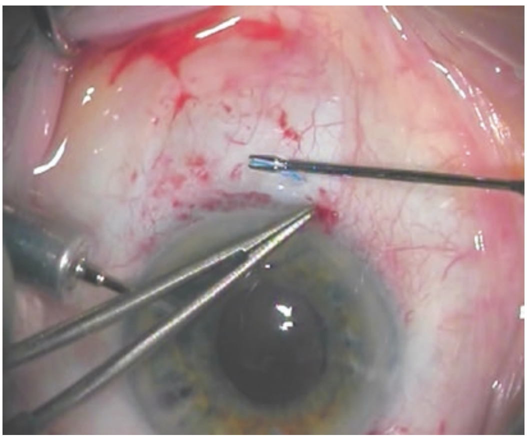

Fig. 12.14 Curved Scharioth forceps is used to grasp the very tip of one haptic, and then the haptic is pushed a bit backwards until it can be introduced into the limbusparallel intrascleral tunnel

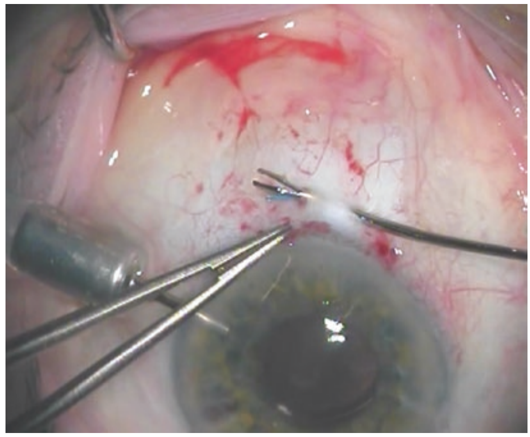

Fig. 12.15 Forceps holding the haptic is pushed through the limbusparallel intrascleral tunnel, after tip is externalized the haptic is released, forceps is then turn and closed before withdrawn, this will reduce risk of catching the haptic

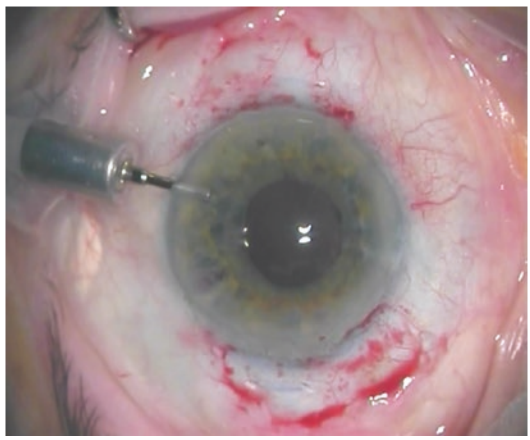

Fig. 12.16 Both haptics are placed intrasclerally, it is important that the haptic is completely covered by sclera

create an intrascleral tunnel counter clockwise at the edge of the scleral bed. This tunnel (so called Scharioth tuck) is prepared with a 27G needle and the haptic is then introduced with the help of a tying forceps. Then scleral flap and conjunctiva are closed with fibrin glue (Figs. 12.19, 12.20, 12.21, 12.22, 12.23, and 12.24).

Totan and Karadag introduced another modification of intrascleral haptic fixation [31]. With the help of a 23G or 25G transconjunctival trocar system a short intrascleral tunnel is created. Then the tip of the haptic is grasped and while externalized the trocar cannula is removed. The haptic is left in a short intrascleral tunnel. The reduced surgical time and trauma seems to be advantageous but has to be weighted with an increased risk for postoperative IOL dislocation. Furthermore as the intrascleral haptic fixation is very short an intraoperative finetuning (final minimal repositioning of the IOL) is not possible. The authors report in a small study with 29 eyes that there was no significant difference between this technique and the original Scharioth technique [32].

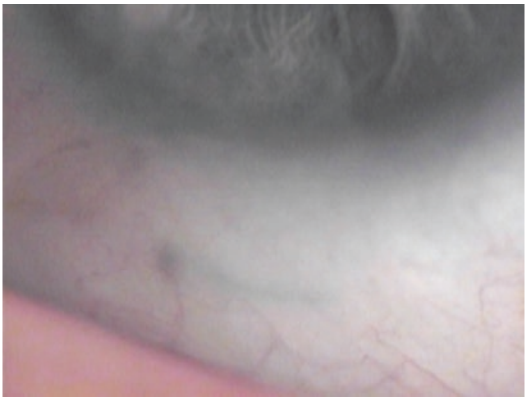

Fig. 12.17 Slit lamp photo 8 years postoperative after sutureless intrascleral haptic fixation, no sign of inflammation or scleral erosion in the area of incarcerated haptic

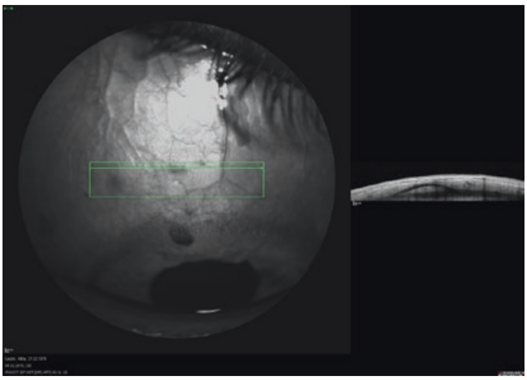

Fig. 12.18 Postoperative anterior segment OCT, left image showing intrascleral placement of IOL haptic without scleral changes or signs of leakage

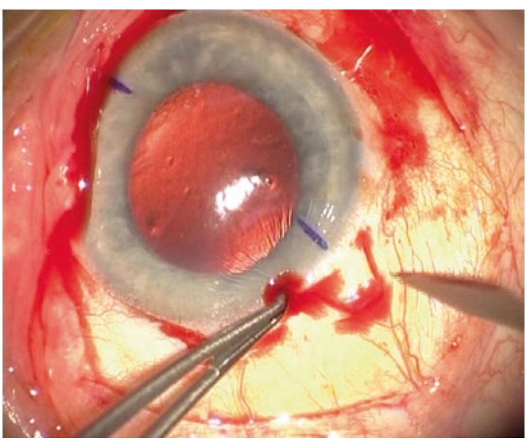

Fig. 12.19 Glued IOL technique, preparation of scleral flap, note corneal marks to improve location

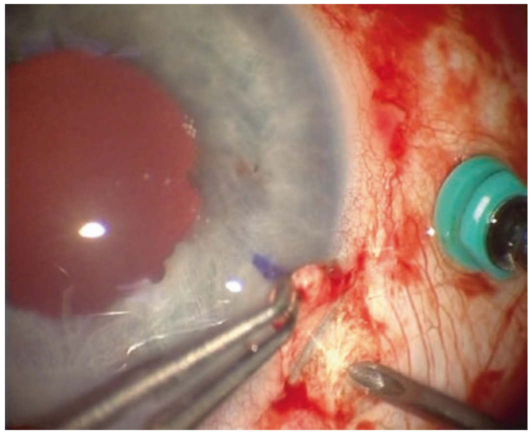

Fig. 12.20 Glued IOL technique, under flap ciliary sulcus sclerotomy with 23G sharp cannula

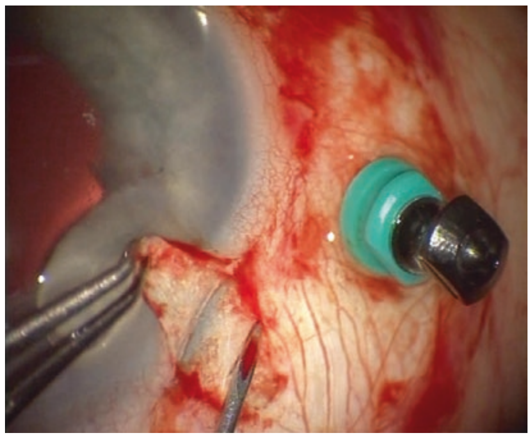

Fig. 12.21 Glued IOL technique, Scharioth tuck is performed with 27G sharp cannula at the margin of scleral bed

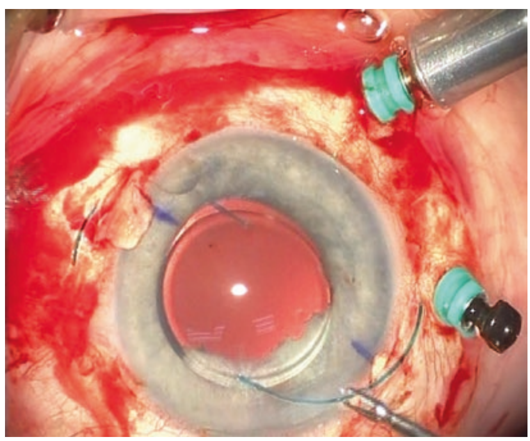

Fig. 12.22 Glued IOL technique, leading haptic externalized, trailing haptic prior to implantation

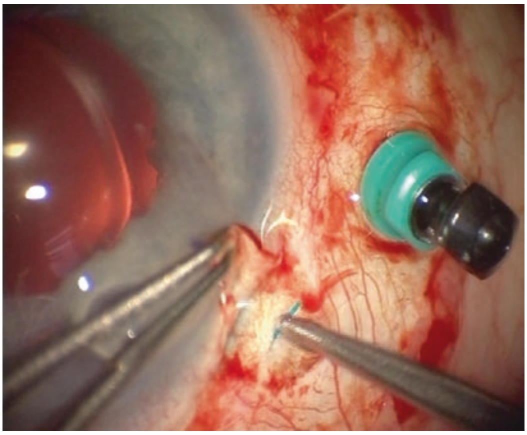

Fig. 12.23 Glued IOL technique, haptic is grasped with a tying forceps and implanted into the Scharioth tuck

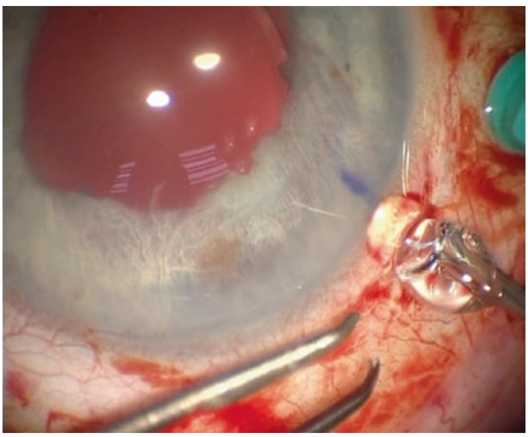

Fig. 12.24 Glued IOL technique, fibrin glue is applied under the scleral flap and then later to close the conjunctiva

In young patients subluxated or even luxated crystalline lens after severe trauma or Marfan syndrome implantation of a multifocal IOL might be indicated. We reported in 2011 on our positive initial results [33]. Three piece PCIOL (ReZoom and Tecnis Multifocal, AMO, Santa Ana, USA) have been used with described technique for sutureless intrascleral haptic fixation. To improve refractive outcome in case of postoperative ametropia laser refractive surgery (BIOPTICS) could be used. We recommend LASEK or PRK because the use of a suction ring during LASIK could weaken the intrascleral fixation. In some patients a corneal wavefront guided laser refractive surgery could be used to reduce higher order aberrations (Fig. 12.25) [34].

