Luigi Caretti
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Editors

Glaucoma Surgery

Treatment and Techniques

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Contents

Anatomy

1

Luigi Caretti and Lucio Buratto

In glaucoma surgery, comprehensive knowledge and understanding of the sclero-corneal limbus and the anatomy of the irido-corneal angle (Figs. 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6) are absolutely essential.

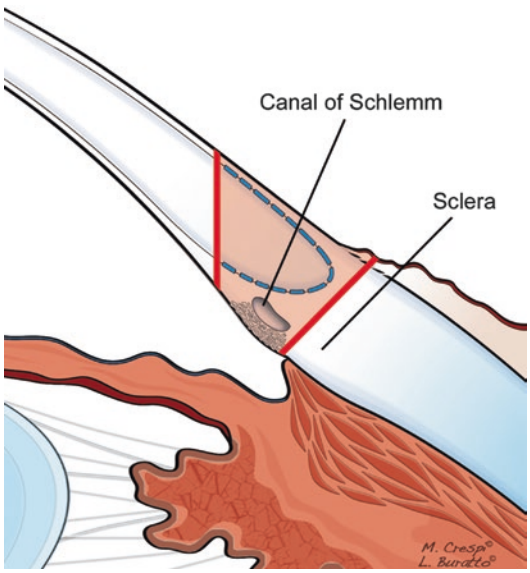

Fig. 1.1 Anatomy of the limbus (in section).
– the *red lines* define the block of tissue known as the limbus;
– the *broken blue line* indicates the transition zone between the cornea and the sclera.
The limbus is approximately 1 mm wide, and it is larger on the vertical meridian where cornea and conjunctiva epithelium merge on the boundary with the Bowman membrane. Posterior to this border, the clear and bluish fibers of the cornea merge with the white and opaque fibers of the sclera. In this point, they separate to get the insertion of the corneal fibers: this results in a clearly visible bluish transition band.
The recognition of these important anatomical landmarks is essential for correct surgical access to the angular structures. Infact the termination point of these corneal fibers lies above the scleral spur and the root of the iris; consequently, this is an important surgical landmarks for the structures of the iris-corneal angle

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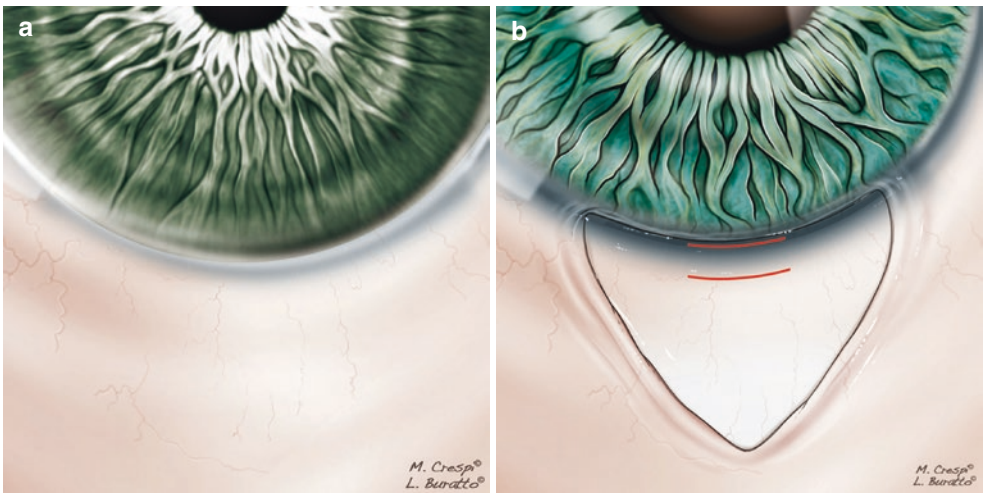

Fig. 1.2 Anatomy of the limbus (view from above).
(**a**) Limbus prior to the conjunctival dissection
(**b**) Limbus following the conjunctival dissection. In the drawing, it is outlined by *red* markings.
The surgical limbus is the *blue-gray* area lying between the sclera and the clear cornea (outlined by *red* markings); it can be identified following the removal of the conjunctiva and the Tenon's capsule (**b**). Its posterior margin normally overlaps the anterior portion of the sclero-corneal trabecular meshwork. Schematically we can identify the following structures, from anterior to posterior: the anterior margin of the limbus, consisting of the Schwalbe line, the posterior boundary consisting of the scleral spur, and finally the trabecular meshwork that lies between these two structures. The conjunctiva and the Tenon's capsule are inserted into the cornea at the Bowman membrane, and cover the limbus. In most anti-glaucomatous surgeries (particularly if they are penetrating), the conjunctiva and the Tenon's capsule must be respected and handled with care: the integrity of these structures makes an important contribution to the surgical outcome. The Tenon's capsule is firmly adhered to both the conjunctiva above and the episclera below, along a line that extends for approximately 1 mm posteriorly to the sclero-corneal junction. Because of this anatomical relationship during the preparation of a fornix based flap it is possible to dissect the conjunctiva and the capsule together, as though the two structures formed a single layer, starting the incision in correspondence with the external limit of the Bowman membrane. This type of dissection is little traumatic and permits easy and accurate restoration of the original anatomical relationships. A thin and highly-vascularized layer of connective tissue—called the episclera—is located below the Tenon's capsule. Consequently, from the outside to the inside, there is the alternation of highly-vascularized layers, such as the conjunctiva and the episclera, and completely avascular layers, such as the Tenon's capsule and the sclera

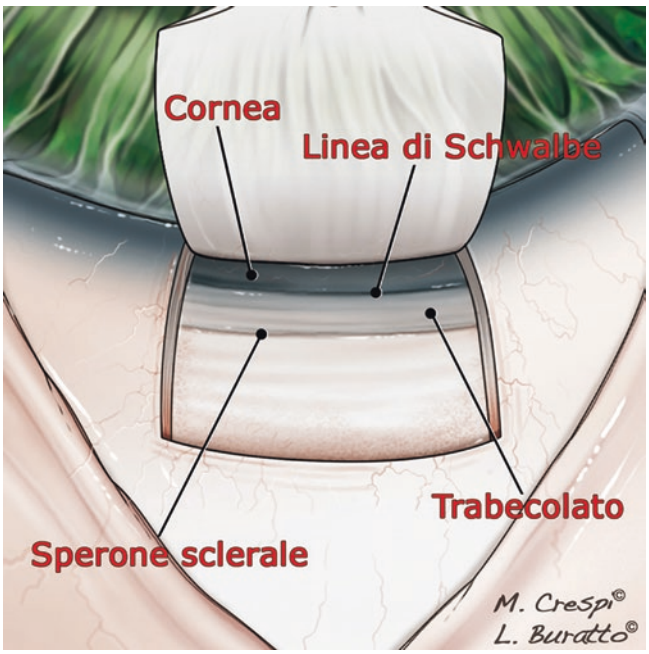

Fig. 1.3 Surgical anatomy of the limbus following sclera dissection. View of the main surgical landmarks during the dissection to create a scleral flap at a depth of 1/3 of the scleral thickness.
The posterior margin of the flap normally overlaps the anterior portion of the sclero-corneal trabecular meshwork. Schematically, we can identify the following structures, from anterior to posterior: the anterior margin of the limbus, consisting of the Schwalbe's line, the trabecular meshwork and the posterior margin consisting of the scleral spur: consequently, the surgical limbus includes the Schwalbe's line in the anterior portion, the trabecular meshwork in the middle and posteriorly, the scleral spur. When glaucoma surgery is performed, the surgeon must always be aware of these surgical landmarks

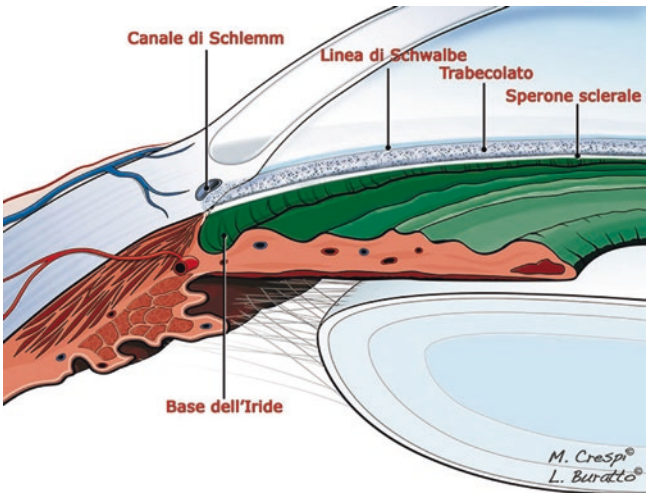

Fig. 1.4 Anatomy of camerular angle.
Iris root is another important anatomical landmark: in normal eyes, it is located 1.5–2 mm behind the limbus. However, in smaller eyes (hyperopic eyes), it will be found more anteriorly proportionally to the smaller dimension of the eye.
The ciliary body is located behind the insertion point of the iris root and below the scleral spur. Accidental incision of the ciliary body is an extremely serious surgical error. The ciliary body is a ring with an almost triangular section; it lies on the internal surface of the sclera and it extends from the scleral spur to the ora serrata. The ciliary ring projection on the scleral wall extends posteriorly for 7 mm from limbus in the temporal side and for 6 mm in the nasal sector.
When glaucoma surgery is performed, the surgeon must be aware of iris-corneal width and iris root insertion point. Infact, during this type of surgery, it is important to distinguish between an open and a closed irido-corneal angle.

1. When the angle is open:
   – if the incision is performed through the anterior edge of the limbus, the access to the anterior chamber (AC) will be anterior to the Schwalbe's line
   – if a middle-limbar incision is performed, the AC is accessed in correspondence to the Schwalbe's line
   – when a posterior incision is performed, it will lie above the scleral spur.
2. When the angle is closed:
   – a middle-limbar incision is considered as a surgical error as it penetrates the AC through the angle or even through the ciliary body, with potentially serious consequences. Consequently, a more anterior or anteriorly angled incision is recommended

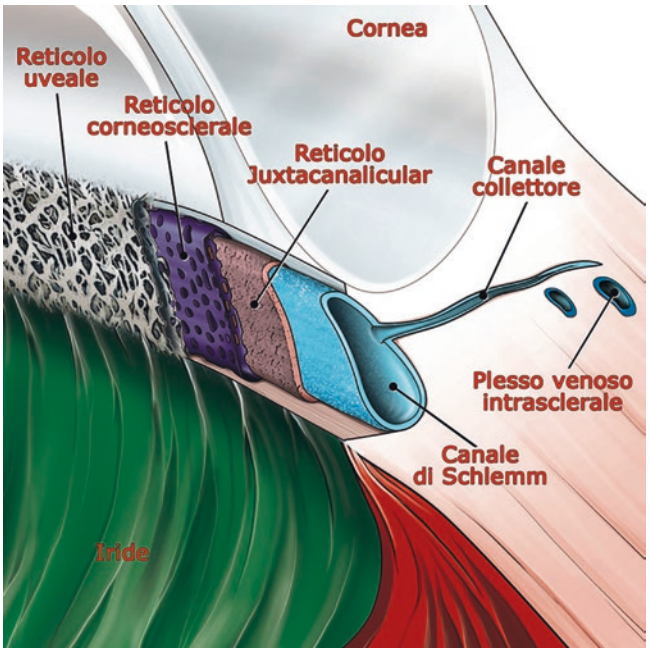

Fig. 1.5 Schlemm canal.
The Schlemm's canal is an important structure to know in order to perform some glaucoma surgeries, such as canaloplasty and the ab externo trabeculotomy. This is a circular canal creating a complete ring that extends for the entire circumference of the limbus. The Schlemm's canal has a diameter that varies between 190 and 370 μm; it is delimited laterally by the scleral spur and posteriorly by the filtering portion of the trabecular meshwork (refer also to Fig. 1.4). Its projection on the external surface of the eyeball lies immediately behind the posterior limit of the limbus. The Schlemm's canal is connected by an intrascleral venous plexus to an episcleral venous plexus: both of these venous plexus collect the Schlemm's collector channels and are important structures for the aqueous humor outflow. Regarding the gonioscopic aspects, the most important reference points are the scleral spur and, when visible, the Schwalbe's line

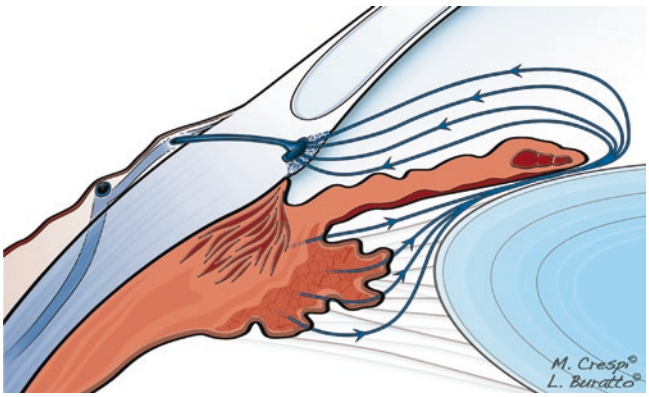

Fig. 1.6 Outflow pathways of aqueous.
The glaucoma surgeon must also be familiar with trabecular meshwork physiology to better comprehend the rationale behind the most recent anti-glaucomatous surgical techniques, such as the new mini-invasive anti-glaucomatous surgical techniques (MIGS). The trabecular meshwork and the internal wall of the Schlemm's canal are the main outflow routes for the aqueous humor. The aqueous humor exits the eyeball through the dense sieve of the trabecular meshwork. The aqueous humor reaches the adjacent Schlemm's canal, that drains directly into the aqueous veins. The trabecular network contains three different layers. The layer of tissue closer to the AC is the uveal trabecular meshwork. This consists of a network of connective tissue extensions that originates from the iris and the ciliary body. This layer does not provide high resistance to the outflow of the aqueous humor because the intercellular spaces are large. The next layer is the sclero-corneal trabecular meshwork, characterized by lamellas covered with epithelial-like cells that lies on a basal membrane. The lamellas consist of glycoprotein, collagen, hyaluronic acid and elastic fibers. The third layer is the juxtacanalicular trabecular meshwork, that is in direct contact with the internal wall endothelial cells of the Schlemm's canal. It consists of cells contained in a dense extracellular matrix. This layer provides the greatest amount of resistance to the outflow of aqueous humor because the intercellular spaces are very narrow. Finally, the aqueous humor crosses the endothelial cell layer of the Schlemm's canal, that is the final barrier that the aqueous humor has to overcome before it exits the eye

Anesthesia

2

Luigi Caretti and Lucio Buratto

Introduction

The anesthesia used in a surgical procedure for glaucoma depends primarily on the surgeon's personal preferences. However, the complexity of the surgical procedure, the presence of other systemic clinical conditions and patient collaboration also play important roles.

A glaucoma surgical procedure, alone or in combination with phacoemulsification, can be performed under general or topical anesthesia, but more frequently loco-regional (retrobulbar, peribulbar, sub-Tenon) anesthesia is preferred.

Across the world, most surgeons perform these procedures under local anesthesia, with cardio-vascular monitoring and a venous line open available. It is advisable to have an anesthetist on call to manage any possible adverse events, despite these being extremely rare.