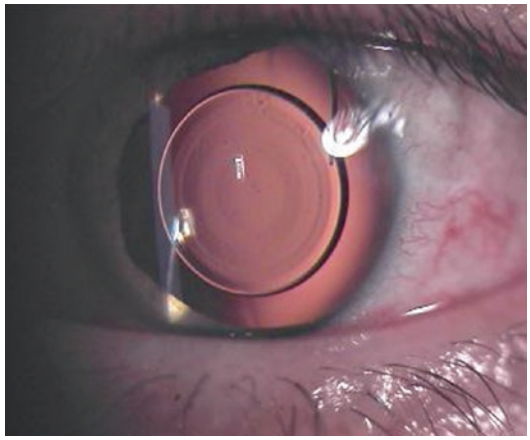

Fig. 12.25 Intrascleral haptic fixation of multifocal PCIOL 6 weeks postoperative prior to iris reconstruction in a 34 years old male after lensectomy and pars plana vitrectomy for traumatic subluxation of a hypermature cataract and retinal detachment after severe blunt trauma, final best uncorrected visual acuity for distance and near 0.8

Conclusion

Management of secondary implantation or refixation of dislocated intraocular lenses with the use of scleral tunnel fixation of the haptic is less technically demanding because it stabilizes the intraocular lens in the posterior chamber without difficult suturing procedures and uses a real microsurgical approach if injector assisted IOL implantation is used in combination with 25G or even 27G vitrectomy system. Incarcerating a longer part of the haptic stabilizes the axial position of the PC IOL, which should decrease the incidence of IOL tilt. Up to ten years follow up with only minimal complication after the early postoperative period and learning period for this procedure seems to indicate the excellent long term stability of intraocular lenses fixated with this technique. In our opinion the only possible contraindications are chronic scleritis or scleromalacia, but these are very rare conditions.

However cataract and vitreoretinal surgeons should be familiar with different techniques for fixation of intraocular lenses because we will be faced with situation were an intraocular lens is already implanted and requires secondary intervention. In future urgent phacoemulsification problems like dropped nucleus less often will need revision, but more often we will see eyes with late dislocation of the entire capsular bag after primary uneventful cataract surgery because of chronic ongoing disease like pseudoexfoliation syndrome. We should be able to select a less demanding and traumatizing technique which gives a great chance that no further intervention is necessary.

Material and Companies Address

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www.dorc.nl

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Part VIII

Retina: 27G Pediatric Vitrectomy, Robotic Surgery

Vitreoretinal surgery has undergone dramatic changes in the last 10 years through the introduction of trocars. The most recent development is the advent of a new two-blade vitreous cutter (Geuder, Germany; Dorc, The Netherlands) which has a cutting rate of 10.000–12.000 cuts/min and simultaneously a constant flow. **Dr. Spandau** from Uppsala, Sweden will demonstrate 27G vitrectomy with a TDC cutter in pediatric patients – from ROP to FEVR.

Will robotic surgery be the future in ocular surgery and replace the surgeon? **Dr. Charles Mango** from New York, USA, will report about the latest state of robotic technology for eye surgery.

Pediatric Vitrectomy with 27G TDC Cutter

13

Ulrich Spandau

27G and TDC Cutter

27G – Size Does Matter

A 23G, 25G and 27G trocar fit into each other like Russian Babushkas (Fig. 13.1). 27G has an inner diameter of 27G and an outer diameter of 25G. 25G has an inner diameter of 25G and an outer diameter of 23G. And finally 23G has an inner diameter of 23G and an outer diameter of 22G.

27G has therefore no leakage, the globe is watertight without sutures and the tiny instruments cause less intraoperative trauma.

We are convinced that size does matter. Size was the major motivator to switch from ECCE to phacoemulsification. The small incisions of phacoemulsification are better in almost all aspects than the gaping wound of ECCE: faster postoperative recovery, improved visual results, less astigmatism and a closed and safe globe.

The same principle applies for vitrectomy. Small sclerotomies and small instruments induce less intraoperative trauma, less leakage, prolonged postoperative gas-filling and faster postoperative recovery. The principle "the smaller the gauge, the better" is evident.

The Dilemma of the Law of Hagen–Poiseuille

Physics are against small-gauge vitrectomy. The Hagen–Poiseuille equation states that the flow is proportional to the fourth power of the internal diameter of a lumen. See Fig. 13.2. If for example the diameter of the lumen is reduced by half then the flow resistance will increase 16-fold. This is the case if you switch from 23G to 27G.

This striking difference in flow between 23, 25 and 27G can be shown in performance measurements of the vitreous cutter. Continue with the next chapter.

A 27G TDC Cutter Is as Powerful as a Regular 25G Cutter

If you measure the required time for a vitreous cutter to aspirate artificial vitreous then you will find that a 27G cutter is 30 % slower than a 25G cutter. And the latter is 30 % slower than a 25G cutter (Fig. 13.3).

This physical obstacle can only be overcome with more powerful vitrectomy machines and

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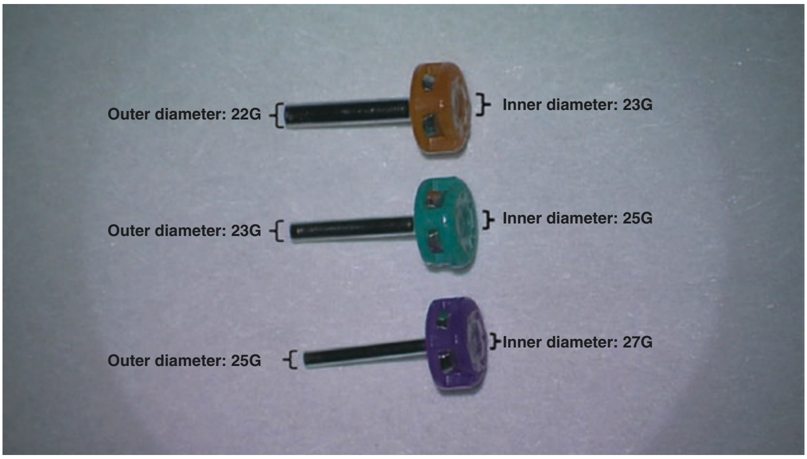


Fig. 13.1 The inner diameter of a 23G trocar is 23G but the outer diameter is 22G. A 23G trocar has therefore a 22G sclerotomy. The outer diameter of a 27G trocar is 25G. It is obvious that a 25G sclerotomy is water-tighter than a 22G sclerotomy

Gauge	Internal diameter in mm	Flow ~ diamter^4	
20	0,52	0,073	
23	0,39	0,02	
25	0,29	0,007	
27	0,20	0,0016	16 x less flow than 23G

Fig. 13.2 Hagen–Poiseuille equation (**Flow ≈ diameter ^{4}**) and its relevance for vitrectomy

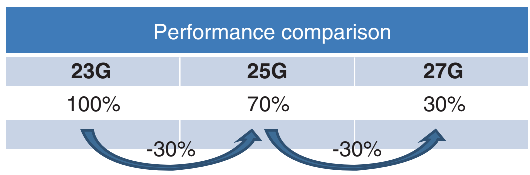


Fig. 13.3 Performance comparison of a cutter in relation to the Gauge. Measured is the aspiration time of artificial vitreous (Courtesy DORC)

especially a new design of vitreous cutters (Videos 13.1 and 13.2). A novel 27G TDC cutter (for details see below) is as fast as a 25G regular cutter (Video 13.5).

Double Cut Vitreous Cutter

History of 27G

27G vitrectomy was developed in 2010 from Oshima and colleagues in Japan. The old 27G cutter had lower fluid dynamics and less cutting efficiency than a 25G cutter. The same applied also for aspiration and infusion rates. These obvious disadvantages of 27G became obsolete after a novel type of vitreous cutter was introduced. The companies DORC (Netherlands) and Geuder (Germany) developed this novel double-cut citreous cutter (Fig. 13.4).

History of Double-Cut Vitrector (Videos 13.1, 13.2, 13.3, and 13.4)

The initial idea for the novel vitreous cutter came from Hayafuji and colleagues from Japan in 1992 (see Fig. 13.5). After a journey of trial and errors the final vitrector was developed in 2013 from DORC. This new vitreous cutter has two open cutting ports and a second cutting blade. It is named Twin Duty cycle (TDC) cutter. This new invention comprises two new features: 1) a permanent flow and 2) two cutting blades.

The New TDC Cutter Is Much faster than the Regular Cutter

Video 13.5: Left regular cutter Right TDC cutter 6000 cpm/450 mmHg

Video 13.6: 6 27G-asteroid hyalosis_TDC cutter

The two cutting blades have the result that the cutter cuts two times during one movement, effectively doubling the cutting speed. The vitreous cutter has a cutting rate of 8000 cuts/min. But the actual cutting rate with two cutting blades is 8000 × 2 =16,000 cuts/min, which reaches new dimensions. The second novelty is a continuous and even flow due to the two open cutting ports. This novel technology reduces vitreous traction, decreases the surgical time and increases the safety of surgery (Figs. 13.6 and 13.7).

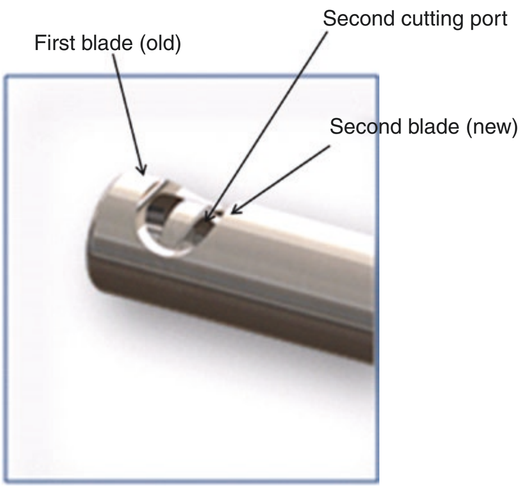


Fig. 13.4 The novel Twin duty cycle (TDC) cutter. The cutter has 2 open cutting ports and a second cutting blade

The New TDC Cutter Has a 1.5–1.75 More Power Than a Regular Cutter

Video 13.5: Left regular cutter Right TDC cutter 6000 cpm/450 mmHg

Figure 13.8 shows that the TDC cutter has 1,5× higher performance than a regular cutter. This results in a fast core vitrectomy.