Sometimes it may be useful to associate low grade sedation to the local anesthesia. Using local (or topical) anesthesia has several advantages over general anesthesia:

- Lower morbidity and mortality associated with general anesthesia
- Lower incidence of nausea and post-operative vomiting
- Better cardio-pulmonary stability
- Rapid return to walking
- prolonged post-operative analgesia
- lower costs.

The most common agents used for local anesthesia are mepivacaine (duration of action: 45–90 min), lidocaine (duration of action: 1.5–2.5 h), bupivacaine (duration of action: 2–4 h) and ropivacaine (duration of action: 2–6 h). The longer duration of action of ropivacaine gives the patient a couple of extra hours of post-operative analgesia.

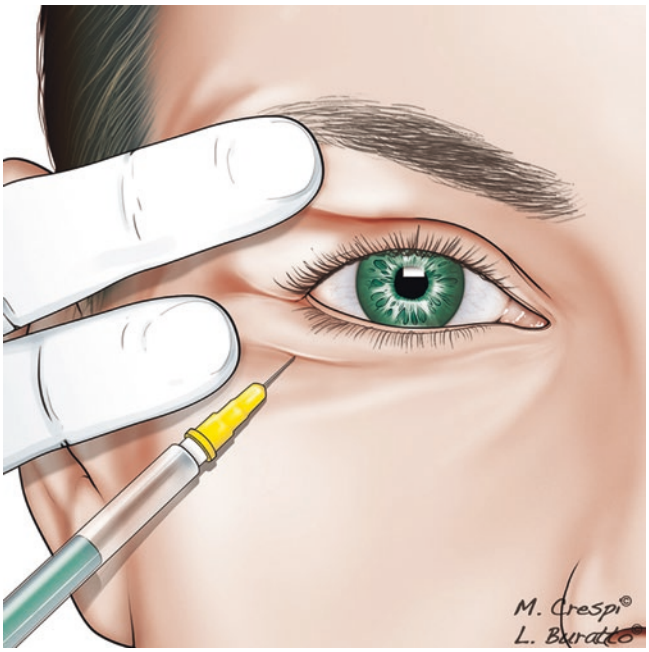

Fig. 2.1 Retrobulbar anesthesia used in glaucoma surgery

The retrobulbar block is the elective choice for most surgeons, as a good degree of akinesia and analgesia can be achieved with a limited amount of anesthetic agent. Compared to peribulbar anesthesia, it reduces the possible increase of intraorbital pressure (Fig. 2.1).

Retrobulbar Anesthesia in Glaucoma Surgery

Generally-speaking, a blunt 25G needle is used (Atkinson retrobulbar needle Eagle Labs, Rancho Cucamonga, California). The technique can include also injecting 2 cm^3 of the

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anesthetic agent into the eye's internal canthus. It is advisable to associate a small quantity of hyaluronidase (5 U\mL, that is 0.5–1 mL in the 10 mL syringe) to facilitate the diffusion of the anesthetic agent. Akinesia of the orbicularis muscle is achieved by slowing injecting 1.5 mL of anesthetic in front of the orbital septum.

In the event the surgeon opts for peribulbar anesthesia, four periconic injections should be performed in the four quadrants to allow a better distribution of the anesthetic agent.

Sub-Tenon anesthesia has the advantage of not increasing the intraorbital pressure, due to the small quantity of anesthetic agent injected (1.5 mL) and the disadvantage of a greater haemorrhage risk. Several different quadrants have been proposed for the injection: supero-temporal, internal canthus and infero-nasal.

In all cases of injected anesthesia, the block can be achieved by using 2% carbocaine (or 2% lidocaine) possibly in association with 0.50% Marcaine (1:1) if the procedure is expected to last longer than normal.

Digital eye massage consents better diffusion of the anesthetic solution and reduces the intraocular pressure (IOP); this is an important phase in the preparation of the patient for surgery. However, many surgeons do not apply this technique because they believe it induces an additional transitory IOP increase—dangerous for patients affected by glaucoma; pressure values are maintained at between 30 and 40 mm Hg for approximately 20 min.

If total eyelid akinesia is required, a facial nerve block can be associated (Van Lint).

Some authors use topical anesthesia—4% xylocaine and 0.5% tetracaine HCl; in this case, in addition to topical anesthesia, the surgeon may also opt for an intracamerular injection of preservative-free 1% xylocaine. Good exposure of the operating field can be achieved by asking the patient to look downwards.

Generally-speaking, surgeons will opt for a form of anesthesia that will produce total akinesia, considering the fine surgical maneuvers required as the scleral flap dissection.

General anesthetic is usually reserved for patients not suitable for local anesthetic—children, adults who suffer from claustrophobia, patients who are extremely anxious or affected by an altered mental state, those with a history of poor collaboration during previous surgeries under local anesthesia, patients affected by nystagmus, tremors or those patients who are unable to lie in a supine position for any length of time. Some surgeons prefer to use general anesthesia for great personal peace of mind during surgery; others consider local anesthesia to be associated with greater risk in some patients (those with serious blood-clotting disorders, or with very long eye bulbs, for example in cases of severe myopia or congenital glaucoma).

The above comments apply to all of the surgeries described in this book.

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Penetrating Surgery and Its Surgical Variants

3

Luigi Caretti and Lucio Buratto

Introduction

In general, surgery and/or parasurgical laser treatment for glaucoma are indicated in case of poor tonometric control, or in the event of poor patient compliance to treatment. Several surgical options are available; they have different degrees of efficacy and also different complication rates. The decision regarding the treatment pathway is taken on a case by case basis, and this makes a standard treatment protocol difficult to define.

Of the various surgical options, trabeculectomy is still the gold standard in antiglaucoma surgery, particularly when associated with the use of antimetabolites.

Traditionally, trabeculectomy is indicated in the following cases:

- Uncontrolled open- or closed-angle glaucoma
- Open- or closed-angle glaucoma controlled with more than two drugs (to achieve very low IOP)
- Post-traumatic glaucoma
- Unsuccessful glaucoma surgery.

Trabeculectomy reduces the intraocular pressure (IOP) by allowing the aqueous humor outflow from the anterior chamber (AC) into the subconjunctival space or, more precisely, below the Tenon capsule; this filtration occurs through an opening in the scleral wall at the altered trabecular meshwork. The extraocular space below the conjunctiva in which the discharged aqueous humor accumulates is called a bleb and this is subsequently drained by the blood vessels.

The trabeculectomy procedure guarantees excellent tonometric and visual results in the vast majority of eyes operated. However, providing the numbers and the precise percentages continues to be a laborious task, due to difficulties associated with comparing the various published works. These studies are often different in terms of the method used (retrospective or prospective, randomized or not, etc.), and due to the numerous variants of the surgical technique.

In recent times, many surgeons associate anti-metabolites with the trabeculectomy procedure: the antimetabolite would appear to improve the efficacy of the procedure, even though some authors believe there is no solid scientific evidence to support clear superiority of mitomycin-C (MM-C) compared with the standard trabeculectomy procedure.

Surgical Technique

As previously mentioned, the trabeculectomy procedure reduces the IOP by allowing the aqueous humor drain into the sub-conjunctival space, or more precisely, to below the Tenon capsule; this filtration occurs through an opening in the scleral wall at the level of the trabecular meshwork and is inevitably influenced by post-operative scarring involving the conjunctiva and the Tenon capsule.

We will now describe probably the most popular trabeculectomy technique. However, a variety of modifications may be introduced during the various phases of the procedure, such as: type of conjunctival limbus, type of scleral access, use of antimetabolites and the method used to remove the scleral-corneal block.

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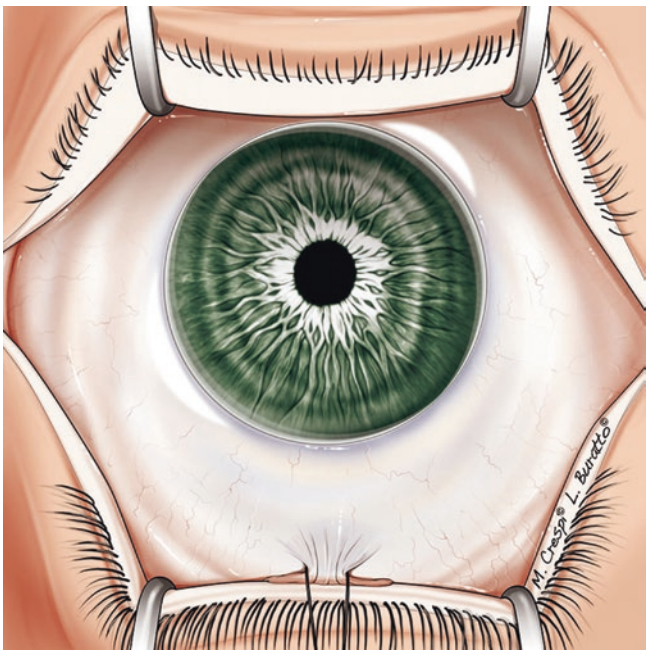


Fig. 3.1 Exposure of the operating field. The first step of the procedure is the correct exposure of the operating field; this will provide the surgeon with easy access to the delicate ocular structures he will be handling. Placement of a traction suture, normally in 4.0 silk, in the superior rectus muscle has proven to be useful in the event the surgery is performed under loco-regional or general anesthesia: it will be tight during the scleral surgical phases and released during the phases on the cornea or in the AC. Dedicated forceps (Graefe or Verzella forceps) are generally used to catch the muscle. Once the suture has been passed through the tissue, the silk suture is anchored with a Dieffenbach clamp or small Pean forceps

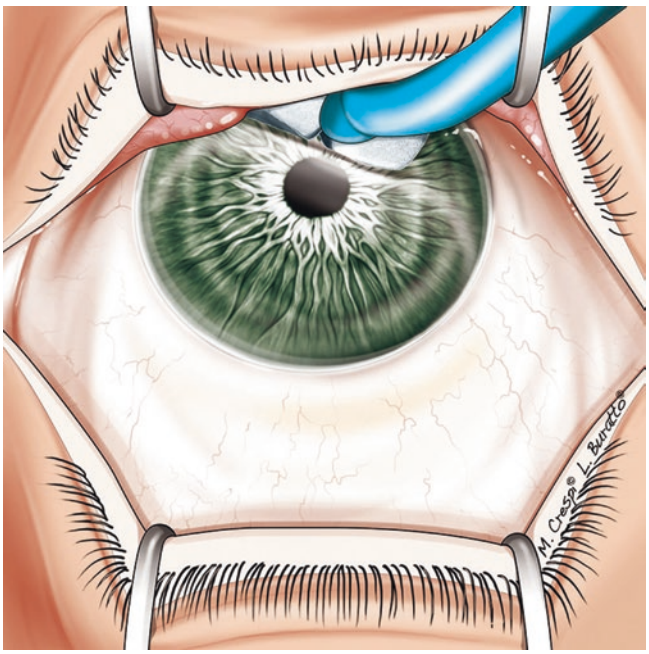


Fig. 3.2 Exposure of the operating field in the scleral phase. As an alternative to the traction suture, to achieve good exposure of the operating field in the scleral phase, the surgeon can wedge a suitably shaped merocel sponge into the blepharostat. With this maneuver, the surgeon can rotate the bulb (inferoversion) and this will provide him with easy access to the superior sector of the sclera. Once the scleral phase of the operation has terminated, the sponge is removed and the eye bulb returns to its original position to allow the subsequent phases of the surgery on the cornea or in the AC to be performed

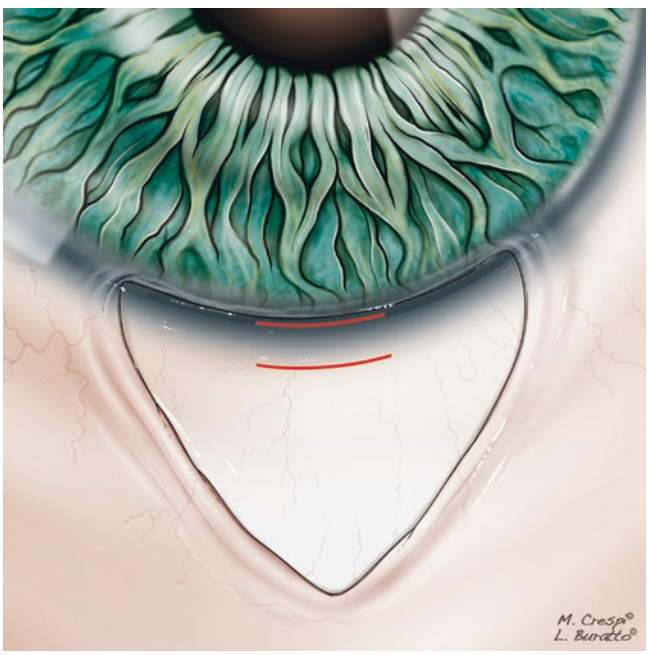


Fig. 3.3 Preparation of scleral bed. In the first phase of the operation, the surgeon creates a conjunctival-capsular flap at 12 o'clock, with a base at the limbus or the fornix; the width of the incision must be approximately 6–7 mm; in case of limbus based flap the incision is created about 8–10 mm from the limbus. The choice of the flap (with the base at the fornix or the limbus) depends substantially on the surgeon's preference and the requirements of the individual case. The fornix based hinge is the more popular. Following the preparation of the conjunctival-capsular flap, the scleral bed and the surgical limbus are exposed (*red line* in Fig. 3.3; refer also to chapter "Anatomy", Fig. 1.3). Diathermy is used to stop any bleeding from the scleral surface; this procedure must be relatively conservative as it must not affect the scleral tissue. Prior to the creation of the conjunctival-capsular flap, the surgeon must control the position of the venous collectors (perforating) to avoid these being cut: it is extremely important to avoid detaching the conjunctiva at a point where it is will not be possible to perform the subsequent phases of the procedure due to perforating vessels presence. The surgeon should delicately rub a blunt instrument (for example the closed arms of Westcott scissors) over the surface to create a transitory ischemia of the conjunctiva; this will provide a clear view where the venous collectors are positioned. In this way, the surgeon can select the most appropriate point to start the conjunctiva-capsular detachment