27G Is Very Useful for Following Pathologies (Figs. 13.9 and 13.10)

The small 27G sclerotomies and instruments enable intraoperatively a minimal surgical trauma and postoperatively a watertight globe; postoperative hypotony does not occur with 27G. All surgical indications which require these features make them to excellent candidates for 27G:

1. Children eyes: No sutures necessary
2. Long eyes: No sutures necessary, excellent tamponade
3. Uveitis eyes: 27G causes minimal postoperative inflammation
4. Silicone oil removal: Less hypotony compared with 23G and 25G
5. Retinal detachment: The small sclerotomies result in less leakage and prolonged gas tamponade
6. Lens exchange: Less hypotony compared with 23G

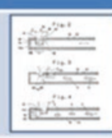
Year	Description	Image
First idea (1992)	M. Hayafuji Y. Hanamura S. Niimura	
DORC (1996)	Vitreous Shaver with 3 adjustable (slit) aspiration ports	
Luiz Lima (2010)	New dual port cutter system	
Rizzo (2011)	Extra aspiration port in internal capillary	
DORC (2013)	Twin Duty Cycle Vitrectome	

Fig. 13.5 Historical development of TDC cutter (Photo courtesy DORC)

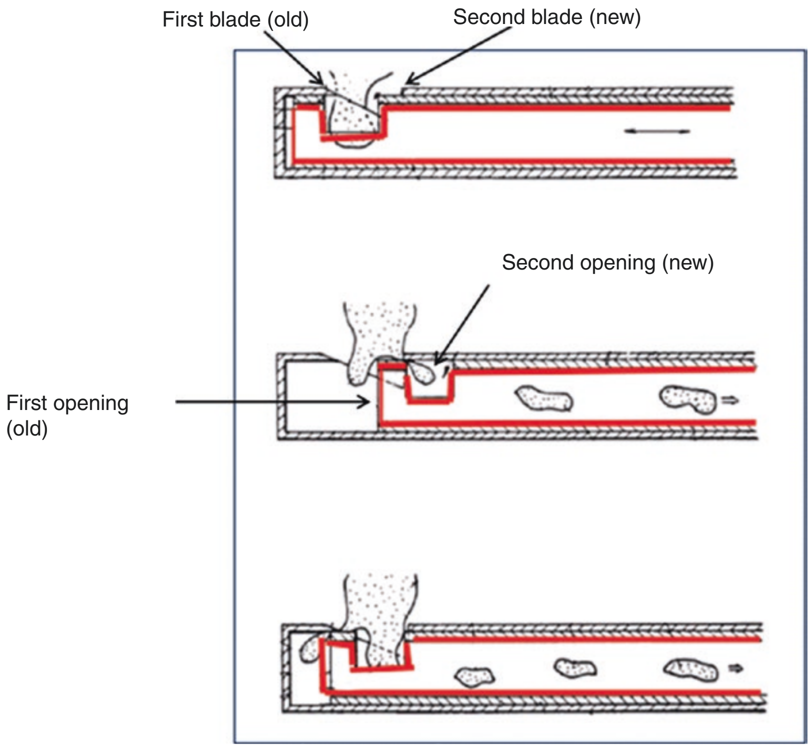


Fig. 13.6 Illustration of a TDC cutter in action. One movement (forwards and backwards) results in two cuts. In old cutters one movement (forwards and backwards) results in one cut. The novel two blade cutters have therefore the same movement frequency like old cutters but a double cutting frequency: 5000 × 2 = 10,000 cuts/min

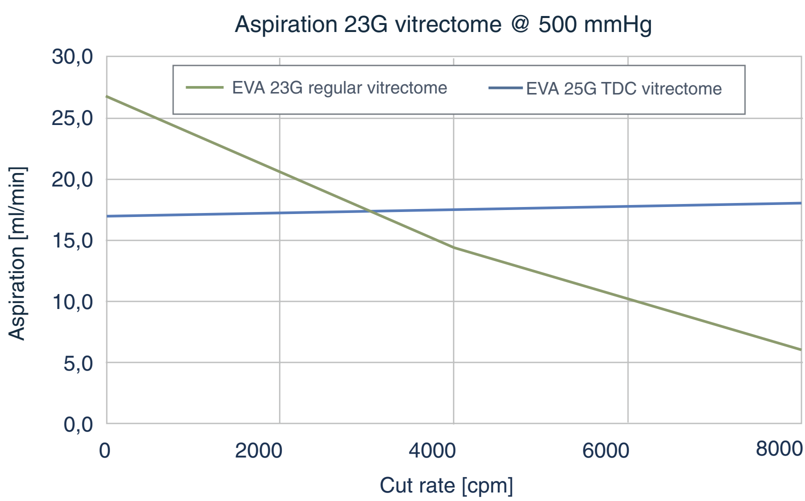


Fig. 13.7 Comparison of an old 23G cutter versus a new TDC 27G cutter. The new cutter has a stable flow in the complete cutting range from 0 to 8000 cuts/min. The old cutter has a high aspiration at 1000 cuts/min and a low aspiration at 8000 cuts/min

Fig. 13.8 Performance comparison of TDC cutter vs. regular cutter (Courtesy DORC)

TDC cutter 	Regular cutter 	Comparison
23G TDC	23G regular	164%
25G TDC	25G regular	176%
27G TDC	27G regular	150%
27G TDC	23G regular	48%
27G TDC	25G regular	71%
27G TDC	27G regular	150%

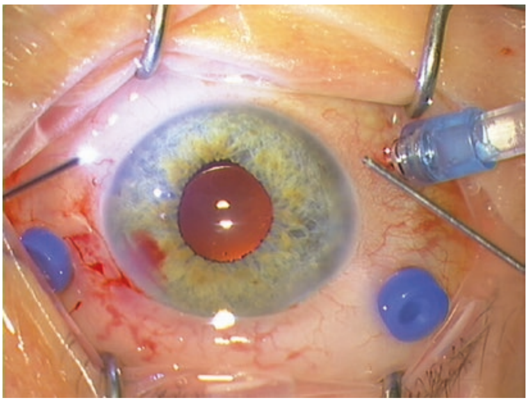


Fig. 13.9 Intraoperative status of 3-port vitrectomy with 27G trocars from DORC, high infusion line, vitreous cutter and a light fiber

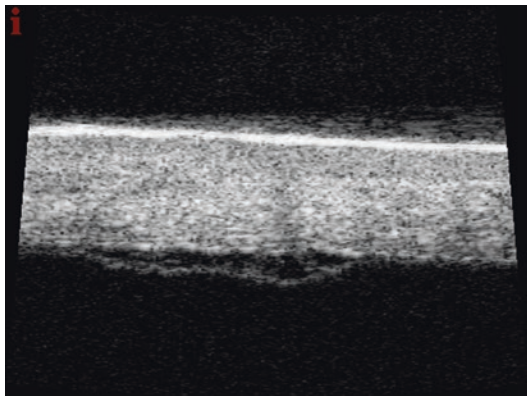


Fig. 13.10 A histological section of a sclera after removal of a 27G trocar. The sclerotomies are watertight, require no suture and no hypotony is present the day after. This is an excellent feature for long eyes and children eyes

27G Is Less Useful for Following Pathologies
These indications have a low risk of postoperative hypotony. There is not really a difference to 23G and 25G regarding this important feature:

1. Macular pucker: No advantage to 23G except of faster postoperative recovery
2. Macular hole: better tamponade with 27G but clinically no difference

If you, however, wish a white eye after 1 week follow-up like after phacoemulsification, then you should again choose 27G.

The following videos illustrate the novel features of 27G and the TCD cutter:

Video 13.6: 27G–asteroid hyalosis_TDC cutter

Video 13.7: Diabetes_27G_EVA

Video 13.6: Tractional detachment

Pediatric Vitrectomy

General Introduction

We operate all children eyes with 27G. The reason for this is that the sclera of young eyes is soft and leaks more easily than an adult eye. In addition, we perform a perpendicular and not a lamellar insertion of trocars due to the risk of damaging the lens. If you perform a perpendicular insertion with 23G or 25G trocars you need to suture the sclerotomies. In 27G a suture is not necessary and this is also valid for newborn eyes.

Fig. 13.11 Site of sclerotomy in relation to the age

Age	0	1-6 mts	6-12 mts	1-3 yrs	3-6 yrs	6-18 yrs	Adult phakic	Adult pseudophaki
Site of sclerotomy (mm)	1,0	1,5	2,0	2,5	3,0	3,5	4,0	3,5

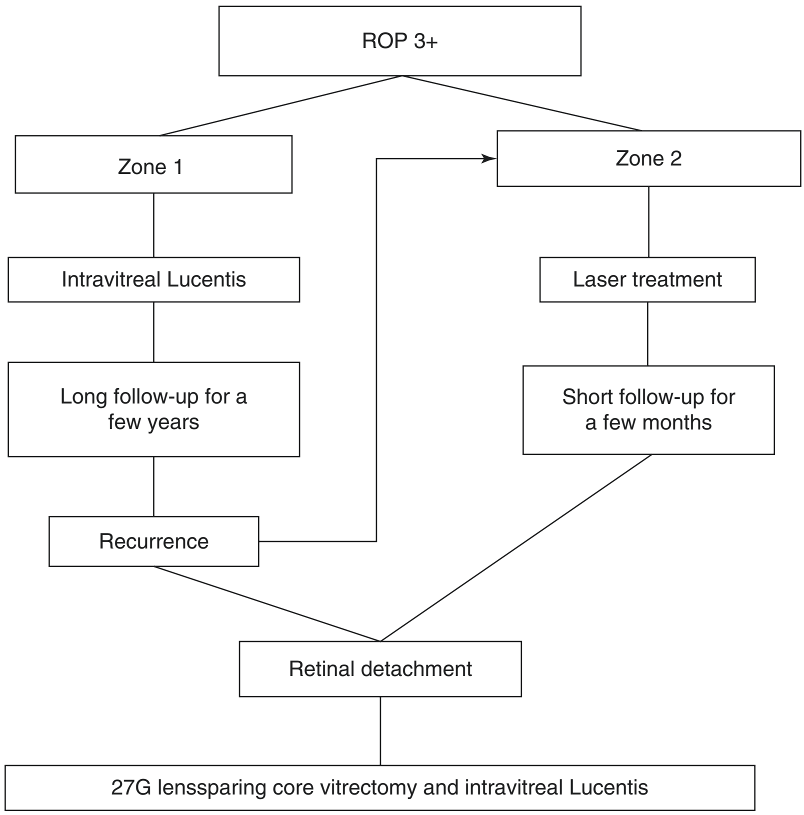


Fig. 13.12 Our treatment algorithm for treatment of ROP

Physiology of a Neonate Eye

In the neonatal eye, the pars plana region is incompletely developed and almost not existent. The axial length of a newborn eye is 16 mm in the 34th gestational week and 17 mm in the 40th gestational week. The anterior retina lies just behind the pars plicata. The site of sclerotomy is therefore much closer to the limbus. The sclerotomy should be performed 1.0 mm behind the limbus. See Fig. 13.11. The newborn eye has a huge lens compared to the globe. A big lens and a short sclerotomy site allow only a small canal to insert and manoeuvre the instruments. Utmost care is needed in inserting a vitreoretinal instrument or in administering an injection, because it may cause inadvertent lens touching, traction on the vitreous base, and retinal damage.

The vitreous body is completely intact; there is no degeneration of the vitreous body present. The vitreous body is very firmly attached to the retina; a PVD is virtually not possible. If you try to induce a PVD you risk creating a retinal tear.

Retinal Detachment Secondary to ROP

A retinal detachment for ROP is a tractive retinal detachment and not a rhegmatogenous retinal detachment. Due to the fact that a retinal break is not present, there is no need for a tamponade or even postoperative posture. The aim of surgery is to remove the vitreous body in order to relieve retinal traction. The retina will reattach in a few days after surgery. In addition an anti-VEGF injection is needed to reduce the vascular activity and remove the pathophysiologic stimulus of the tractive detachment. We use ranibizumab (Lucentis®) because the half-life in serum is lower compared to bevacizumab (Avastin ®). Regarding the dose, we use 50 % adult dose, i.e. 0.025 ml Lucentis.

In a 4 A and 4B detachment, we have an excellent experience with the sutureless 27G technique; to perform a lens sparing vitrectomy and inject intravitreal Lucentis.