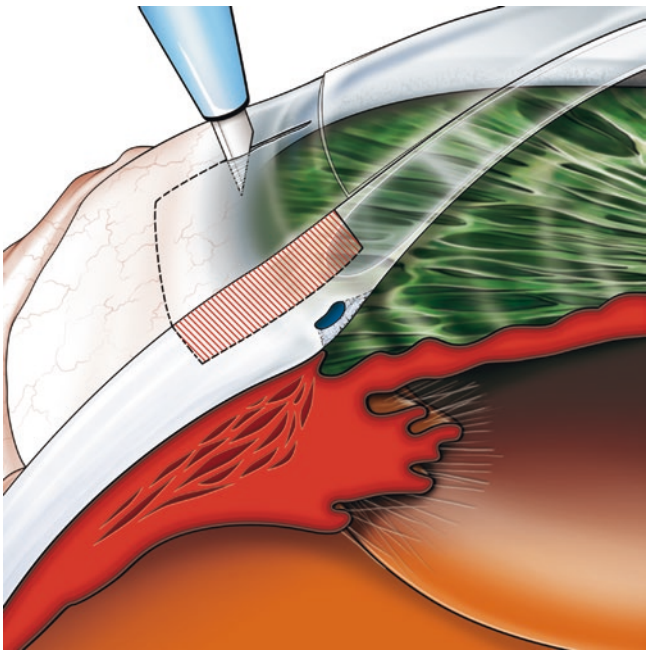
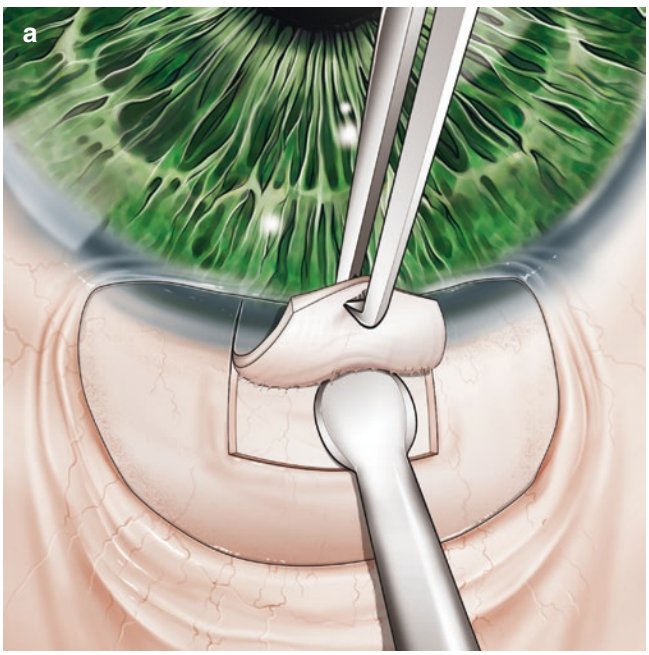
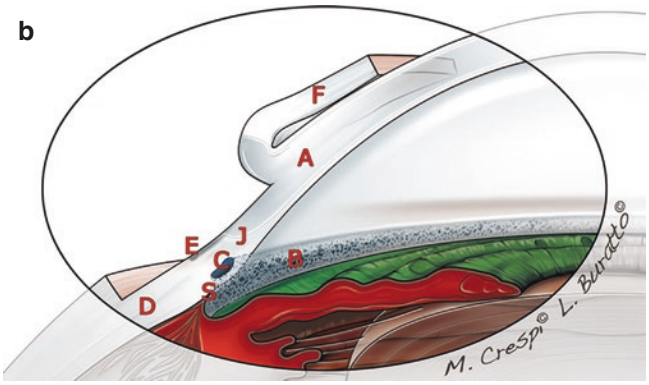


Fig. 3.4 Creation of scleral flap. Once a suitable area has been identified, preferably lying between two venous collectors, the surgeon creates the scleral flap. This dissection should be extended for 1 mm in clear cornea (indicated by the *broken red lines*). The flap can be created in a range of different shapes and dimensions. Normally, it is trapezoidal (but it can be rectangular, square, triangular or circular); the dimensions can vary between 5 × 5 and 4 × 3 mm. The thickness is approximately 200–250 μm, that is approximately one-third of the scleral depth. The optimal depth of the incisions is indicated in the drawing with oblique red lines. Common mono-use blades or better a pre-calibrated diamond lancet can be used





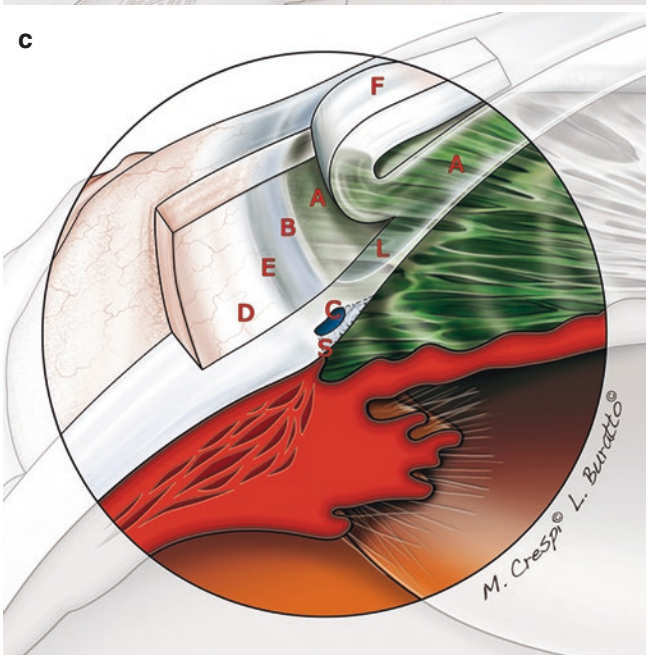


Fig. 3.5 (**a**) Scleral flap dissection. The scleral dissection is performed on a single plane parallel to the sclera at a depth of 200–250 μm. It can be completed using common bevel-up crescent knives, or with a specially-produced Grieshaber bevel-up knife. This incision extends for approximately 1 mm in clear cornea, just behind the limbus. The dissection is started from the posterior incision at the desired depth and is then extended anteriorly on the same surgical plane. For the correct execution of this maneuver, as the sclera is being cut, it is useful to hold the flap with Hoskin toothed forceps (for example Colibrì forceps) and pull the tissues gently: in this way, the scleral fibers will be pulled tight making it easier to identify and cut the fibrils with the crescent knife, creating a single cleavage plane. As mentioned before, the dissection is extended for approximately 1 mm in clear cornea. (**b**) Identification of surgical landmarks following scleral flap dissection. The drawing shows that below the scleral dissection the following structures are present: the flipped over scleral flap (F), the clear cornea (A) in an anterior position, the trabecular meshwork (*gray line*) which consists of parallel fibers (B) that merge with the white opaque scleral fibers (D). The junction between the gray trabecular meshwork (B) and the sclera (D) corresponds superficially (E) to the scleral spur (S). The Schlemm Canal (C) lies adjacent to the scleral spur (S). The surface landmark (E) of the scleral spur is an important surgical marker: it indicates the position of the scleral spur (S) and therefore indicates both the posterior margin of the corneo-scleral trabecular meshwork that the surgeon will remove during the trabeculectomy and the position of the Schlemm canal. As the surgeon is observing the eye from above, he can identify the following surgical landmark (in sequence and centripetally): the scleral spur, the trabecular meshwork, the Scwhalbe line and the cornea, or surgical limbus (also refer to chapter "Anatomy", Fig. 1.3). (**c**). Lateral section of relationship between internal structures and external surgical landmarks. See description of (**c**)

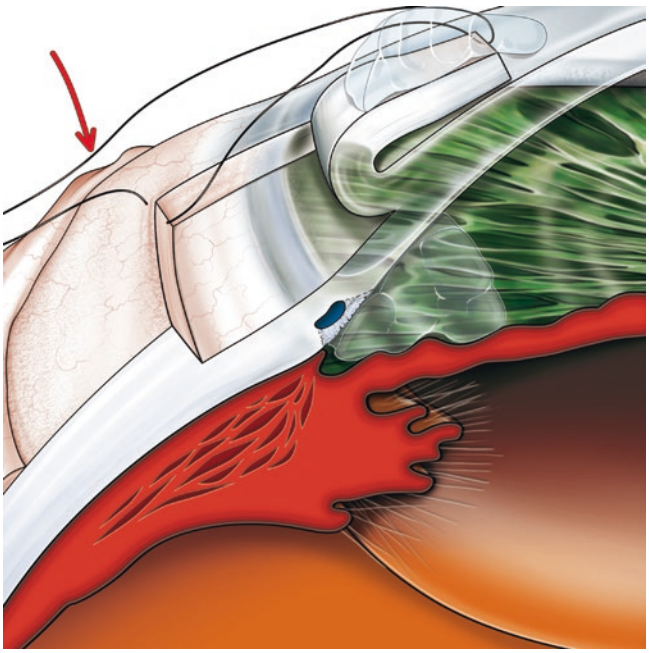


Fig. 3.6 Exposure of trabecular meshwork. Once the scleral flap has been created, the surgeon must proceed with the trabeculectomy. To expose the surgical limbus that includes the trabecular meshwork, the surgeon can add a viscoelastic substance (VES) to the flap that has been flipped-over. Alternately, one of his assistants can delicately catch the flap with non-traumatic forceps, for example, Hoskin forceps, and flip it over. Prior to the trabeculectomy and the basal iridectomy, as a precautionary measure, many surgeons will opt to position two nylon 10.0 sutures at the top of the flap (*red arrow*). The suture thread is only passed through the tissue and not knotted: in this way, after having completed the trabeculectomy and the basal iridectomy (the two critical phases of the operation), the surgeon will be able to close the flap immediately
Prior to the trabeculectomy, it is advisable to inject a small amount of dispersive VES (such as Viscoat) into the AC through a service incision to avoid a sudden loss in AC depth and to distance the iris during the trabeculectomy procedure

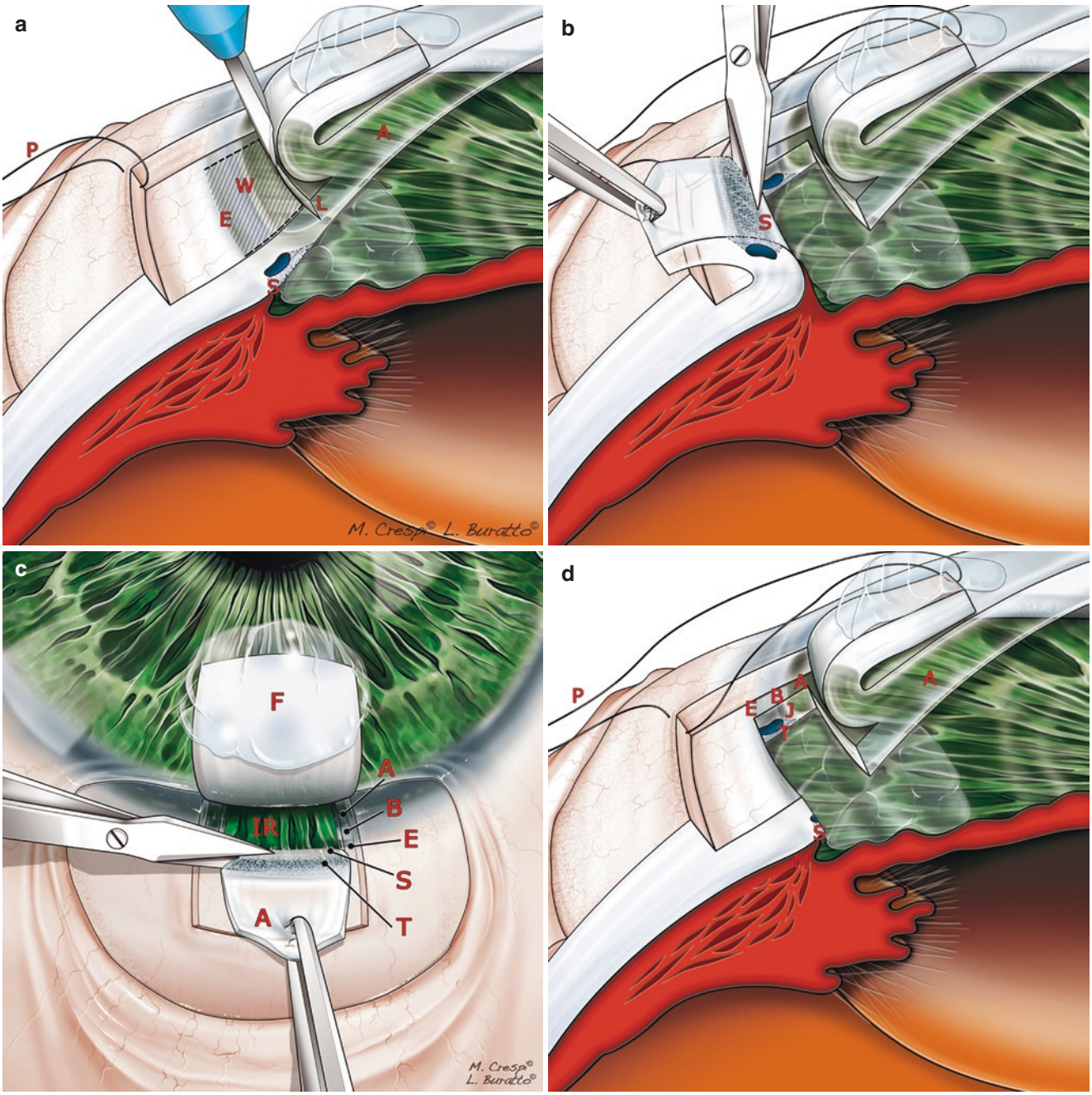

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Fig. 3.7 (**a**) Traditional trabeculectomy: scleral incision parallel to the limbus. In Cairns's original technique, a first incision is created with a knife parallel to the limbus (anterior incision) in clear cornea (A), below the scleral flap, that penetrates into the AC. The plug of tissue to be removed (W) must measure 2 × 2 mm. It extends from the surgical limbus (L) located anteriorly to the scleral spur (located posteriorly) (S) indicated by the posterior edge of the gray band (E).
(**b**) Traditional trabeculectomy: completion of the creation of the sclero-corneal plug creation e its removal. Starting from the edge of the anterior incision parallel to the limbus, the surgeon creates another two radial incisions to reach the posterior edge of the surgical limbus, corresponding to the scleral spur (S). This will define three-sides of the piece of tissue to be removed. It can be flipped over with surgical forceps to expose the structures on the internal face, particularly the sclero-corneal trabecular meshwork for removal. This is finally removed with Vannas scissors, without emptying the AC. As mentioned above, prior to opening the AC, it is useful to inject some dispersive VES (Viscoat) onto the area where the trabeculectomy will be performed. This posterior incision is created just in front of the scleral spur (S), taking care to include the trabecular meshwork in the cut. To this end, the surgeon will expose the scleral spur by posteriorly flipping-over the sclero-corneal plug.
Removal of the block of trabecular meshwork tissue (trabeculectomy) is the crucial part of the procedure and can be performed in a number of ways—with knives, scissors, drills or scleral punches. The choice of instrument depends largely on the surgeon's choice. However, the scleral punch would appear to guarantee smoother margins and a certain degree of standardization for the procedure.
Over the years, the main technical variations proposed for this type of procedure involve the shape of the scleral flap and the shape of the filtrating hole.
(**c**) Traditional trabeculectomy: surgeon's view (from above). This drawing shows the final posterior incision for the removal of the trabecular meshwork plug (as in the previous drawing). Also shown is the surgeon's view of the most important anatomical structures involved in a correct trabeculectomy with the conjunctival fornix based flap. The surgeon uses forceps to flip over the trabecular meshwork plug to expose the posterior surface. Moreover, using Vannas scissors, he will create the posterior incision anterior to the scleral spur (S), including the trabecular meshwork (T). The scleral spur (S) corresponds externally (E) to the junction between the white opaque sclera and the gray band (B). The drawing also indicates the scleral flap (F), the clear cornea (A), the iris (I) and the iris processes (IR).
(**d**) Exposure of different structures of trabecular meshwork following traditional trabeculectomy. The opening (window) created by the removal of the tissue plug can be observed. The insertion of the ciliary muscle (M) remains intact and anchored to the scleral spur (S). The Schlemm canal is not visible. The trabecular meshwork (T) lies along the radial wall of the opening (window).
The drawing also illustrates the clear cornea (A) and the junction (J) between the cornea and the sclera.
Adjacent to the radial wall of the opening (window), there is a portion of the scleral flap that has not been removed and this is a landmark for the internal structures: clear cornea (A), the gray band (B) that represents the external marker for the trabecular meshwork, and the external marker (E) of the scleral spur (S).
The radial wall has been removed on the side opposite of the opening (window). The anterior incision is located in clear cornea. The posterior incision is located just anterior to the scleral spur.
The conjunctival flap has its base at the fornix