Timing of Surgery

Timing of surgery is of utmost importance. We only operate ROP stage 4 A (retinal detachment and attached macula) and 4B (retinal detachment and detached macula). See Fig. 13.12. We do no operate stage 5 ROP. Do not operate too late. The risk that you will not succeed is high and the risk that you will have complications is even higher. Try to operate in stage 4 A.

Surgery: Intravitreal Lucentis® Injection

We inject 0.025 ml Lucentis in non-vitrectomized eyes. If possible, we use the microscope in order to see the medication enter the eye. Both eyes are therefore dilated. Mark the sclera 1.0 to 1.5 mm behind the limbus, pierce the eye globe with the syringe and aim towards the optic nerve. The newborn lens is thick and can be easily damaged. Find the tip of the syringe under the microscope. Then inject the medication. Observe that the medication leaves the tip of the syringe.

Surgery: Lenssparing 27G Vitrectomy

Video 13.9: ROP_RE

The surgery is easy but you have to operate absolutely without complications: No lens touch, no retina touch and NO retinal tear. A lens touch will result in a lensectomy and amblyopia. A retinal touch with retinal tear will result in retinal detachment and blindness. Be careful when inserting the trocars and instruments. Aim towards the optic nerve. Perform a central and peripheral vitrectomy. Do not induce a PVD; it is almost impossible in newborn. Do not remove membranes; you may induce a retinal tear. A tamponade is not necessary.

Surgery Step-by-Step
<u>Instruments</u>

1. 3-port 27G trocar system
2. 120D lens
   <u>Medication</u>
   Lucentis®, alternatively Avastin®
   <u>Tamponade</u>
   None

<u>Individual Steps</u>

1. **3-port 27G trocar system**
2. **Core vitrectomy**
3. **Peripheral vitrectomy**
4. **Injection of 0.05 ml Lucentis**
5. **Removal of trocar cannulas**

The Surgery Step-by-Step: Figs. 13.13, 13.14, 13.15, 13.16, 13.17, 13.18, 13.19, 13.20, and 13.21

1. **3-port 27G trocar system**
   Insert the trocar cannulas 1.0 mm behind the limbus. Aim with the trocar cannulas towards the optic nerve. We insert the trocars straight (perpendicular) into the eye due to the risk to damage the eye (Figs. 13.13 and 13.18). The sclerotomies will remain watertight. Then attach the infusion line to the infusion trocar and double check that the infusion trocar is located inside the vitreous body.

Surgical Pearls No. 73
<u>Location of infusion cannula in pediatric vitrectomy</u>: The infusion cannula tends to turn towards the lens resulting in a blockage of the

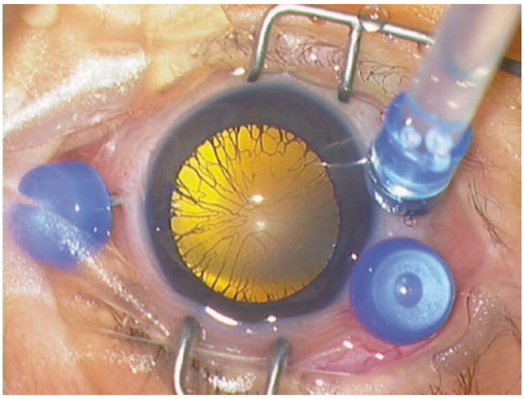


Fig. 13.13 Case report 1. RE A 27G lens- sparing vitrectomy (DORC) in a newborn eye in 34th gestational week (right eye)

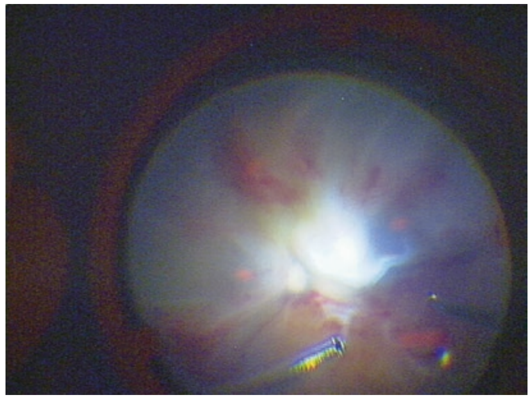


Fig. 13.15 Case report 1. RE Core vitrectomy and then injection of Avastin

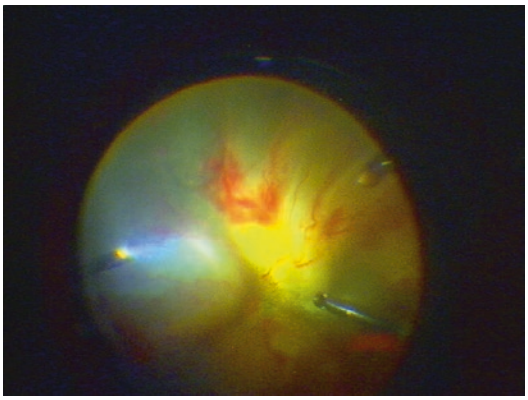


Fig. 13.14 Case report 1. RE A stage 4B-5 detachment

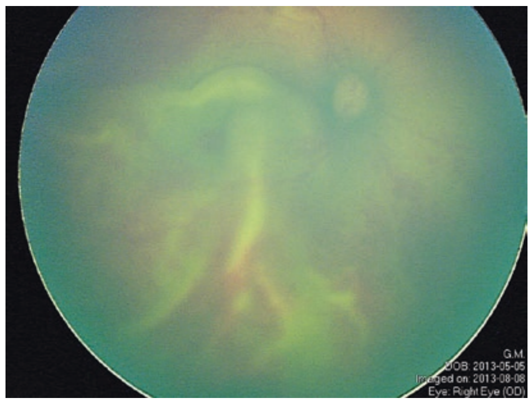


Fig. 13.16 Case report 2. RE First postoperative day. The retina is almost completely reattached

Fig. 13.17 Case report 1. RE 14-day follow-up. The retina is reattached. Note the exudates at the posterior pole

infusion. The dangerous consequence of this event is a bulbar hypotony with choroidal detachment. Observe therefore constantly the position of the infusion trocar during surgery.

2. **Core vitrectomy**
3. **Peripheral vitrectomy**

Insert the instruments carefully by aiming them towards the optic nerve. Remember: The lens of a newborn is much larger than the lens of an adult (ratio lens/globe). Begin with a core vitrectomy and continue then with a peripheral vitrectomy (Figs. 13.14 and 13.19). Hold a secure distance to the retina. Caution: Avoid a retinal touch. If you induce an iatrogenic hole you can close the case.

4. **Injection of 0.05 ml Lucentis**

Attach a 27G backflush cannula to the Lucentis syringe. After completion of vitrectomy inject 0.05 ml Lucentis into the vitreous cavity. Remark: We use here the complete Lucentis dose because the vitreous has been removed.

Surgical Pearls No. 74

Anti-VEGF dose for ROP: In vitrectomized eyes we inject the adult dose of Lucentis. The reasoning for this is that a medication in an eye without vitreous body has a shorter half-life than in an eye with vitreous body.

5. **Removal of trocar cannulas**

Remove first the instrument trocars and press a surgical instrument against the incision. Remove in the end the infusion trocar. A suture is not necessary even if you performed a perpendicular incision!

Complications

1. The infusion trocar may rotate towards the lens and block the infusion resulting in a choroidal detachment.
2. A retinal tear will lead inevitably to a retinal detachment which cannot be cured.
3. A lens touch will result in lensectomy and consequently amblyopia.

Case Report No. 1: ROP Stage 4

Video 13.9: ROP_RE

Figures 13.13, 13.14, 13.15, 13.16, 13.17, 13.18, and 13.19

The neonate was laser treated in the 36th gestational week because of ROP stage 3+. One week later the retina on both eyes was detached. The right eye showed a beginning stage 5 detachment and the left eye a stage 4B detachment (Figs. 13.14 and 13.9). Both eyes had extensive preretinal and subretinal hemorrhages.

Three 27G trocars were inserted 1 mm behind the limbus. The insertion was performed perpendicularly (not lamellar) (Figs. 13.13 and 13.18). A central and peripheral vitrectomy was performed. The vitrectomy was performed with an EVA vitrectomy machine (DORC), a cutting speed of 7000 cuts/min and a vacuum of 500 mmHg (Fig. 13.15). At the end, 0.4 mg ranibizumab was injected into the vitreous cavity. No PVD, no peeling and no tamponade were performed. The trocars were removed and the sclerotomies were not sutured. The surgical time of each eye was less than 20 min.

On the first postoperative day, the conjunctiva was white, the globe normotensive. The retina was completely attached on the LE and almost completely attached on the LE (Figs. 13.16 and 13.20). After 14 days follow-up, the retina was peripherally and centrally attached in both eyes (Figs. 13.17 and 13.21).

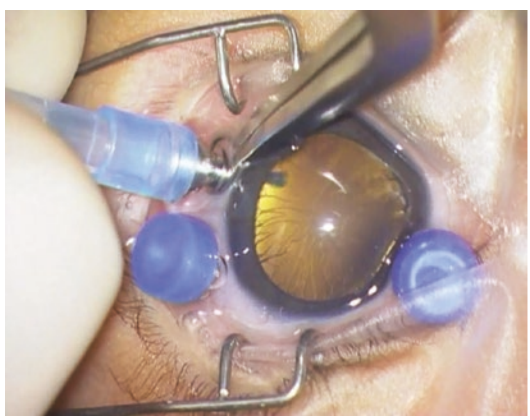


Fig. 13.18 Case report 1. LE A 27G lens- sparing vitrectomy (DORC) in a newborn eye in 34th gestational week. Note the tunica vasculosa lentis (left eye)

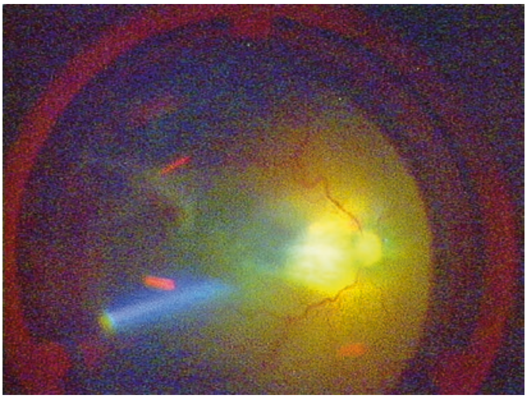


Fig. 13.19 Case report 1. LE A stage 4B detachment

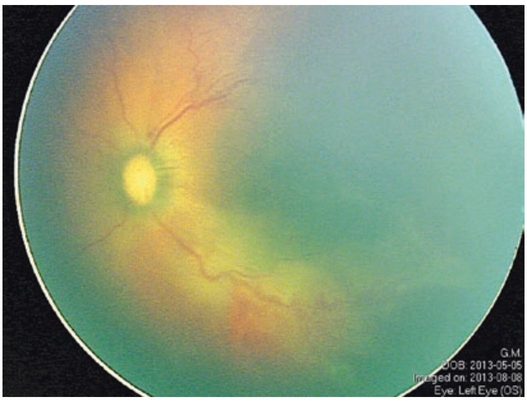


Fig. 13.20 Case report 1. LE First postoperative day. The retina is already reattached

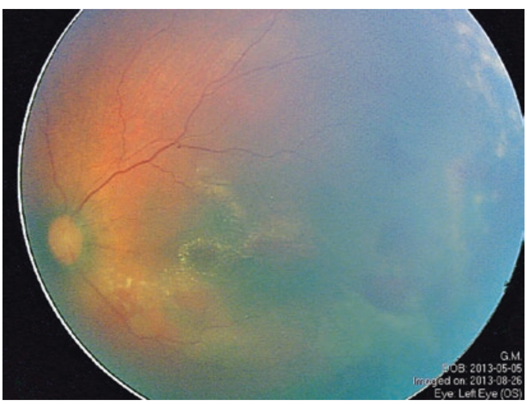


Fig. 13.21 Case report 1. LE 14-day follow- up. The retina is reattached

FAQ

Does the Retina Reattach after Removal of the Vitreous?