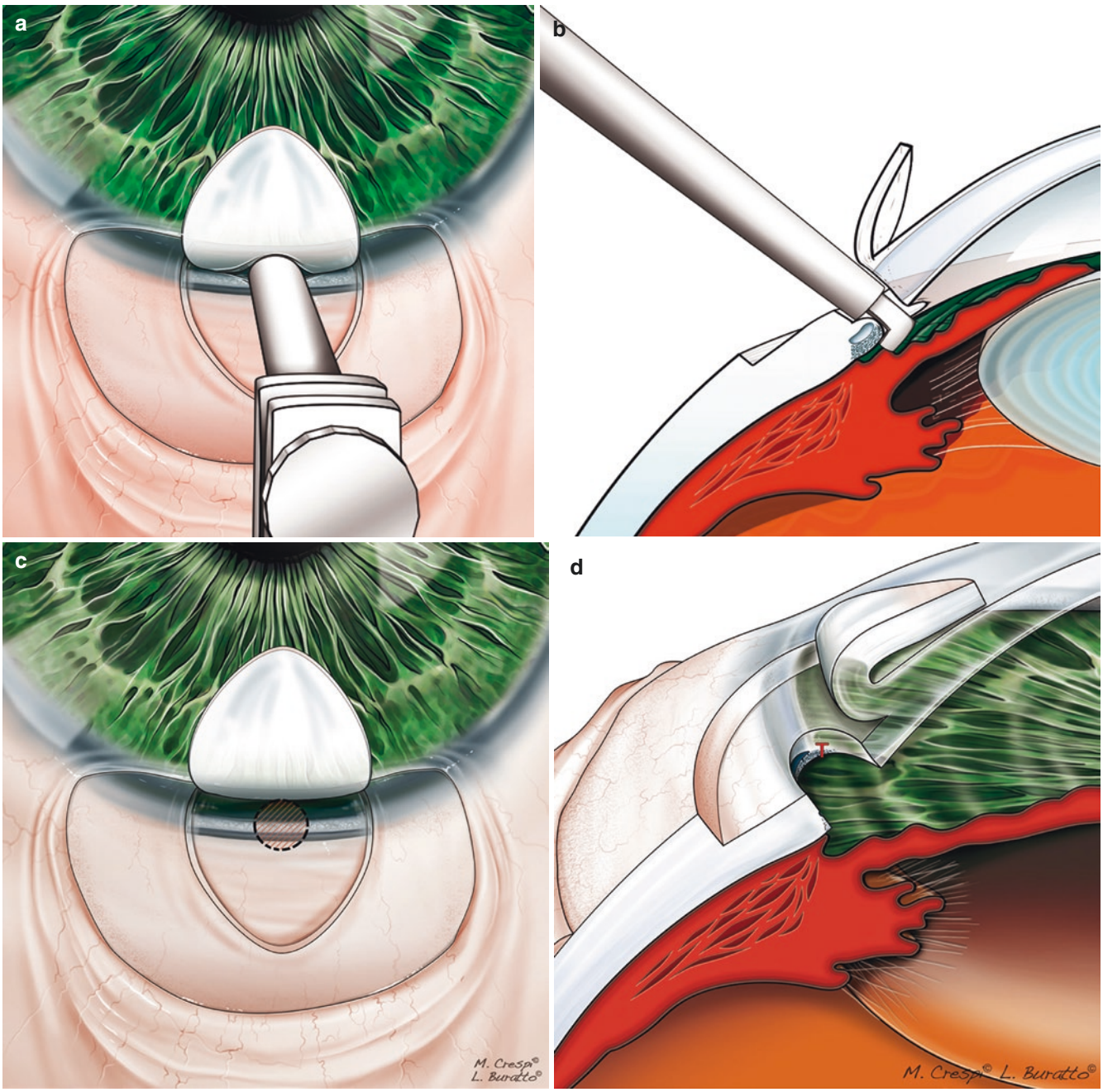

Fig. 3.8 (**a**, **b**) Trabeculectomy with scleral punch: (**a**) surgeon's view from above; (**b**) side view. The scleral punch is an alternative to the traditional method.
This would appear to guarantee smoother edges and a more standardized trabeculectomy. First, the surgeon creates a full-depth 2 mm corneal incision, using trapezoidal blades. It is important that this incision lies on the Schwalbe line, meaning that it will be in front of the trabecular meshwork. The trabeculectomy is performed with the punch technique. The surgeon should make a visual check to ensure that the trabecular meshwork is included in the tissue removed. Sometimes it may be necessary to punch several times to obtain a satisfactory result.
(**c**) Trabeculectomy with scleral punch: surgeon's view (from above) of the precise location of the tissue removal made with punch. The *dotted black circle* indicates the exact location of the bite, which must include the trabecular meshwork.
(**d**) Appearance of the trabeculectomy created with the punch technique. Observe the shape of the trabeculectomy, that includes the trabecular meshwork (T)

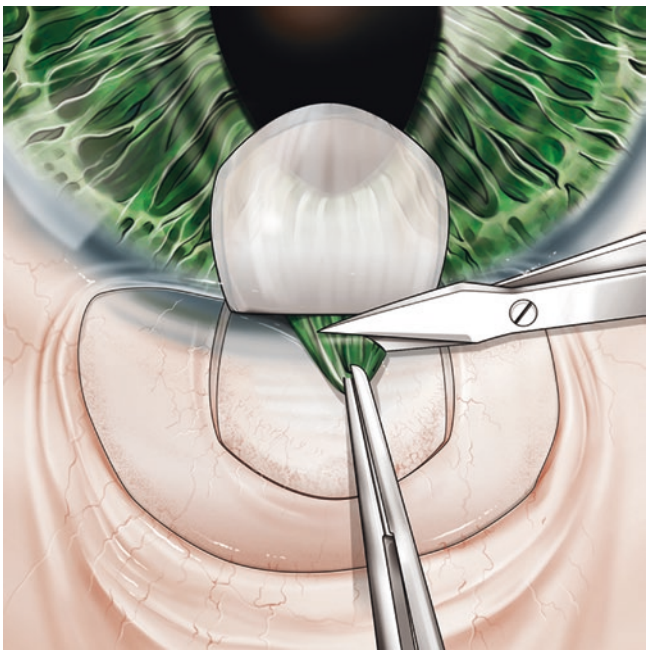

Fig. 3.9 Basal iridectomy. Once the trabeculectomy has been completed, the surgeon continues with the basal iridectomy, that must be sufficiently wide to prevent the iris being involved in the stomia. To ensure that the iridectomy is the correct size, the root of the iris should be clearly visible: for this reason, pilocarpine eyedrops should be instilled prior to surgery to induce appropriate miosis. If the patient is affected by mydriasis, either because subjected to a combined phaco-trabeculectomy procedure or because there is a certain degree of mydriasis induced by the loco-regional anesthesia, an injection of acetylcholine in the AC may be useful. If this does not produce suitable miosis, the iris can be delicately distanced from the angle with the spatula.

For the basal iridectomy, the iris is caught through a scleral opening with dedicated fine toothed forceps, (iris or Colibrì forceps) and transported outside of the AC. On occasion, as soon as the AC is opened, the iris will tend to prolapse spontaneously through the incision. The iris is cut peripherally, parallel to the limbus, using Vannas or DeWecker scissors. The surgeon must pay attention to the stroma and to the pigmented layers of the iris to create a full-depth iridectomy.

During the iridectomy, the surgeon must check the position of the pupil: in this way, he will avoid cutting too close to the pupil. He must also take care to avoid removing the tissue too close to the iris root in order to reduce the risk of rupture of the base, iridodialysis or intraocular bleeding

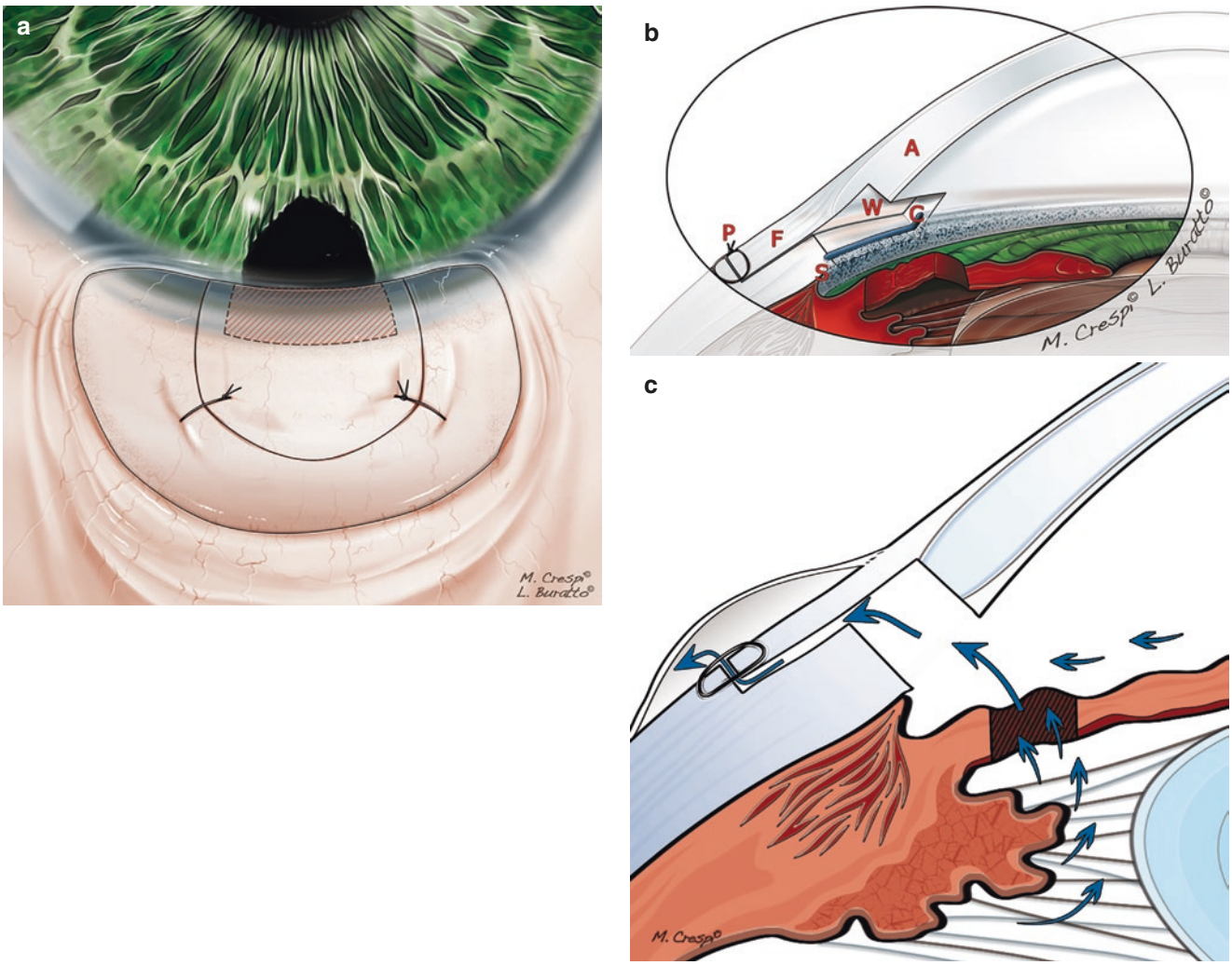

Fig. 3.10 (**a**) Suture placement. At this point, the surgeon positions one or two sutures in 10-0 nylon on the flap, if these have not already been positioned; the knots must always be recessed in the tissue. The knot that we prefer is the 1.1.1 Siepser—it is elegant and there is the possibility of adjusting the tension. Nylon is the most appropriate material for a laser section in the event of postoperative ocular hypertension.

As an alternative to nylon, an absorbing suture (10-0 vicryl) can be used to progressively increase the filtration (10-0 polyglactin reabsorbs in approximately 1 week), and the conjunctiva and Tenon capsule are sutured.

Some surgeons prefer to position 5 sutures on the flap.

With a flap with base at the fornix, two tobacco pouch sutures (in 10-0 nylon or 8-0 vicryl) positioned at 11 and 1 o'clock will cover the entire scleral flap and this will normally ensure that the incision is adequately sealed.

The creation of a flap with base at the limbus, on the other hand, necessitates a separate suture for the Tenon capsule (preferably in 8-0 vicryl) and for the conjunctiva (10-0 nylon).

(**b**) Final appearance (internal view) following trabeculectomy. The non-full thickness scleral flap (F) is repositioned and sutured with nylon suture 10.0 (P). Note the iridectomy (I), the trabecular meshwork window (W) and the Schlemm canal (C) that in this eye is positioned anteriorly to the scleral spur and hence was included in the removal of the sclero-corneal trabecular meshwork.

(**c**) Outflow of the aqueous humor following trabeculectomy. The surgery concludes with the introduction of a small quantity of BSS in the AC through the paracentesis that, through the trabeculectomy created, passes underneath the conjunctiva to form the bleb (indicated with the *blue arrow* in the drawing): this procedure provide the evidence that the surgical manuever was correctly performed. Any residual dispersive viscoelastic can be left in the AC, because it will not cause any important increase in IOP in the postoperative.

Finally, the surgeon will wet the walls of the paracentesis.

At the end of the procedure, the surgeon can inject a steroid-antibiotic combination into the inferior fornix.

When the blepharostat is removed, the surgeon must pay attention to avoid undesired pressure on the bulb that could lead to the AC shallowing

Topical Application of Antimetabolites During Trabeculectomy

The use of antimetabolites during the trabeculectomy has gained a widespread popularity over the last 10 years, to such a degree that the majority of ophthalmologists consider it to be an obligatory phase of the procedure. These agents are used to reduce cell proliferation and consequently sub-conjunctival scarring in the postoperative period. The best results have been observed with the intraoperative application of MM-C. In the filtering procedure, MM-C is normally diluted to a concentration of 0.02 mg/ml and prepared by the hospital pharmacy. MM-C is normally applied using a dedicated sponge tip (K-sponge, Katena products Inc., Denville, NJ), or alternately non-dedicated like merocel sponge tips or the terminal tip of a common sponge product, that has been suitably shaped and normally positioned between the Tenon capsule and the superficial flap (see Fig. 3.11), and sometimes also sandwiched underneath it if necessary (see Fig. 3.12). The application usually lasts for 2 min. Before the sponge is positioned on the sclera, it is necessary to control that its size will avoid any direct contact with the free margin of the conjunctiva and the Tenon capsule. The risk of contact is reduced further if, when the sponge has been positioned underneath the capsule, the surgeon lifts the edge of flap with two forceps for the duration of the antimetabolite application (see Fig. 3.13). When the damp sponge is being positioned, it is equally important to avoid any direct contact between the antimetabolite and the limbus, to reduce the risk of limbal stem cells deficiency.

The sponge is removed after 2 min and the surgical area is irrigated with abundant BSS; the forceps used to position the fragment of sponge soaked in the antimetabolite must also be adequately rinsed. In the combined procedures of phacotrabeculectomy, MM-C is normally applied when the phacoemulsification has been completed. MM-C must be applied to the scleral bed prior to the trabeculectomy procedure, to avoid undesirable penetration of the drug into the AC, as it can have a toxic effect on the endothelium. The conjunctival

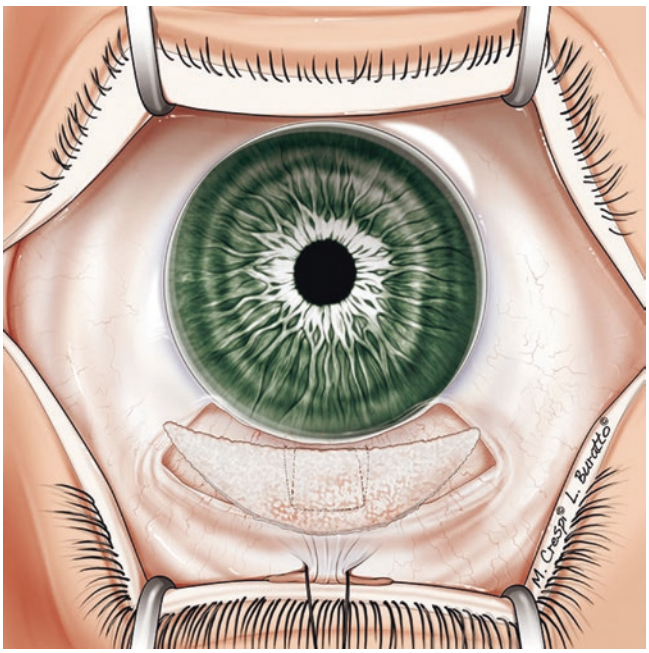

Fig. 3.11

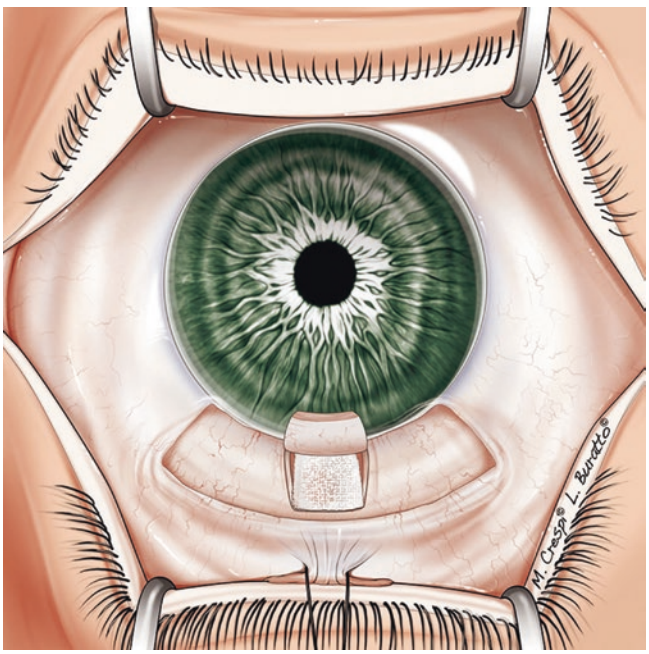

Fig. 3.12

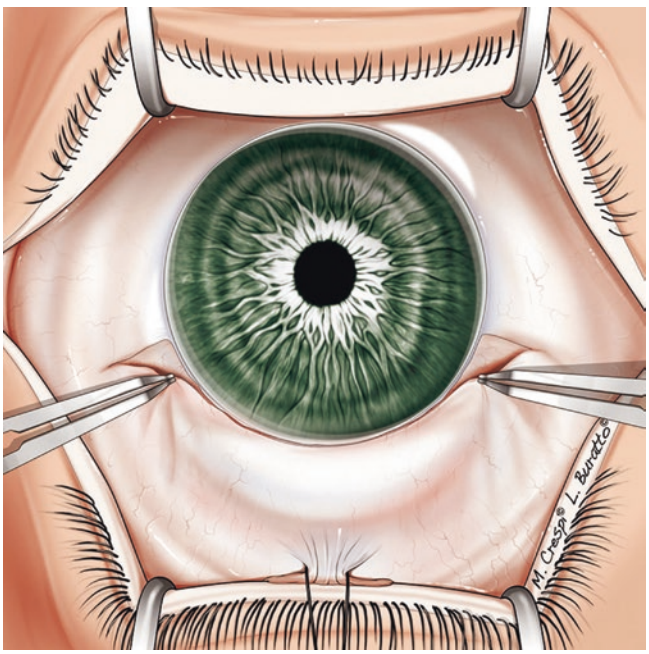

Fig. 3.13

suture must be applied meticulously with several closely-positioned passages. In the case of base fornix flap, some surgeons apply a continuous running suture that anchors the conjunctiva to the peripheral cornea.

Alternative Drugs to Mitomycin-C

Administration of **5-fluorouracil (5-FU)** has been suggested as an alternative to MM-C. However, this product does not improve the long-term filtration success and consequently most surgeons have abandoned its use. 5-FU can be administered in the post-operative period, with several 5 mg subconjunctival injections, and it has even been suggested for intraoperative use.

In recent years, the use of **anti-VEGF drugs (Anti-Vascular Endothelial Growth Factor)** has been suggested to control the scarring process of the bleb following the trabeculectomy. Recently, some surgeons have examined the effect of a subconjunctival injection of bevacizumab (Avastin) associated with the trabeculectomy: however, the results have been less promising than those obtained with MM-C.

Combined Phaco-trabeculectomy

There are several alternatives for the phaco-trabeculectomy procedure. The first decision facing the surgeon is the identification of the site for the phaco; this is traditionally performed in a superior position, in correspondence to the scleral flap used for the trabeculectomy **(one way phaco-trabeculectomy)**. Alternately, the two procedures can be completed through two different openings: in this case, a standard trabeculectomy is performed in the superior quadrants only after having completed the phaco in a temporal position **(two-way phaco-trabeculectomy)**.

Following the creation of the conjunctival-capsular opening, a pre-incision of width approximately 2–3 mm is created 2 mm from the limbus, at a depth of approximately one-third of the scleral thickness; the sclera is dissected with a bevel-up knife and extended to approximately 1 mm in clear cornea.

Then a 1 mm paracentesis is created at approximately 2 h from the tunnel and this is used to fill the AC with viscoelastic.

Phaco-trabeculectomy with a single access (one-way): completion of the scleral tunnel with 2–2.2 mm knives. The scleral tunnel is completed with a sharp blade of variable diameter that depends on the tip of the phaco machine used (usually 2–2.2 mm). Then the surgeon proceeds with the phaco surgery and the implantation of the intraocular lens, through this access incision. Implantation of foldable lenses is recommended to respect the delicate anatomical limbal structures. Following the implantation of the IOL, the residual viscoelastic is aspirated from the AC with a mono- or bi-manual infusion/aspiration system.

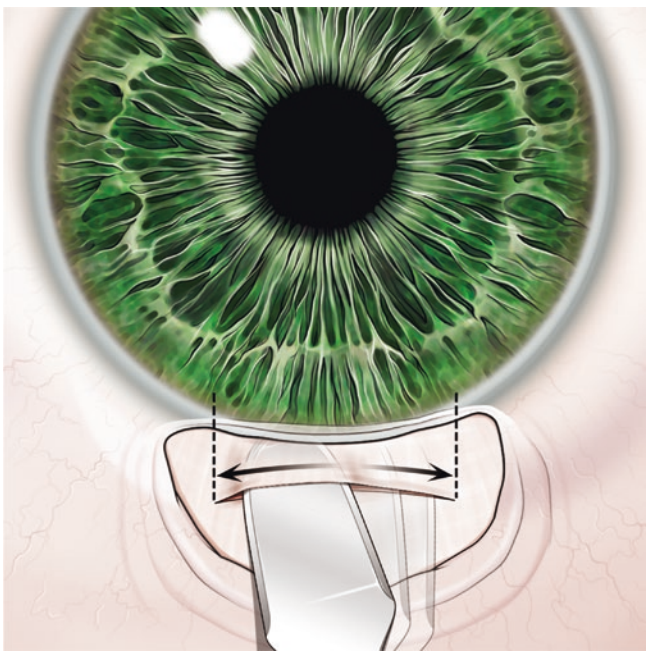

Fig. 3.14 Phaco-trabeculectomy with single access (one-way): creation of the scleral tunnel. With the combined phaco-trabeculectomy procedure with *single access*, the creation of the scleral tunnel, successively used to create the flap, guarantees excellent closure of the AC during the phaco procedure

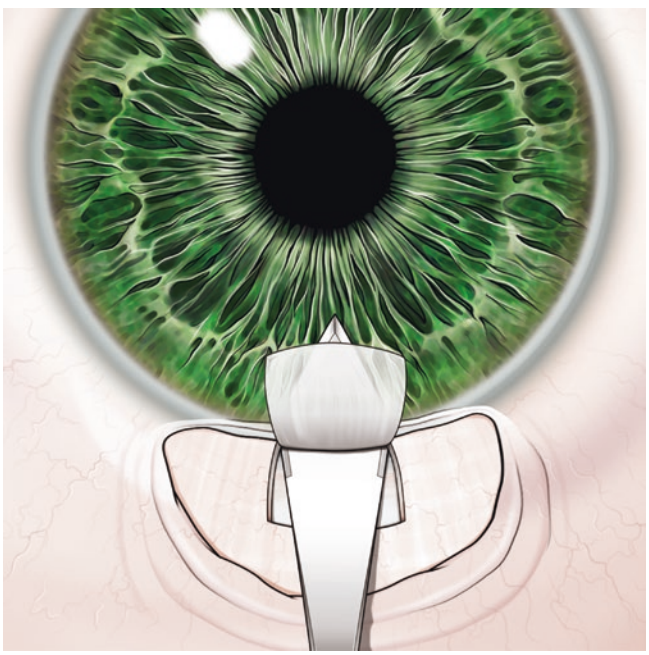

Fig. 3.15 One way phaco-trabeculectomy: scleral tunnel creation using 2-2.2. mm surgical knife

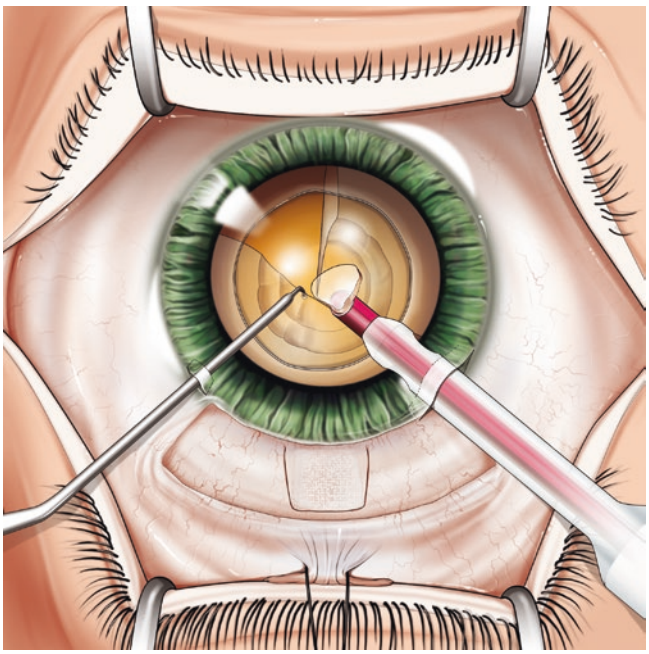

Fig. 3.16 Phaco-trabeculectomy with separate access (two-way)

The injection of acetylcholine into the AC at the end of the phacoemulsification, after the aspiration of viscoelastic from the AC, reduces the possibility of iris involvement in the following phases of the procedure.

Once the phaco procedure has terminated, it is advisable to inject a small quantity of adhesive viscoelastic in a single bubble over the superior sector of the iris in correspondence to the trabeculectomy site. Many authors believe that the VES should deliberately be left in the AC until the end of the operation to avoid sudden loss of AC depth following the trabeculectomy procedure.

It is now possible to transform the tunnel into an L-shaped scleral flap, with a radial incision (1.5 mm long) starting from one of the two posterior angles of the tunnel. In this way, the landmarks for the trabeculectomy are exposed. Then the surgeon proceeds with the basal iridectomy and the sutures of scleral flap and conjunctiva as described previously.

Phaco-trabeculectomy with separate access (two-way).The use of a separate incision for cataract removal, temporarily positioned in clear cornea, has gained considerable popularity over the last 15 years. Many of the debates on the combined procedure with one access have been resolved by the combined procedure with two accesses. Consequently, at the time of writing, the two-way technique is the most commonly used.

This approach has minor differences with respect to the two single traditional procedures: a conjunctival flap and a scleral flap are created at 12 o'clock, without penetrating the AC. The surgeon then moves to the lateral position for the phacoemulsification and the implantation of the IOL, to then return to the 12 o'clock position for the trabeculectomy, the basal iridectomy and the suture of the flap and the conjunctiva.

This sequence allows the sclero-corneal incisions to be performed with the eye bulb intact and tonic.

The advantages reported by the supporters of this technique are:

- Reduced manipulation of the conjunctiva and the sclera in proximity of the bleb
- The possibility of cutting the nylon sutures applied to the scleral flap with a laser, independent of the phaco incision, with no change to the scarring process (an important factor when antimetabolites are used)
- Access to the AC is facilitated thanks to the greater visibility
- No compromise with the incisions and conciliation of two opposite requirements (filtration for glaucoma and complete closure for the cataract procedure).

The disadvantages are associated with the amount of time necessary for the surgeon to change his position and the risk of leakage from the corneal tunnel with severe post-operative hypotonia; this risk will increase in the event of phaco burning—an extremely rare occurrence with the new instruments. Some surgeons recommend positioning a safety suture on the corneal incision. And many experts believe that the suture is essential when an antimetabolite is being used.

Complications

The complications of the trabeculectomy procedure can be divided into intraoperative, early onset postoperative and late onset postoperative.

Intraoperative

The intraoperative complications may be related to the trabeculectomy or to the associated cataract procedure; the most important are summarized in Table 3.1.

Early Onset Postoperative

Most of the early onset post-operative complications of trabeculectomy are linked to the development of hypotonia, meaning that they are the cause (loss of aqueous from the boss, excessive filtration) or the effect of it (hypothalamy, choroidal detachment).

Table 3.1 Intraoperative complications

Complication	Conseguence	Treatment
Complications linked to the trabeculectomy		
Rupture of the conjunctiva	Postoperative hypotonia-endophthalmitis	Suture or plasty
Rupture of the scleral flap	Postoperative hypotonia	Suture
Hemorrhage	Hypoema-Postoperative hypotonia	Washing; coagulants; TPA for the clots
Complications linked to the phacoemulsification		
Burn of corneal tunnel	Loss of retention (postoperative hypotonia)	Change incision site
Rupture of the posterior capsule	Loss of vitreous with possible involvement in the stoma	Accurate vitrectomy
Zonular dialysis	Loss of vitreous with possible involvement in the stoma	Accurate vitrectomy Tension ring

The development of antimetabolites has exacerbated this problem, particularly regarding leakage of aqueous from the bleb, with an incidence of 40%, according to some study results. Even though some surgeons report a lower percentage of between 1% and 30%, and not all comparative studies have demonstrated an increase in the episodes of leakage following the intraoperative application of MM-C, it should be emphasized that when using this product, maximum care must be taken when suturing the conjunctiva (and the Tenon capsule) and the scleral flap. Contrasting results have been reported for the incidence of leakage from a fornix based compared to a limbus base conjunctival flap.