Yes. The vitreous body in newborns is completely intact. An inflammatory contraction of the vitreous will result in retinal traction and detachment. If you remove the vitreous body and reduce the vascular activity, the retina will reattach within a few days.

What About ROP Stage 5?

The surgical success in stage 5 is low. If the funnel is closed anteriorly you cannot access the vitreous cavity without causing a tear into the retina. If the funnel is closed posteriorly a surgical approach may be successful.

FEVR

Familial exudative vitreoretinopathy is a genetic eye disorder of the eye and does not affect other parts of the body. The inheritance is autosomal dominant. In FEVR the growth and development of retinal blood vessels is pathological and results in exudative leakage and hemorrhage.In addition, the peripheral retina is ischemic and peripheral neovascularizations may be present. Other diseases with peripheral neovascularizations are listed in Fig. 13.22. The final outcome of this disease is often characterized by retinal folds and detachments.

Case Report No. 2: FEVR

(Figures 13.23, 13.24, 13.25, 13.26, 13.27, 13.28, 13.29, and 13.30, Video 13.10)

A 10 y/o girl was submitted to us for examination of an unknown retinal pathology on the right eye. The visual acuity was normal. On the left eye the visual acuity was reduced to light perception since approximately ½ year. The reason was a dense vitreous hemorrhage. We performed an examination in general anaesthesia. Using a Retcam we made picture photographs of both eyes (Fig. 13.23). We continued with a Retcam angiography and now an extensive retinal isch-

Diabetes
ROP
M. Eales
FEVR
Incontinentia pigmenti (Bloch Sulzberger)

Fig. 13.22 Retinal diseases with peripheral neovascularization

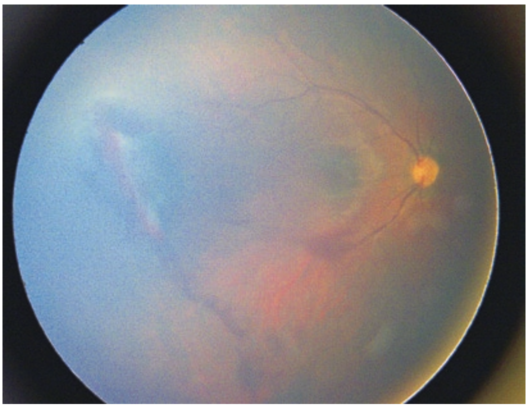


Fig. 13.23 A 10 y/o girl was submitted to us for diagnosis and therapy of peripheral neovascularizations on the RE. The LE had a dense vitreous hemorraghe

Fig. 13.24 Angiography with the Retcam machine reveals an extensive ischemia of the peripheral retina. We injected Lucentis® in both eyes

emia in the periphery was visible (Fig. 13.24). Our diagnosis was a retinal ischemia with peripheral neovascularizations. We injected therefore Lucentis® in both eyes.

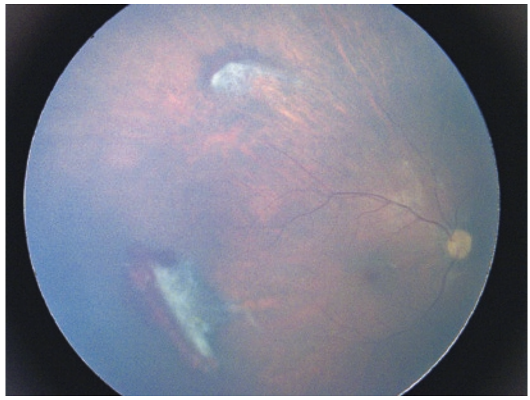


Fig. 13.25 One month follow-up. The peripheral neovascularizations are reduced in size

Fig. 13.26 An angiography is performed. The white line demarcates the border between ischemic and vascularized retina

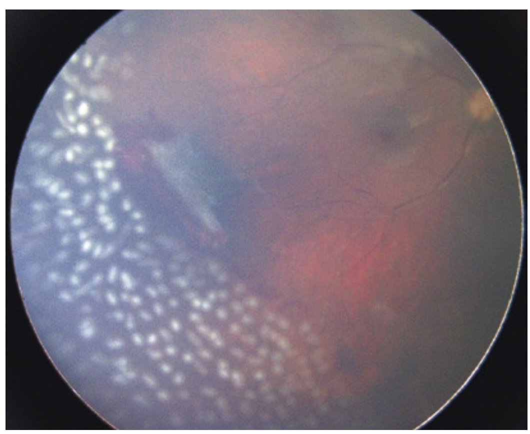


Fig. 13.27 According to the angiography a laser indirect ophthalmoscopy (LIO) is performed. This colour photograph taken directly after laser treatment

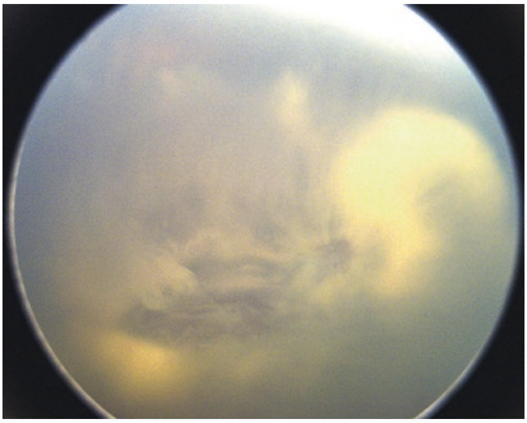


Fig. 13.28 A dense vitreous hemorraghe is present on the LE

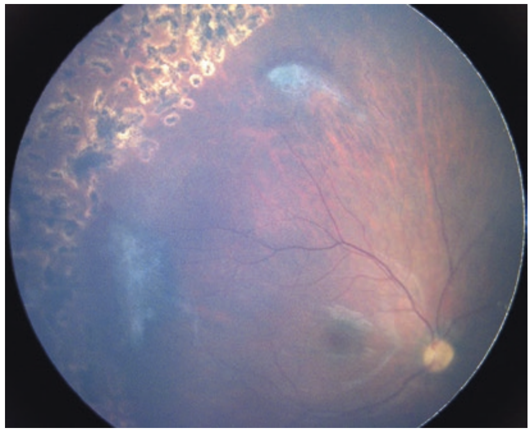


Fig. 13.30 The retina was treated once with LIO (laser indirect ophthalmoscope). The ischemic retina cannot be assessed

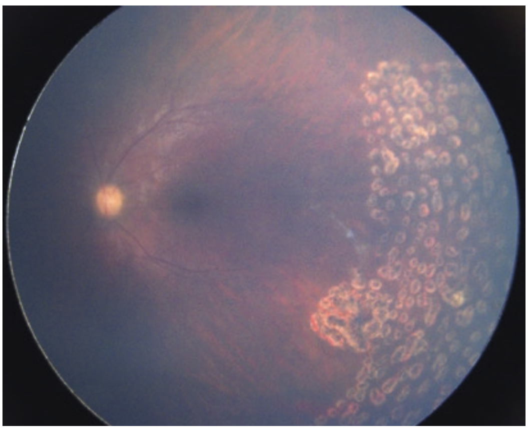


Fig. 13.29 A 27G lens sparing vitrectomy with peeling and laser is performed. The colour photograph shows the retina 1 month postop

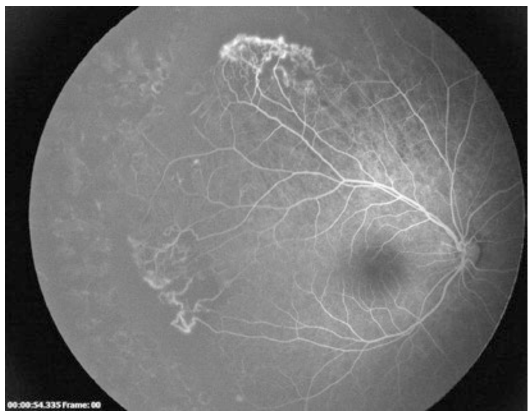


Fig. 13.31 Early phase of angiography: The neovascularizations at the border to the ischemic retina are well visualized

One month later we repeated an examination in general anaesthesia (Figs. 13.25, 13.26, 13.27, and 13.28). Retcam photography demonstrated reduced peripheral neovascularizations in the right eye (Fig. 13.25) and a dense vitreous hemorrhage with uncolored blood cells in the left eye (Fig. 13.28). We repeated the angiography and performed a LIO (laser indirect ophthalmoscopy) according to the angiography because the border of the retinal ischemia could not be seen with ophthalmoscopy. On the left eye a 27G lens sparing vitrectomy was performed (Video 13.10).

One month later the visual acuity was measured with 1.0 on both eyes. We repeated an examination in general anaesthesia (Figs. 13.29, 13.30, 13.31, and 13.32). The Retcam angiography revealed a bleeding at the edge of the neovascularizations and residual retinal ischemia. The left eye showed a quite fundus in ophthalmoscopy as well as in angiography. We decided to perform a simultaneous angiography – laser treatment in the right eye. Continue with the following chapter.

Simultaneous Angiography and Lasertreatment for Children with Ischemic Retinopathy

We describe a novel technique of simultaneous angiography with Retcam and lasertreatment

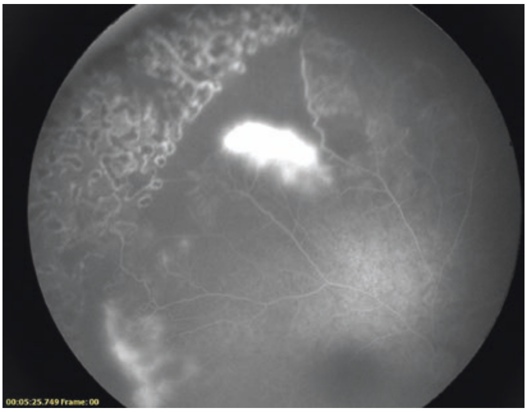


Fig. 13.32 Late phase of angiography: The laser effects are now well visualized. The angiography reveals clearly the residual ischemic retina

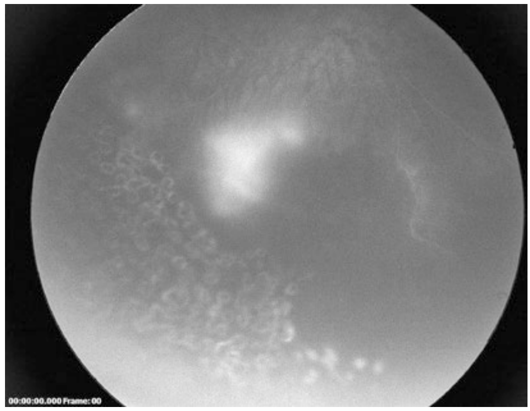


Fig. 13.34 After first laser treatment: Note the laser spots at 6 o'clock

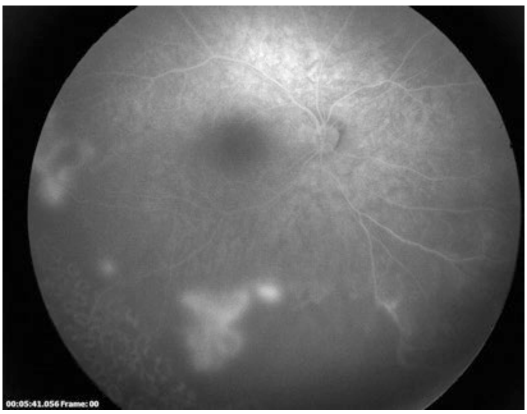


Fig. 13.33 In the inferior pole a large not lasered area of ischemic retina is revealed using angiography

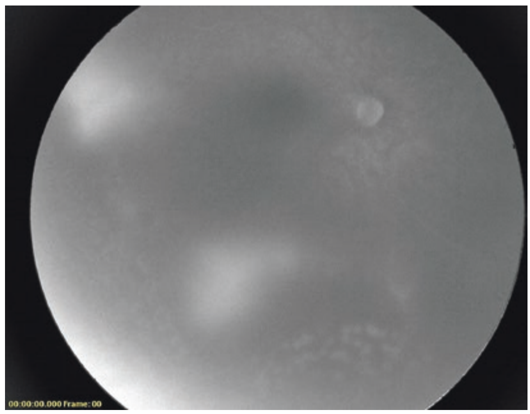


Fig. 13.35 After second laser treatment: Note the convex shape of laser treatment. There is residual ischemia. The angiography pictures (Figs. 13.31–13.36) are performed within one session

with indirect ophthalmoscope for the treatment of ischemic retinopathy such as FEVR.

The Retcam machine is used for photography of the retina of premature newborn. Two recent functions expand the usage of the machine. The first one is the storage of all photographs on a central server. All users in the country (i.e. clinics using Retcam) can store and access these pictures. This allows an effective telemedicine. Instead of describing the fundus with many words a simple picture can demonstrate the urgency of treatment. The second function is an integrated angiography in the most recent Retcam 3 machine.

The newborn or child can be examined in local or general anaesthesia. We prefer general anaesthesia so that we can continue with lasertreatment if necessary. After injection of fluoresceine pictures are taken. Thereafter the angiography photographs are evaluated and the extent of the retinal ischemia retina is assessed. In ROP newborn this assessment is clinically easy due to the presence of the ridge. But in diseases such as Incontinentia pigmenti or FEVR or Morbus Eales no ridge is present and the border between vascularized and ischemic retina is very difficult to assess. Using angiography, however, the border is evident (Figs. 13.25 and 13.26). After laser treatment, we repeat angiography during the same

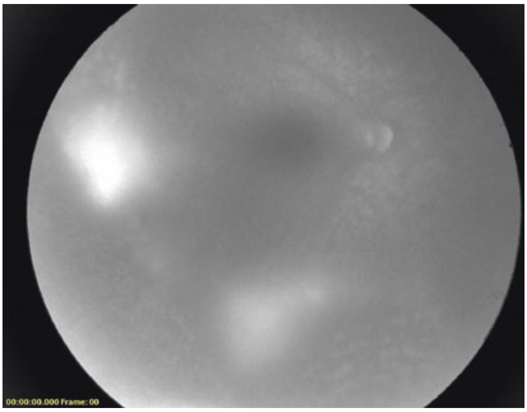


Fig. 13.36 After third laser treatment: Now the retinal ischemia is completely treated

Fig. 13.37 Case report 9. Persistent hyperplastic primary vitreous (PHPV). A closed funnel from the optic head to the lens

surgical session in order to evaluate the laser effects and the residual ischemic retina. If necessary, a second laser treatment is performed. This procedure can be repeated several times during the same surgical session (Figs. 13.33, 13.34, 13.35, and 13.36). Remark: We inject only once fluoresceine.

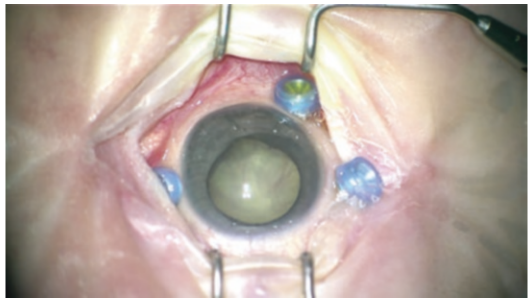


Fig. 13.38 Case report 9. A newborn with unilateral PHPV. Note the retrolental mass

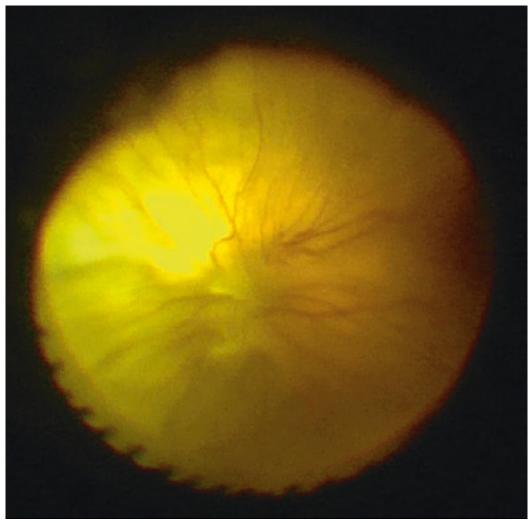


Fig. 13.39 Case report 9. The retrolental tissue

Our Procedure for Simultaneous Retcam Angiography and Laser Indirect Ophthalmoscopy: Figs. 13.33, 13.34, 13.35, and 13.36

1. General anaesthesia
2. Examination of the newborn/child with indirect ophthalmoscopy.
3. Taking pictures with the Retcam.
4. Changing to angiography modus.
5. Injection of fluoresceine 0.08–0.1 ml per kilo/bodyweight.
6. Taking angiography pictures

7. Laser treatment according to the angiography pictures
8. Repeat angiography (late phase) to evaluate the lasertreatment
9. This procedure can be repeated a few times.

Case Report No. 3: PHPV

Figures 13.37, 13.38, and 13.39

Video 13.11: PHPV and 27G

A 23-day-old newborn was admitted to us for surgery of a retinal detachment of the right eye. At birth he had a large right pupil which did not react to light. There was a clear red reflex. An examination in general anaesthesia was scheduled. The axial length on the right eye was measured with 14.60 mm and white-to-white with 10 mm. An anterior segment examination showed a strong iris hyperemia, posterior synechiae at 6 o'clock and a zonular lysis from to 11 to 1 o'clock. A white vascularized tissue behind the lens was present (Fig. 13.38). B-scan revealed a funnel- shaped hyperfluorescence from the optic nerve to the lens. The retina seemed to be attached. The examination of the left eye revealed an axial length of 16.81 mm and a W-t-W of 11 mm. Anterior segment and posterior segments were regular. The parents were informed about the findings and consented into an operation. A 27G lens-sparing vitrectomy was performed and the retrolental tissue was removed (Figs. 13.38 and 13.39). The view to fundus was poor, and it seemed that retinal vessels were visible. An ERG is scheduled in 6 months.

Case Report No. 4: Neurofibromatosis Type 2 with Intraoperative OCT

Figures 13.40, 13.41, 13.42, 13.43, and 13.44

Video 13.12: Neurofibromatosis 2

Video 13.13: Intraoperative OCT

Intraoperative OCT allows an OCT of the anterior and posterior segment during an ongoing corneal or retinal surgery (Figs. 13.40 and 13.41).

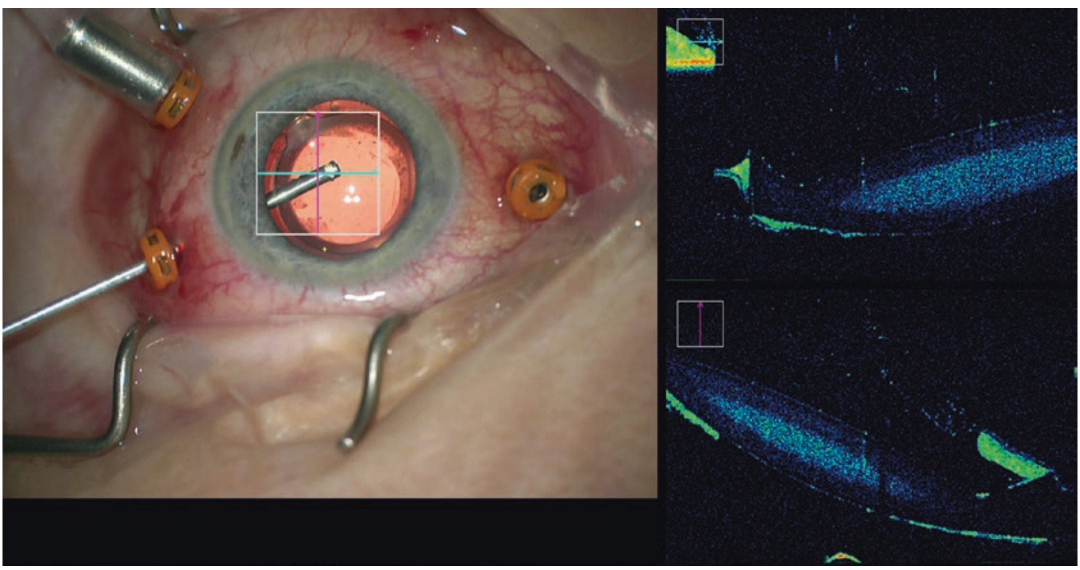


Fig. 13.40 Intraoperative OCT of the anterior segment with the Zeiss Rescan 700 microscope

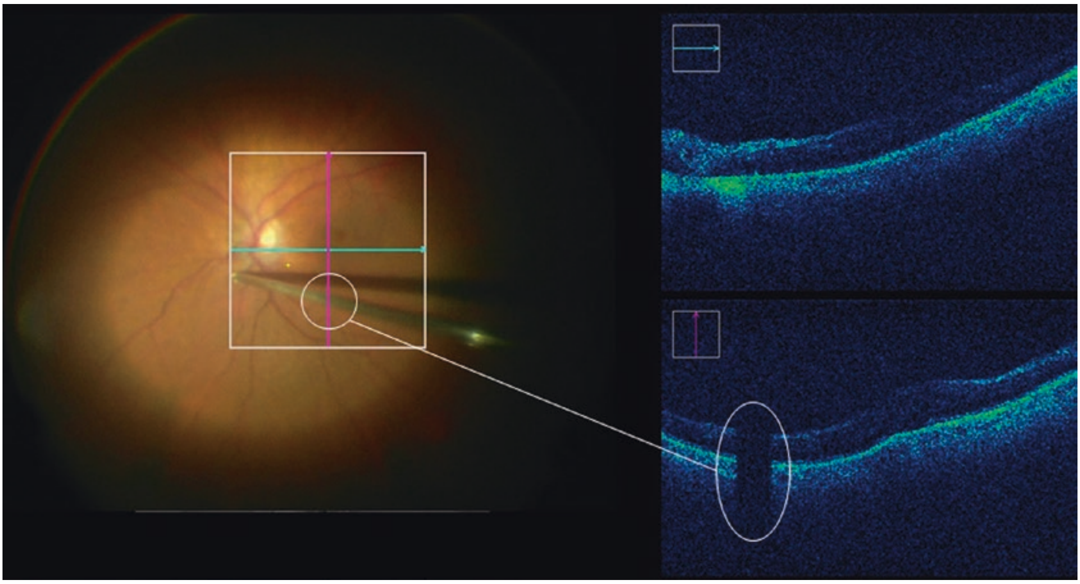


Fig. 13.41 Intraoperative OCT of the posterior segment during macular peeling with the Zeiss Rescan 700 microscope. Note the vitreous cutter on the OCT image