The first way to treat leakage involves the application of a large diameter soft contact lens (or in alternative, a mildly compressive patch consisting of a rolled piece of gauze that will lightly compress the upper eyelid and consequently the bleb) and the instillation of antibiotic eyedrops; if the situation has not resolved within a couple of days, the surgical revision of the bleb will be necessary.

Excessive filtration is another condition that can easily lead to hypotonia and may depend on the use of antimetabolites, on an excessively large sclerotomy or insufficient suturing of the scleral flap.

In some cases, the situation may be resolved by applying a compression patch on the bleb (a slightly compressive patch created with a rolled-up piece of gauze that lightly compresses upper eyelid and consequently the boss), to reduce the filtration; otherwise surgical revision and the new sutures on the flap will be necessary.

No matter the origin, hypotonia may lead to a loss of AC depth, and even to athalamy, that is observed in 1–5% of operated eyes; choroidal detachment is frequently associated with hypotonia and is the most serious complication of glaucoma surgery.

In the combined cataract and glaucoma surgery, the transition from ECCE to phaco has resulted in a reduction in the frequency of some complications, most importantly, the choroidal detachment.

The incidence of hypoema is considerably reduced with respect to the ECCE trabeculectomy. Hypoema may be associated with the need of pupil dilating maneuvers, abnormal bleeding from the camerular angle, incomplete episcleral cauterization or irido-ciliary damage caused during the sclerectomy. The situation usually normalizes within 1–3 weeks.

Compared to EECE, phaco surgery in the combined procedure has resulted in a reduction of the intraocular pressure spikes, that could cause perimetric deterioration in eyes affected by advanced glaucoma.

Other possible early onset postoperative complications include a fibrinoid reaction in the AC (that is transitory and often linked to manipulations of the iris), entrapment of the iris in the filtrating stomia, choroidal haemorrhage or corneal deficiency.

A rare complication is the onset of endophthalmitis in the first 6 weeks post-operative (approximately 1 in every 1000 cases).

One fairly common complication is an increase in the IOP in the early post-operative period, due to insufficient filtration: careful patient monitoring in the postoperative period is essential to allow appropriate treatment to be initiated if required. If ocular hypertension is observed in the first few post-operative days (even on Day 1), the treatment will consist of a delicate massage of the bulb as this will encourage filtration with consequent re-filling of the bleb.

Treatment of ocular hypertension that appears a few days after surgery involves argon laser lysis or removal of the suture(s) from the scleral flap, a maneuver that will result in the immediate filling of the bleb. Lysis of the suture is an ambulatory procedure and involves the use of a dedicated contact lens (Hoskin lens). The lens applies mild pressure to the bulb to temporarily ischemize the conjunctival blood vessels: this maneuver will expose the suture(s) to rupture.

The argon laser paremeter parameters are as follows: power 400 mW, time 0.01 s, diameter 50 μm.

The suture(s) are removed from the scleral flap in the operating room, with the creation of a small button-hole on the conjunctiva to consent access of the microknives to cut the suture and a microforceps to catch and extract it. Finally, an absorbable suture is applied to the conjunctival buttonhole.

This procedure can be performed 20 days from surgery if the boss was present until a short time before.

The argon laser parameters are: 400 mW power, 0.01 exposition time, 50 mc diameter.

The scleral flap suture removal is performed in surgery room creating a small conjunctival buttonhole in order to access the suture that will be cut by micro knife and then removed by a micro forceps. Finally an absorbable suture is applied through the conjunctival buttonhole.

This procedure can be performed also 20 days after the surgery if the bleb was present since shot time before.

Late-Onset Postoperative Complications

The most serious complication of the filtering procedure is the onset of septic endophthalmitis. MM-C (and also 5-FU), inducing the development of a thin walls bleb, increases the probability of intraocular infection even several months after the surgery: as shown by some studies, streptococcus is commonly the main agent involved. However, the incidence of late-onset endophthalmitis is fortunately a very rare occurrence. It should be pointed out to the patient that the formation of a bleb will be a permanent risk for infection.

The advent of MM-C has also resulted in an increase in the number of cases of chronic hypotonia, with possible maculopathy (an incidence of between 2 and 5%): fortunately, this is a rare event. The treatment aims to restore the pressure to values above 5–6 mm Hg; positive results can also be achieved through the application of suture points in addition to those applied during the primary procedure.

If the surgeon observes an interruption of filtration caused by scarring, he should massage the bleb and perform needling if required; in the cases that cannot be treated, a new surgery (with MM-C associated) will be inevitable. Opacification of the posterior capsule (PCO) is the most common complication observed following the combined procedure.

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Non-penetrating Glaucoma Surgery (NPGS): Viscocanalostomy, Deep Sclerectomy and Canaloplasty

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Luigi Caretti and Lucio Buratto

Introduction

Non-penetrating glaucoma surgery (NPGS) is selectively used on the altered structures responsible for ocular hypertension. It is performed without penetrating the eye bulb; and different to other widely-used techniques, it is essentially extraocular surgery. In this way, the surgeon avoids the possible complications associated with penetrating surgery, such as trabeculectomy, still considered to be the gold-standard in the surgical treatment of open-angle glaucoma. In primary open-angle glaucoma and in some cases of secondary glaucoma, resistance to drainage of the aqueous humor is principally produced by the juxtacanalicular trabeculate and the internal wall of the Schlemm's canal: these are the two target structures of NPGS. The choice regarding which procedure to use in a patient affected by glaucoma must be taken on a case by case basis and it is extremely difficult to propose a standard treatment protocol. There are three types of procedure that are included in this group: viscocanalostomy, sclerectomy and more recently, canaloplasty. Canaloplasty is the procedure that in recent times is receiving greater consensus among the specialists of glaucoma surgery. And increasingly, this type of surgery is performed in combination with the cataract procedure (phacoemulsification).

Traditionally, NPGS is reserved for the following cases:

1. Closed-angle glaucoma compensated with miotics or other drugs;
2. Open-angle glaucoma compensated with two drugs (with a target pressure that is not excessively low);
3. Glaucomas in which low ocular pressure is a serious complication following the filtering procedure.

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Modern scientific literature reports that NPGS is a possible surgical option for all forms of open-angle glaucoma (primary or secondary), particularly in the early stages and with target pressures that are not excessively low (for example, glaucoma that is compensated with just one drug). Moreover, these techniques are indicated in uveitic glaucoma (given that they cause low grade post-operative inflammation), in glaucoma associated with severe myopia and with the Sturge-Weber syndrome, conditions that are at a risk of choroidal haemorrhage and consequently of post-operative hypotonia following filtering surgery. These techniques would also appear to be indicated in cases of glaucoma with severely altered or thinned conjunctiva in which a trabeculectomy with anti-mitotic drugs could be dangerous. The non-penetrating surgical techniques generally improve the safety profile of glaucoma surgery. There are absolute contraindications to NPGS in case of neo-vascular glaucoma and the ICE (Irido-Corneal-Endothelial Syndrome); relative contraindications include chronic closed angle glaucoma and eyes with extensive damage to the trabeculate (for example, post-trauma recession of the angle, previous laser trabeculoplasty treatments). Canaloplasty may be contraindicated in the event of previous procedures that preclude the incannulation of the Schlemm Canal, or in eyes in which the distal aqueous humor outflow pathway has collapsed or contains obstructing scar tissue.

In the neovascular glaucoma, the extensive fibrovascular phenomena that block the filtration of the aqueous at the angle cannot be compensated by dilatating the Schlemm Canal. In cases of chronic closed angle glaucoma, the advantages of NPGS are eliminated by the easy contact of the iris to the internal surface of the Descemet's window: consequently, intraoperatively there is an increased risk of the iris touching to the internal surface of the Descemet's window; and postoperatively, there is a reduced possibility of filtration; if the surgeon wishes to proceed with the viscocanalostomy procedure or a canaloplasty in the case of closed angle glaucoma, he must perform a basal iridectomy

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through a paracentesis or, alternately, a laser iridotomy, and prescribe miotic eyedrops for the initial 3 or 4 weeks postoperative.

Viscocanalostomy

Viscocanalostomy is a non-perforating technique developed by Robert Stegman (Pretoria, South Africa) to avoid the problems associated with scarring.

The viscocanalostomy has two advantages over the trabeculectomy:

1. The elimination of the filtering bleb eliminates all of the problems associated with it, primarily the failure caused by the conjunctival, Tenonian and scleral scarring processes;
2. The fact that the AC has not been opened reduces the possibility of hypotonia, hypothalamy/athalamy, inflammation and cataract in the postoperative period.

The moderate popularity viscocanalostomy has achieved in recent years has meant that many surgeons have started using this technique, even in combination with phacoemulsification.

The literature available on viscocanalostomy, and the literature on the deep sclerectomy, was initially limited, though it has increased in recent years. Encouraging data have been reported with inferior success percentage rates compared to trabeculectomy in the majority of cases. A careful analysis of the literature has shown that non-penetrating procedures (viscocanalostomy, deep sclerotomy, canaloplasty) consent good control of the IOP in the early postoperative period but they are also associated with a high percentage of late failures. Regarding the comparison of trabeculectomy with non-penetrating glaucoma surgery, the literature reports contradictory results. While some authors have recently underlined how the use of the non-penetrating techniques (with or without phacoemulsification) have produced results that are comparable in terms of a reduction in the IOP, others have highlighted greater efficacy of the trabeculectomy with or without MM-C compared to the non-penetrating techniques. Recent literature has reported a better safety profile of the non-penetrating techniques compared to trabeculectomy, while a superiority in terms of tonometric reduction has not been observed. In conclusion, thanks to the better safety profile and further improvements to the surgical technique, with or without phacoemulsification, these types of non-penetrating techniques are currently a valid surgical option, particularly in those cases where the target pressure is not excessively low.

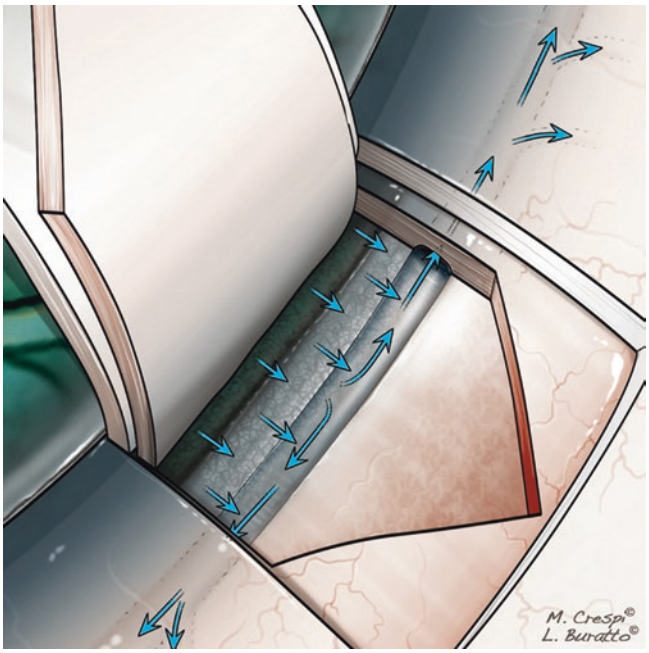

Fig. 4.1 Rational and presumed mechanism of action of the viscocanalostomy procedure. The viscocanalostomy aims to restore the physiological drainage pathway for the aqueous through the Schlemm Canal and the venous collectors; filtration into the sub-Tenon space is excluded. This mechanism is possible with the creation of an intrascleral space, called a lake, into which the aqueous from the anterior chamber (AC) drains (seeps) through a specifically-created fine membrane: the Descemet's window, constructed of the anterior layers of the sclerocorneal trabeculate and the Descemet membrane. The aqueous is collected in the lake and from here passes directly to the cut ends of the Schlemm Canal; the canal's lumen has already been incannulated and dilated with an injection of viscoelastic. The aqueous drains from the canal into the collector vessels and finally into the episcleral venous network. The aqueous collected in the lake may also drain into the underlying choroid, increasing the uveo-scleral outflow pathway

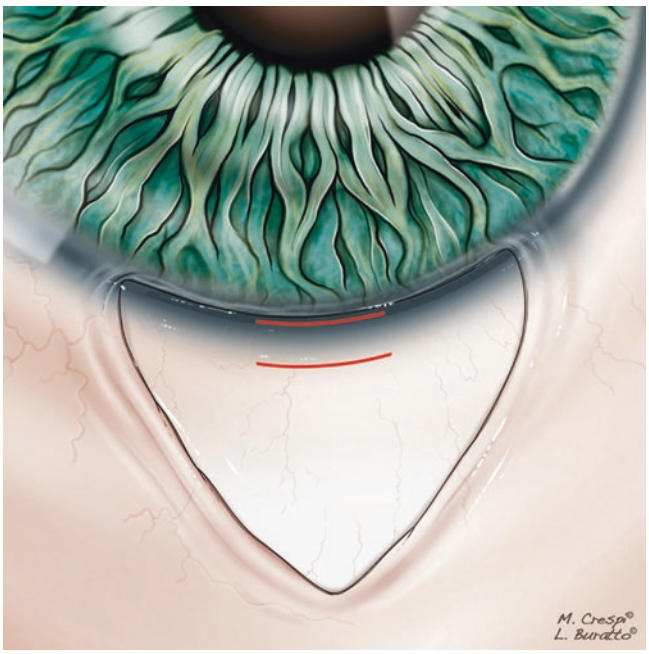

Fig. 4.2 Preparation of the scleral bed. Surgical technique: the surgeon exposes the eye bulb sufficiently using a traction suture or a Merocel sponge tip as illustrated for the trabeculectomy (see Chap. 3, Figs. 3.1 and 3.2). The surgical procedure begins at 12 o'clock with the preparation of a conjunctival flap with fornix based, 8–9 mm wide (similar but slightly wider than the flap of the trabeculectomy) and includes the Tenon capsule. The surgical limbus must be identified as this is an important surgical landmark (*red lines*). To keep the surgical field relatively free from blood, the surgeon may request the continuous help of an assistant or he can place small fragments of sponge on the sclera and replace them frequently. The surgeon must reduce to a minimum the diathermy of the episcleral vessels; these must be protected as they are essential for the drainage of the aqueous humor. The main vessels must be identified and not damaged to prevent excessive bleeding. If diathermy is inevitable, it will be necessary to use reduced values and coagulate the individual vessels one-by-one. As an alternative to parsimonious cauterization, good hemostasis can be achieved by the topical application of ornipressin (L-ornithine 8-vasopressin, marketed with the name "POR & Ferring", Sandoz, Switzerland); this molecule is a vasoconstrictor free from any adrenergic action. When applied topically, it provokes a local ischemia that lasts for about 2 h. As an alternative, some surgeons apply a few drops of standard adrenalin