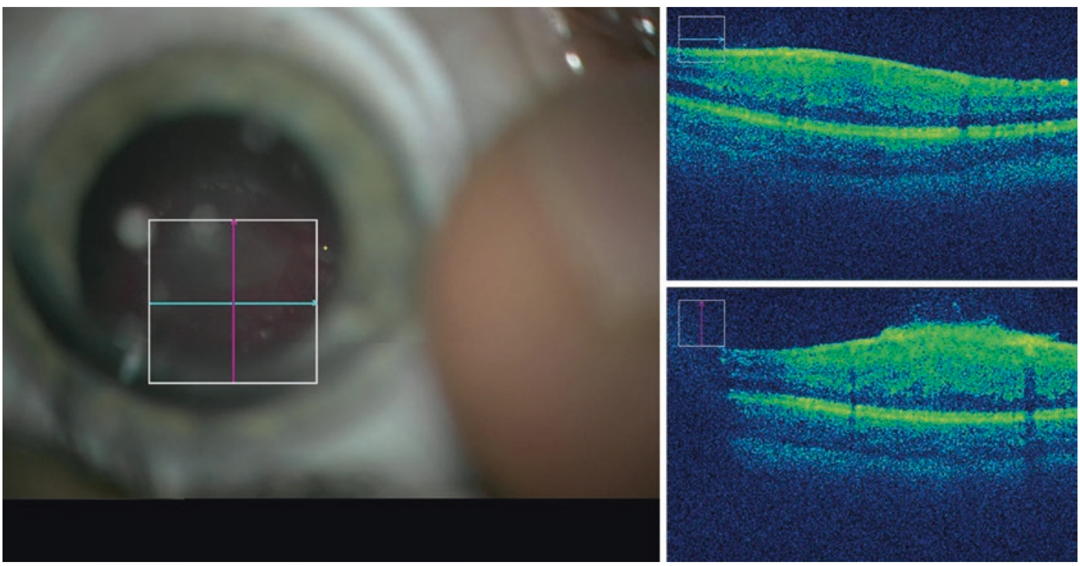


Fig. 13.42 A plano concave lens is placed on the cornea and the intraoperative OCT (Rescan 700) is switched on

The following case report will illustrate the advantages of the intraoperative OCT (Zeiss Rescan 700):

A 5 y/o boy with known neurofibromatosis type 2 was admitted to us for assessment of a macular pucker. Visual acuity was measured bilateral with 0.8. Before starting surgery, we performed an intraoperative OCT. We placed a contact lens (DORC) on the cornea and performed an OCT (Figs. 13.42 and 13.43). Then the membrane was successfully removed with 27G vitrectomy (Fig. 13.44). A follow-up half a year later showed no improvement of the visual function.

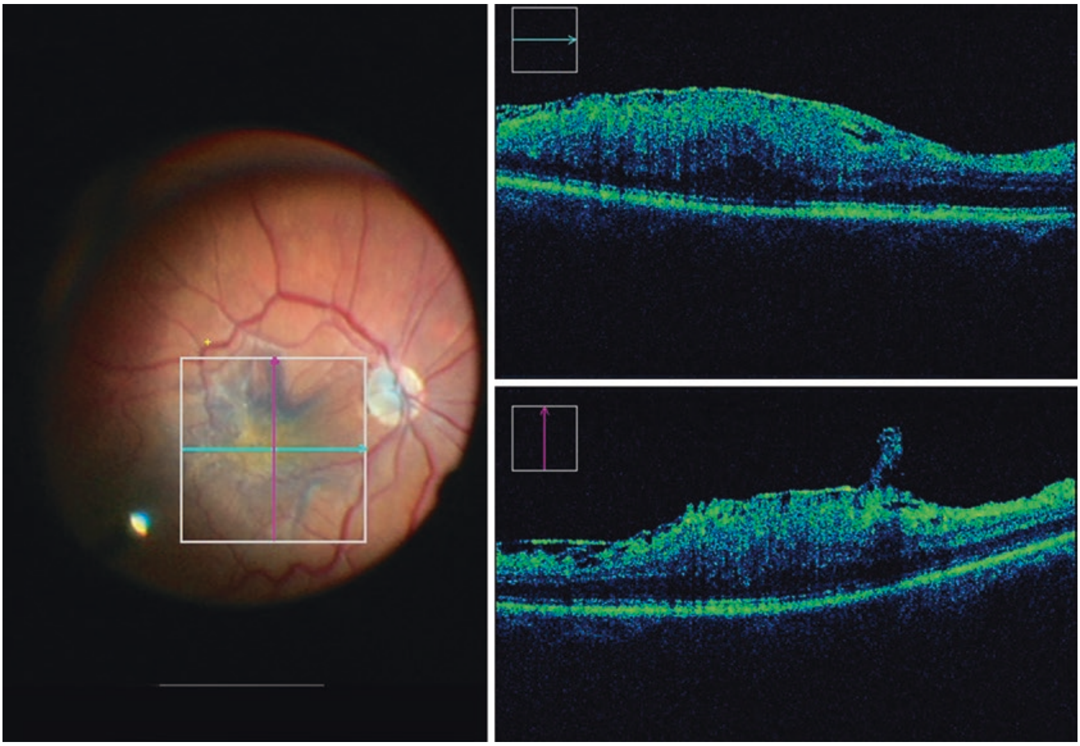


Fig. 13.43 The OCT screen provides an excellent fundus photograph with OCT

Fig. 13.44 A fundus photograph of the macular pucker

14 Robotic Eye Surgery

Charles W. Mango, Angelo Tsirbas, and Jean-Pierre Hubschman

Introduction

Ophthalmology is a field at the forefront of innovation. Improvements in surgical instrumentation and refinements in surgical techniques have resulted in improved outcomes while decreasing operating time. Digital ultrahigh definition microscope utilization, real-time overlays of intraoperative OCT data, and automated laser assisted cataract surgery have been recent major contributions to our field. We believe the next revolution in ophthalmology will be the further development and acceptance of robotics.

Robotic Surgery History

A robot is a machine that can do the work of a person and that works automatically or is controlled by a computer [1]. Robotic surgery, or more precisely Robotic-assisted surgery had its beginnings 40 years ago with the development of the Arthrobot [2]. The robot, strapped to a patient's leg, positioned the leg via voice commands from the surgeon. This allowed the surgeon to operate without the need of an assistant for this task. In 1985, the Puma Robot was used to assist in guiding a needle for a brain biopsy [3]. In 1992 the PROBOT was designed and utilized in the first robotic prostatic surgery. Also in 1992, ROBODOC, a robotic system designed to assist in hip replacement surgeries was developed [4]. ROBODOC was tasked with precisely carving out the femur during a hip replacement [5], improving the fitting process as compared to the prior method of carving the femur by hand.

Further development of medical robotic systems yielded the AESOP in 1994. It was a voice activated robot that was used to hold and position an endoscope. The surgeon would say: "AESOP move left" and the positioning arm would move until the "Stop" command was given. Building on this, the next generation ZEUS Robotic Surgical System was developed for microsurgery procedures such as suturing a beating heart [6].

In 2000, the Da Vinci Surgical System was approved for use by the US FDA [7]. The

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Fig. 14.1 Da Vinci Surgical System showing surgeon looking into console viewer, robot with arms separated physically from surgeon's console (Image courtesy of Intuitive Surgical)

Da Vinci Surgical system incorporates a three-dimensional surgical monitor, a surgeon control area, and three robotic slave arms (Fig. 14.1). The robotic arms have seven degrees of movement that allow for the surgeon's wrist and finger motions to be precisely mimicked. Each of the robotic arms can be equipped with a variety of instrumentation to allow for specialized surgical procedures. The monitor and surgeon control area can be separated from the robotic slave arm portion of the machine allowing for remote surgery. This remains the current and most widely used system to our present day. Mainstream use of robotics using this surgical platform have overtaken the fields of Urology [8–11], Gynecology [12, 13], and Cardiovascular surgery [14–16].

Robotic Eye Surgery History

Robotic eye surgery has a relatively short history compared to robotic surgery in general. Whereas other surgical fields have accumulated a significant clinical experience using robotic surgery on patients, the focus of Ophthalmic surgeons has been on demonstrating the feasibility of specific ocular procedures using a robot in a laboratory setting. There are several reasons for this cautious approach to robotic acceptance in the field of Ophthalmology. Ocular surgery already employs minimally invasive techniques providing rapid recovery and excellent outcomes. Eye surgeons have good control and excellent views with the current standard of optical microscopes. Lastly, maneuverability of ophthalmic instruments poses little problem for experienced surgeons with trained hands.

Robotic surgery has addressed the limitations of traditional surgery in other surgical disciplines. Benefits of this system, compared to traditional surgery have demonstrated increased precision, improved range of motion, tremor elimination, increased surgeon safety, and ability to maneuver in confined anatomic spaces [17–21]. These are all central facets to advancement in any surgical field and by extension to ocular surgery. In other words, there is always room for improvement for surgeon control, safety, and patient outcomes in any surgical field.

In 1989, Guerrouad and Vidal described and developed the first robot dedicated to eye surgery, the Stereotaxical Microtelemanipulator (SMOS). The SMOS included a spherical micromanipulator that provided for 6 degrees of freedom. It demonstrated improved accuracy of specific tasks compared to manual surgery, but was slower [22].

The Robot Assisted MicroSurgery (RAMS) workstation developed by Steve Charles and collaborators with NASA's Jet Propulsion Laboratory was first described in 1997 [23]. The RAMS workstation is a compact robot that allowed for extensive precision of movement down to 15 microns along with motion scaling, that is where large movements in the surgeon's hand are translated to micro-movements by the robot.

At the same time, Northwestern University developed a robot that allowed for retinal vessel cannulation inside a cat's eye. The retinal vessels ranged in internal diameter from 20 to 130 microns [24].

In 1998, Yu et al. developed a patented spherical manipulator, similar to the SMOS, specifically to demonstrate feasibility off intra-retinal vascular drug delivery, implantation of ocular microdrainage devices and the intraretinal manipulation of microelectrodes. These tasks were successfully carried out with minimal tissue damage in a laboratory setting [25].

Japanese collaborators created a prototype robotic system based on the SMOS platform that was designed to aid in multiple specific tasks of vitreoretinal surgery [26]. This robot facilitated successful surgical induction of a posterior vitreous detachment, retinal vessel sheathotomy using 25-gauge microscissors, and microcannulation of retinal vessels with a diameter of 100 microns in porcine eyes.

Investigators at Johns Hopkins University developed a steady hand manipulator (SHM) for retinal microsurgery [27]. The design places the pivot point of the articulating probe at the sclera (as it would be in traditional vitreoretinal surgery), Placing the remote center of motion (RCM) at this location minimizes undesirable tension on the eye wall. The SHM provided filtration of tremor that was demonstrated experimentally. Further innovations by this group include intra-operative retina registration that syncs with pre-operative imaging to guide treatment delivery to a specific point on the retina [28]. The Micron, a microsurgical tool that reduces unintentional tremor while preserving eye-hand coordination was also developed and tested. Surgeons experienced up to 52 % reduction in error in validation experiments using the Micron [29].