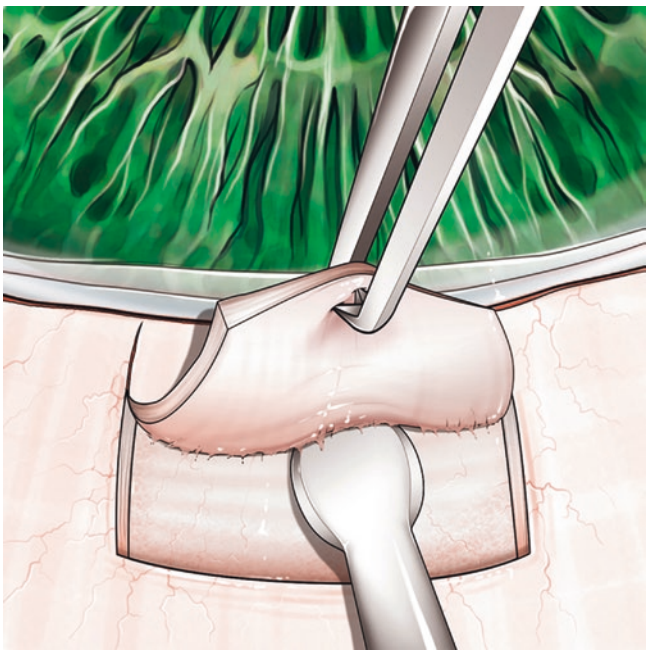

Fig. 4.3 Superficial scleral flap. When the surgeon has identified a suitable area, possibly lying between two venous collectors, he will create the superficial scleral flap that extends into clear cornea for about 1 mm.The flap can be created in a variety of shapes and sizes. Generally-speaking, it has a parabolic shape and the dimensions can vary from between 5 × 5 to 4 × 3 mm for a thickness of approximately 200–250 μmThe dissection can be performed with standard bevel-up crescent knives or with a specially created Grieshaber bevel-up knives

Fig. 4.4 Deep scleral flap. The preparation of the deep scleral flap is a crucial phase in the procedure: only the correct depth of the dissection plane will allow the surgeon to identify the Schlemm Canal. The margins of the deep flap are cut approximately 0.5 mm inside the edges of the superficial flap, to guarantee better closure when the superficial flap is sutured at the end of surgery. Considering the variability of the scleral thickness between individual patients, it is difficult to establish the right depth of the dissection plane: the use of precalibrated blades is a relative contraindication in this phase of the surgery. The more appropriate approach is to reach the edge of the choroid: the blue-gray color must be visible through the residual scleral lamellas. To this end it is essential to work under maximum magnification with extremely low traumatizing instruments that will allow the surgeon to penetrate deeper or remain more superficially when creating the dissection plane with great precision (depending on the surgeon's requirements). If the dissection plane is correct, the surgeon proceeds forward and will automatically reach the point for identifying the Schlemm canal, that becomes 'unroofed' because it is part of the deep flap

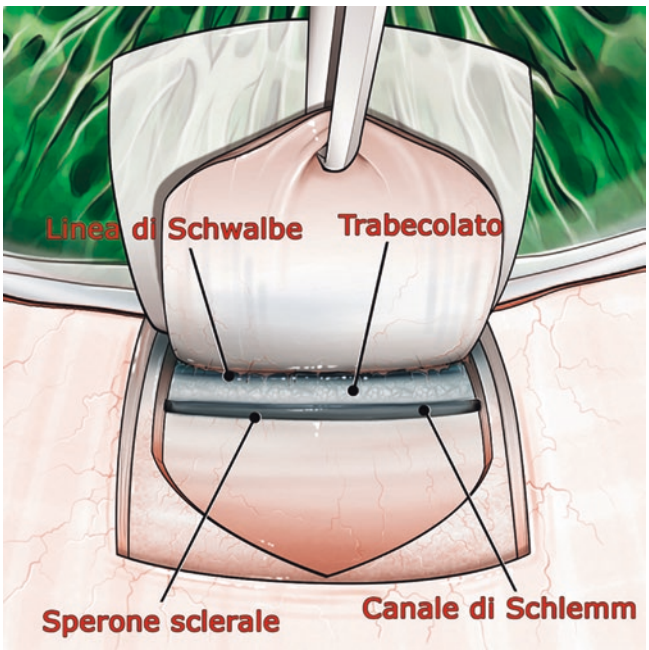

Fig. 4.5 Identification of the Schlemm Canal. Once opened, the Schlemm Canal appears as a dark line, positioned immediately in front of the scleral spur, represented visually by the concave line that anteriorly delimits the scleral bed. In front of the Schlemm Canal, proceeding with the dissection in a centripetal direction, the surgeon identifies the sclera-corneal trabeculate, with its typical granular appearance

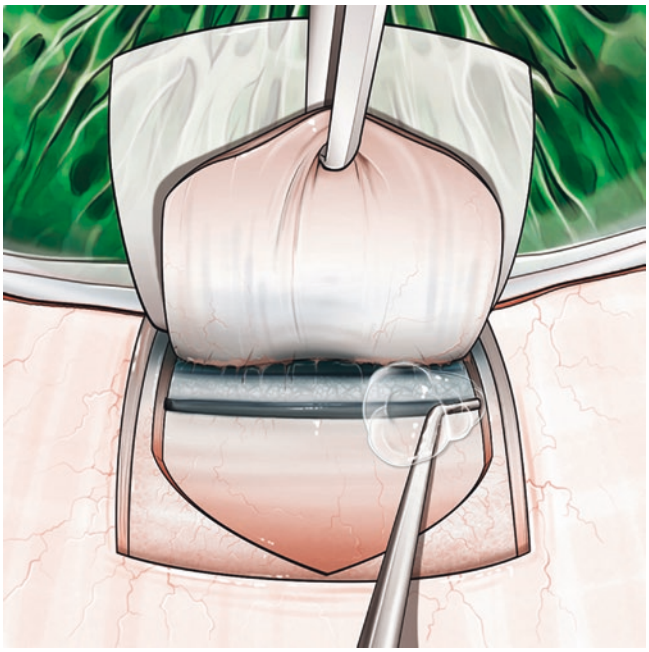

Fig. 4.6 Dilation of the Schlemm Canal. Once the Schlemm Canal has been identified and opened, the surgeon injects some high viscosity sodium hyaluronate inside (Healon GV). This maneuver is performed using a special Grieshaber cannula of external diameter 165 μm and internal lumen of diameter 90 μm. The surgeon must proceed with as little trauma to the structures as possible, allowing the cannula to penetrate just 0.5–1 mm. Simultaneously, the surgeon applies moderate traction on the deep flap. The viscoelastic must be injected slowly through the opening that has been created, avoiding that a sudden increase in the pressure inside the Schlemm Canal ruptures the internal wall, inducing an undesired trabeculectomy. The viscoelastic mechanically dilates the lumen of the canal (that is pathologically reduced in primary open-angle glaucoma), increasing it from 25–30 to over 200 μm. Immediately after the injection, the surgeon will observe that the episcleral collectors will whiten as the viscoelastic passes through the lumen. To achieve maximum dilation on a greater portion of the circumference of the Schlemm, Stegmann suggests repeating this injection two or three times into both ends of the Schlemm. Now the surgeon can proceed with the successive phase, the creation of the Descemet's window

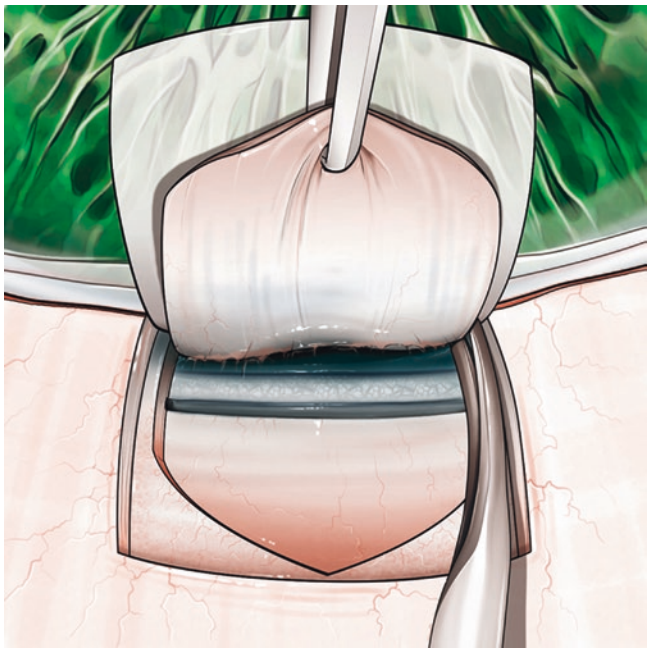

Fig. 4.7 Anteriorization of the sides of the deep scleral flap. A Descemet's window of suitable depth can only be created if, prior to applying pressure on the trabeculate with the sponge, the surgeon has anteriorized the sides of the deep scleral flap for about 1 mm in clear cornea. For this maneuver, Vannas scissors appear to be the ideal instrument to provide the best control during the cut: however, as these scissors are extremely sharp, there is a risk that they may perforate the underlying Descemet's membrane. Micro-scissors with blunt tips would appear to be more suitable for this maneuver

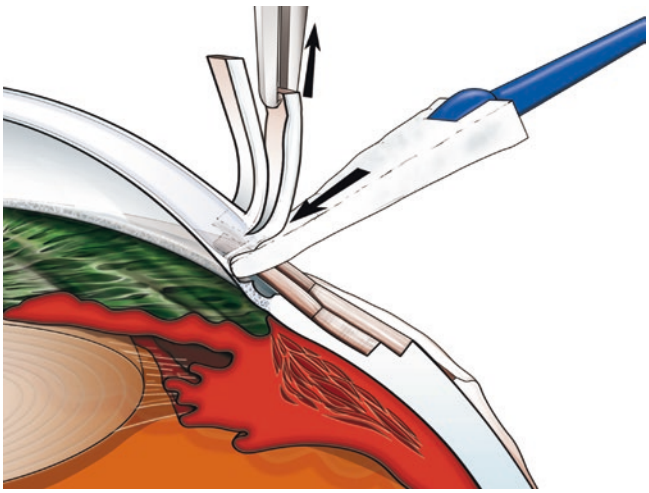

Fig. 4.8 Creation of the Descemet's window. First, a paracentesis is created at 2 o'clock: this will reduce the pressure in the anterior chamber (AC) and in the posterior chamber (PC); it will decrease the risk of perforation and consequently the prolapse of the iris through the window itself. The tonometric drop that follows the creation of the paracentesis will often eliminate the pressure gradient between the AC and the venous collectors, determining an inversion of the venous flow and blood reflux, that from the cut ends of the Schlemm Canal slowly drains onto the exposed surface of the trabeculate. This sign gives us proof that the canal has been identified correctly. In the event of combined surgery, the paracentesis is used to allow the introduction of a second instrument in the AC. The Descemet's window is not created by dissection: the use of instruments that are even moderately sharp will considerably increase the risk of penetrating the AC. The window must be created using blunt instruments, using a sponge tip to exert mild pressure on the anterior edge of the trabeculate and simultaneously applying modest upward traction on the deep flap (*black arrow*). At this point, a reduced IOP will facilitate the success of the maneuver. The surgeon separates the Descemet membrane, that will remain attached to the sclera-corneal trabeculate from the corneal stroma that continues in the scleral tissue of the deep flap. The Descemet's membrane must be at least 500 μm long. Once the Descemet window has been created, in some patients it will already be possible to observe the percolation of aqueous across the Descemet membrane and the exposed portion of the trabeculate

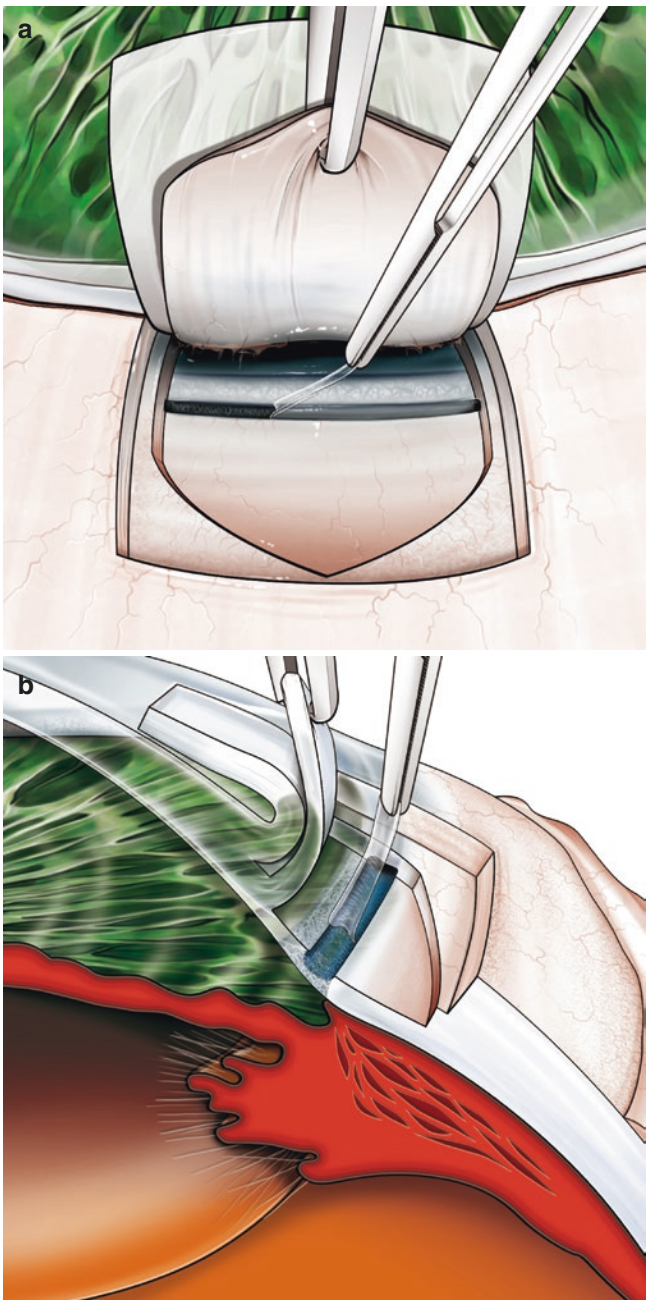

Fig. 4.9 Stripping the internal (deep) wall of the Schlemm Canal. In the event percolation is insufficient or is absent, it will be necessary to remove the obstruction to this filtration: the obstruction will usually be the juxtacanicular trabeculate, or rather the thin layer of connective tissue that separates the endothelium of the Schlemm Canal from the remaining layers of the trabeculate. The juxtacanicular trabeculate is removed—along with the anterior wall of the Schlemm—with a delicate 'stripping' maneuver; at this point, the Descemet's window has been created in front of the Descemet membrane and behind the more internal layers of the trabeculate. The 'stripping' can be repeated several times using fine forceps until adequate percolation has been achieved. If necessary, light stripping can be associated using the bevel-up knife used for the inspection.Stripping of the canal's internal wall can be facilitated if the area is kept dry.Once the stripping of the internal wall of the Schlemm Canal has been completed, the surgeon will observe an increase in filtration across the Descemet's window