In 2006 the feasibility of robotic ocular surgery and robotic ocular telesurgery using the Da Vinci Surgical System was demonstrated through a series of studies [30, 31]. The experiments were performed on harvested porcine eyes placed in an anatomical position using a foam head on a standard operating room table. Visualization of the eye was achieved with a 3D endoscope camera directly above the globe, thus mimicking a view through a standard operating microscope. The 2 robotic arms were placed on either side of the globe at a 45-degree angle, resembling the same approach used by a surgeon to maximize exposure to the ocular surface. The surgeons performed the procedures while positioned at the surgeon control area that was located across the operating room suite. External ocular surgery (cornea suture laceration repair) was performed and deemed feasible (Fig. 14.2). Anterior segment procedures (clear cornea incision creation and anterior capsule capsulorhexis formation) were performed and felt not to be practical given the impossibility to position the remote center of

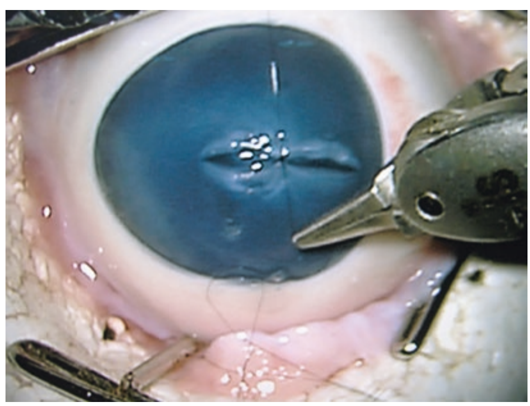

Fig. 14.2 Surgeon's view through the Da Vinci Surgical System showing suture closing of a corneal laceration. A black diamond robotic micro-forcep (controlled by robotic arm) is shown holding one end of the suture. The other robotic micro-forcep is out of the picture frame holding the other end of the suture (Image courtesy of A Tsirbas)

motion at the fulcrum, which caused undue tissue strain. Posterior segment procedures (core vitrectomy and trocar insertion / removal) proved possible, although limitations were noted secondary visualization (difficult view of posterior chamber) and robotic arm issues that did not allow for refined movements within the vitreous cavity.

We have learned over these past several decades that robotics lends itself to ocular surgery in unique ways compared with other surgical disciplines. Tactile feedback mechanisms are advantageous for other surgical fields but are not a necessity for eye surgery. Ocular surgeons rely primarily on visualization as their main tool for performing delicate intraocular tasks. Tremor elimination and motion scaling mechanisms are very important in a microsurgical field involving the eye [21, 32]. Within the confines of the orbit and eyeball, each movement needs to be precise and tremor free. Tremor reduction and motion scaling components of some of these robotic systems has demonstrated this advantage be employed in eye surgery.

Robotic Eye Surgery Today (Video 14.1)

Recent advancements have been made to overcome some of the cumbersome limitations of using the Da Vinci Surgical System.

In order to allow for a more natural vitrector motion by placing the remote center of motion at the fulcrum, a smaller micro robot, the Hexapod Surgical System (HSS) was created [33]. The HSS is mounted to an arm of the Da Vinci Surgical System. The precision and dexterity of this approach was validated by successful insertion of a vitreous cutter through a sclerotomy in porcine eyes.

A robotic forceps advancement, the "Micro hand," was developed to allow for a membrane peeling function necessary in many types of vitreoretinal surgeries [34]. This device was designed to mimic a human hand and is pneumatically controlled, allowing titration of grasping force. Four fingers, with a length of 4 mm each, were used to manipulate fresh retinal tissue of porcine cadaver eyes.

Steerable micro-robots with an outer diameter of less than 500 μm were created and injected through a 23 g needle into the vitreous cavity of cadaver porcine eyes. Using a wireless electromagnetic control headset, researchers were able to achieve coordinated movement of the robots and targeted placement along the retina surface [35]. These micro-robots may act as a future drug delivery system that can be moved to a specific place in the eye (once injected into the eye) using robot steering technology.

Retinal vascular cannulation robots that allow for telemanipulation have been developed [36, 37]. Preliminary feasibility testing shows that this outperforms standard vascular cannulation. An integrated robotic intraocular snake, a submillimeter intraocular dexterous robot prototype has been built [38]. It can eventually be utilized as a steerable needle, steerable forceps, or steerable cannula.

The Intraocular Robotic Interventional Surgical System (IRISS) is a dedicated microsurgical platform capable of performing complete ophthalmic procedures [39]. The design features a remote console which could facilitate telesurgery. The IRISS design includes a head-mounted stereoscopic visualization system, two joystick controls with tremor filtration and scaled motion, custom designed arms appropriately sized to accommodate commercially available instrumentation, and two closely approximated remote centers of motion (pivot points) to reduce tissue stress at the point of ocular entry (Figs. 14.3 and 14.4). Recent trials have focused on three complex ocular procedures: lens capsulorhexis in cataract surgery, 23-gauge core vitrectomy, and retinal vein cannulation. The team is currently developing automated capabilities of the IRISS platform for cataract surgery.

The PRECEYES Surgical System is a prototype robotic system that is being developed primarily for vitreoretinal surgery [40]. It is mounted at the side of the head during vitrectomy surgery and can be brought into place and used as needed (Fig. 14.5). It functions to scale down movements for better precision, filters out tremors, and allows the instrument to freeze in place if the surgeon's hand relaxes. This robotic system is going to be

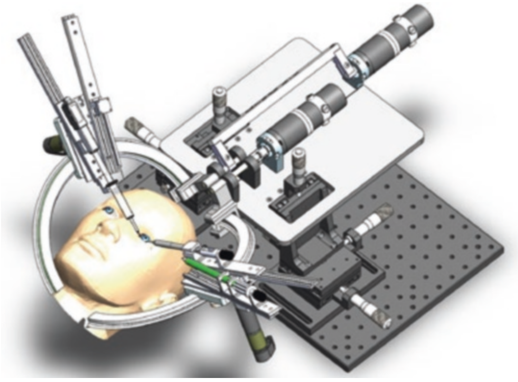

Fig. 14.3 Intraocular Robotic Interventional Surgical System (IRISS) schematic view: custom designed arms appropriately sized to accommodate commercially available instrumentation, and two closely approximated remote centers of motion (pivot points) to reduce tissue stress at the point of ocular entry (Image courtesy of JP Hubschman)

Fig. 14.4 Intraocular Robotic Interventional Surgical System (IRISS) working prototype (Image courtesy of JP Hubschman)

tested for its ability to deliver gene therapy into the subretinal space for a variety of inherited disorders [41].

In 2015, the first human case of robot assisted eye surgery, a pterygium removal, was performed on a 73-year-old patient using the DaVinci robotic surgical system [42].

Today we realize ocular surgery is a field that continues to benefit from incremental advances in robotic technology. Improved instrument engineering, precision scaled movements, integrated tremor reduction, and improved maneuverability

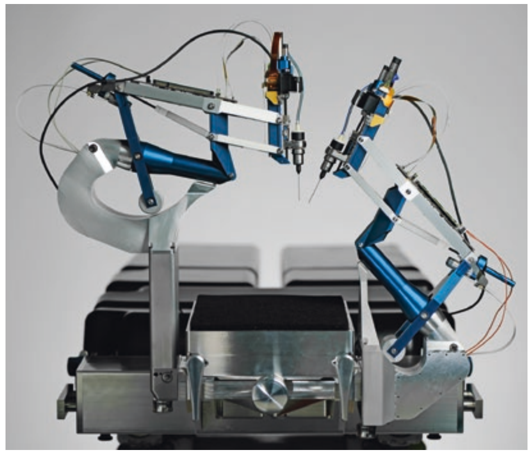

Fig. 14.5 PRECEYES Surgical System prototype showing how it is mounted on the side of the patient's head rest (Image courtesy of PRECEYES)

are all key advancements that robotic integration currently provides.

Robotic Eye Surgery of the Future

The feasibility of telesurgery was demonstrated in 2001 when Marescaux and colleagues performed the first transatlantic robotically assisted surgery on an animal model [43]. This was followed by the first transatlantic robotically assisted laparoscopic cholecystectomy in a human being [44]. Since then, telesurgery has been demonstrated successfully on multiple occasions [45]. Ocular robotic telesurgery may also be feasible, bringing emergency eye care to distant and hard-to-reach locales, such as an isolated island or war torn nation.

In 2016, the Smart Tissue Autonomous Robot (STAR) demonstrated for the first time the ability of a fully autonomous robot to suture up intestine on a live pig [46]. Autonomy would be a logical next step in robotic eye surgery. Performing routine and replicative tasks such as trocar insertions, infusion connection, and trocar removal could save the surgeon valuable time and energy on each case. Future advancements in sensor technology that prevents the vitreous cutter from hitting the retina would allow for a core vitrectomy to be an automated task. Perhaps 1 day, even the most delicate vitreoretinal surgical tasks such as internal limiting membrane peeling will be an automated experience.

Visualization improvements may be the next forefront that dovetails with robotic advancements. 3D ultra-high definition displays with overlayed intraoperative OCT data are already present. Perhaps a full immersion with virtual reality headsets will be the next frontier providing the ability to look around from inside the vitreous cavity. A miniature robotic controlled camera mounted on the end of a vitrector probe would allow for this experience. The surgeon would be able to virtually stand in the vitreous cavity and look up at the underside of the iris simply by looking upwards with virtual reality goggles on. Every structure of the eye would be within potential view and accessible to surgical intervention.

Tele-mentoring is the creation of a virtual classroom, and current robotic and audio/visual infrastructure allows for this to exist. In the first demonstration of tele-mentoring, a laparoscopic colectomy was performed by a novice surgeon taking instructions from an expert surgeon located across a medical campus [47]. Since then, tele-mentoring has been implanted across continents with improving success [48–53]. Ocular surgery lends itself well to the mentoring process as one-on-one training has been the standard over time. It is easy to envision a senior ocular surgeon lending real-time advice (via audio/visual connection) and providing control assistance (via robotic connection) to a novice surgeon located at a remote site.

Conclusion

There are many benefits to the integration of robotics into the field of Ophthalmic surgery. The first advantage is improved precision. Tremor reduction and motion scaling components of current robotic systems allow for this. Whether cannulating a retinal vein or grasping an epiretinal membrane, robotic assistance improves upon traditional manual methods at these tasks. Safety is another benefit that is enhanced with robotic surgery. By means of operating at a distance, the surgeon should rarely come into direct contact with any sharps. This reduces the risk of a surgeon injury considerably and is especially relevant when operating on patients with communicable disease. Lastly, the ability to enhance already excellent visualization platforms by augmenting additional data is a tremendous benefit.

While recognized engineering challenges persist, advancements in ocular robotic surgical systems are forthcoming. Future advances such as autonomic surgical tasks will allow for surgeons to save their energy to focus on the most critical aspects of the procedure while the robot performs the routine portions. Expansion of tele-surgery and tele-mentoring capabilities beyond what we have now will enable teaching and assisting others throughout the world.

Ophthalmology has always been an innovative field. With current robotic technology and forward thinking ideas, the potential for the future is unlimited.

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