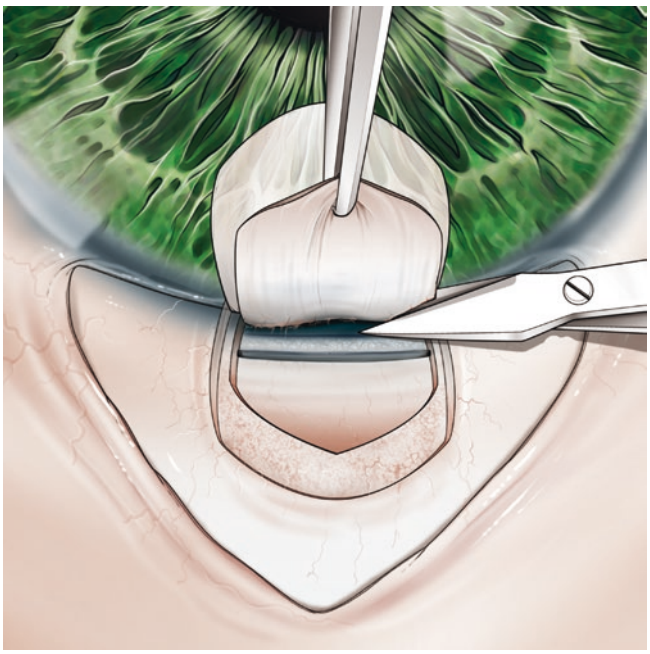

Fig. 4.10 Excision of the deep flap and suture. Once percolation of the aqueous has been achieved, the deep flap can be removed. Vannas scissors are used, again with the risk of inadvertently perforating the Descemet's window below with the sharp tips of the instrument. In this maneuver, it is essential to correctly position the sharp blades of the scissors in parallel with the Descemet window to cut the flap, keeping it distant from the window itself

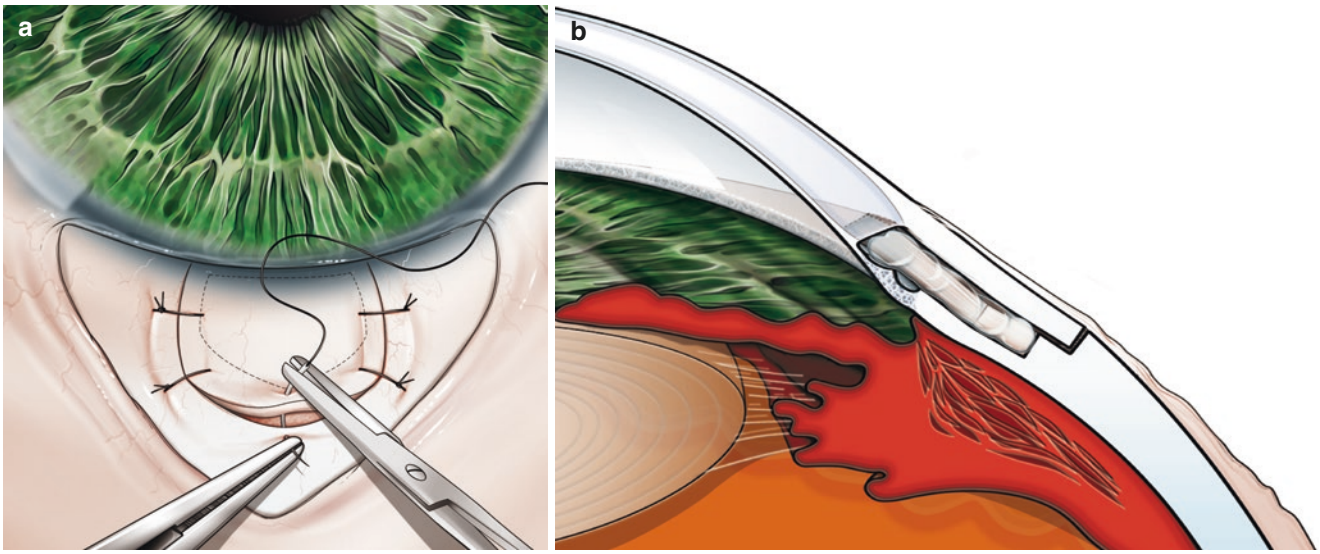

Fig. 4.11 Suture of the superficial flap. The superficial flap is sutured with 5 or 7 tight nylon 10–0 sutures to prevent aqueous filtering to the sub-Tenonian layer below; alternately, the surgeon can use 11–0 polyester sutures (Mersilene). It is essential that the suture provides good closure to prevent the bleb formation. High viscosity sodium hyaluronic can then be injected into the intrascleral lake with the objective of preventing the collapse and reduce scarring in the early postoperative period.Mersilene or nylon are also used for the closure of the conjunctiva, with two sutures applied on the sides of the conjunctival-capsular flap. Alternately, vicryl 8-0 can be used.Finally, a subconjunctival injection of a steroid-antibiotic combination can be performed in the inferior fornix

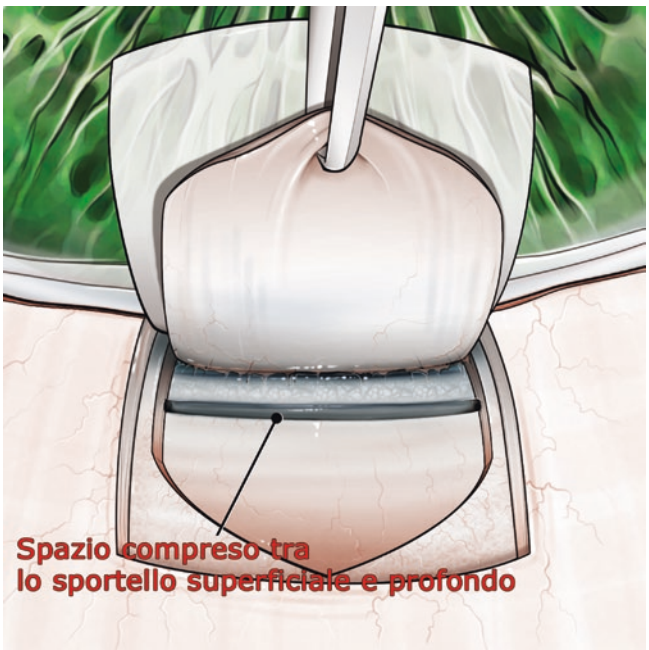

Fig. 4.12 Single access phaco-viscocanalostomy. Combined phaco-viscocanalostomy procedure: as with the phaco-trabeculectomy, in the combined phaco-viscocanalostomy procedure, the surgeon may opt for either a single or a double access. In the event the surgeon prefers the **single access** in the superior position at 12 o'clock, following creation of the superficial and deep flaps and identification the Schlemm Canal, the viscocanalostomy is suspended temporarily: with the deep flap positioned on the scleral bed, the surgeon creates the tunnel as described below and performs the phacoemulsification. When this step has been completed, the surgeon resumes the viscocanalostomy. In practice, the surgeon begins the viscocanalostomy (having identified the Schlemm Canal); the phaco procedure is performed (through a tunnel created below the superficial flap in the most anterior portion); finally, the surgeon creates the Descemet's window and the viscocanalostomy is concluded. Opting for a single access (at 12 o'clock), the tunnel created must also satisfy the requisites of the phaco procedure (intraoperative maintenance of the chamber depth, good closure of the incision at the end of the procedure) and those associated with the viscocanalostomy (that requires absolute integrity of the scleral flaps and the Descemet's window). The tunnel for the phacoemulsification is created following identification of the Schlemm Canal, and prior to creating the Descemet's window. The fragile structure of the window could be damaged by the traumatic maneuvers of the phacoemulsifier. The most suitable location is the space that lies between the superficial flap and the deep flap (indicated in the figure). As the dissection for the deep flap extends approximately 1 mm into clear cornea, the tunnel will also lie in clear cornea. It is approximately 2 mm long with the width depending on the gauge of the tip fitted to the phaco handpiece. The principle advantage of the single access is logistics, as the surgeon will not have to change his position during the procedure. It is important to prevent the IOP rising excessively during phacoemulsification to avoid rupturing the filtration structures in the sclerectomy site with the consequent undesired sectorial perforation of the eye bulb. When the cataract procedure has been completed, the AC is filled with medium or low resting viscosity viscoelastic, and the glaucoma surgery can be resumed with the exposure and opening of the Schlemm Canal. At this point, percolation of aqueous humor is usually observed in phakic eyes; however, following cataract surgery, only a marginal quantity of liquid will be observed. At the end of the phaco procedure, and once the residual viscoelastic has been removed, it is advisable to leave the eye in a condition of hypotonia to reduce the thrust of the iris on the Descemet's window. An injection of miotic into the AC will reduce the risk of iris prolapse in the event of a perforation of the Descemet's window (an event that would warrant a conversion to a trabeculectomy). Finally, the walls of the tunnel and the paracentesis are edemized

Phaco-viscocanalostomy with a double access: in the event of phaco-viscocanalostomy with double or separate accesses, the surgeon can begin the procedure with a phaco in a temporal position, complete it and then proceed with the viscocanalostomy in a superior position. Alternately, in a similar way to a single access, the surgeon can begin with the viscocanalostomy in a superior position and continue with the preparation of the deep flap and the identification of the Schlemm Canal, with the phaco performed in a temporal position and the viscocanalostomy completed superiorly.

Results

Available literature on viscocanalostomy and on the deep sclerectomy was initially scarce, though the quantity has increased in recent years. Regarding the viscocanalostomy (not combined with phaco), Stegmann reported a 3-year success rate of 82.7%. These figures refer to a relative young population of non-white patients (mean age 54 years), with a high preoperative IOP (47 mmHg). These results appear to be exceptional.

Encouraging results have also been reported in Europe and America with percentage success rates lower than the trabeculectomy in the majority of cases.

Compared to the trabeculectomy with NPGS (deep sclerectomy, viscocanalostomy, canaloplasty), the literature has reported contradictory findings. On this subject, as mentioned previously, some authors have recently underlined how the non-penetrating techniques (with or without phacoemulsification) have similar outcomes in terms of a reduction in the IOP, while others have highlighted the greater efficacy of the trabeculectomy (with or without MM-C) compared to the non-penetrating techniques (see also the results for the deep sclerectomy).

Complications

Intraoperative

The procedure (like the deep sclerectomy and canaloplasty) thins the wall of the eyebulb without opening the AC and will avoid a sudden drop in pressure that is traditionally observed with the classical filtering procedures. Consequently, complications associated with this drop in pressure are less frequent (intraoperative bleeding and post-operative detachment of the choroid).

The perforation of the Descemet's window is the most commonly observed intraoperative complication, particularly when the surgeon is learning the technique. If on the one hand, any microperforations can be ignored or even created intentionally to increase the percolation, on the other important solutions of continuity of the window necessitate the conversion to trabeculectomy (or phacotrabeculectomy).

The two factors that condition the management of the perforation of the Descemet's window are the depth of the AC

and an iris prolapse. In the event of tiny holes with no iris prolapse or loss of AC depth, the surgeon can continue the procedure without having to convert the technique.

The perforations with the reduction or the abolition of the AC depth, but without iris prolapse must be treated to prevent the iris prolapsing or anterior synechias forming. The surgeon then proceeds with the introduction of viscoelastic into the AC through a paracentesis, taking care to inject it below the perforated window to distance the iris. The surgeon should inject the smallest amount of viscoelastic to avoid postoperative hypertonia. Moreover, some authors suggest affixing an implant (scleral or corneal patch) on the perforation site to close the hole.

The perforation of the scleral bed, caused by an excessive depth of the dissection plane, in theory can have serious consequences, particularly if it causes bleeding of the ciliary bodies. Nevertheless, this is an extremely rare occurrence. The superficial flap is closed with several sutures (6–8) in 10.0 nylon, when the AC has reformed and the iris repositioned (if it had prolapsed).

In the event an iris prolapse accompanies a large Descemetic perforation, the surgeon should perform a peripheral iridectomy. The superficial flap must be sealed with sutures once the viscoelastic material has been introduced into the surgically-created scleral space to increase the resistance to drainage. Considering that the scleral space created reduces the resistance to drainage of the aqueous humor, it is extremely important that the superficial flap is completely watertight.

Post-operative

In the literature and from the experience of a number of surgeons, it emerges that the postoperative pathway prior to the viscocanalostomy shows an extremely low incidence of complications (see also the complications of the deep sclerectomy). Some complications appear early, others in the late postoperative period.

Redness (hypoema) was reported by a number of authors: it was normally mild and extended for less than 4 mm) but even in the more serious cases, it will reabsorb within three days.

The surgeon may detect pressure spikes in the initial postoperative period (with the pathogenesis probably correlated to Healon GV remaining in the Schlemm Canal, though this is not completely clear). Leakage may be observed, associated with the incorrect placement of the sutures on the conjunctival flap.

Hypotonia and associated consequences are extremely infrequent, even considering that the application of antimetabolites has no place in this surgery.

Postoperative hypertonia is not a frequent complication and should be managed differently based on the cause. There may be several causes:

- An incomplete surgical dissection of the deep flap: in this case, the surgical incision can be reviewed. Revision of the incision site may prove to be difficult and this is one of the reasons many surgeons prefer to intervene on a completely different site.
- Intrascleral hemorrhage: this will be resolved within a few days.
- Excessive viscoelastic in the AC (particularly after combined surgery or the re-formation of the AC following a microperforation): this will be resolved spontaneously within a few days.
- Rupture of the Descemet's window with iris prolapse secondary to hypertonia caused by rubbing the eye, Valsalva's maneuver etc. It is managed with miotics and the gonio-YAG laser on the prolapsed iris. If this is ineffective, the surgeon must proceed with an iridectomy.
- Formation of anterior synechias at the site of the Descemet's window, often secondary to intraoperative microperforations.
- Steroid-induced hypertonia (during the first post-operative week). Even the formation of the filtering bleb (5% of cases according to Stegmann) is considered to be a sort of failure, even though this is normally associated with good tonometric control.

Deep Sclerectomy

The deep sclerectomy is a type of non-penetrating glaucoma surgery. It differs from viscocanalostomy and canalostomy mainly because its goal is to obtain the filtration of the aqueous humor into the intrascleral lake and from here into the sub-Tenonian space (and not to facilitate drainage through the dilation of the Schlemm Canal with viscoelastic, as happens in the viscocanalostomy) (Fig 4.13). Regarding the tonometric results from the deep sclerectomy, numerous studies have demonstrated that the deep sclerectomy (as with the viscocanalostomy and canaloplasty), either when performed alone or in combination with phacoemulsification, can produce a satisfactory reduction in the IOP, with a greatly reduced percentage of complications compared to trabeculectomy. Many papers published in the literature—that have increased quite considerably over the last 8 years—support the efficacy of this technique, that has the same indications as the viscocanalostomy technique. Even though the efficacy of the deep sclerectomy is generally considered to be lower than the effectiveness of the trabeculectomy, additional techniques such as the intraoperative use of antimetabolites, implants and laser gonio-perforation would appear to increase the efficacy. In the past, the addition of collagen to the deep sclerectomy provided contrasting results and it is not possible to state definitely if it will really guarantee an improvement in the filtration.

Surgical Technique

As for the viscocanalostomy, the first phase of the procedure involves the appropriate exposure of the bulb and the preparation of the scleral bed: the conjunctiva and the Tenon capsule are generally cut at the limbus, creating a flap that is approximately 8 mm wide. Hemostasis of the episcleral vessels is performed by bipolar diathermy. It is important not to exaggerate with the settings used to avoid inducing an excessive scarring reaction, with possible retraction of the scleral tissue; however, it is not necessary to protect the venous collectors as in the viscocanalostomy, as they do not play an essential role in the mechanism of action of the deep sclerectomy.

The preparation of the superficial scleral flap more or less reiterates what has already been described for viscocanalostomy. The shape of the flap is usually quadrangular and measures approximately 4 × 4 mm; the surgeon can also prepare flaps that are slightly larger or slightly smaller.

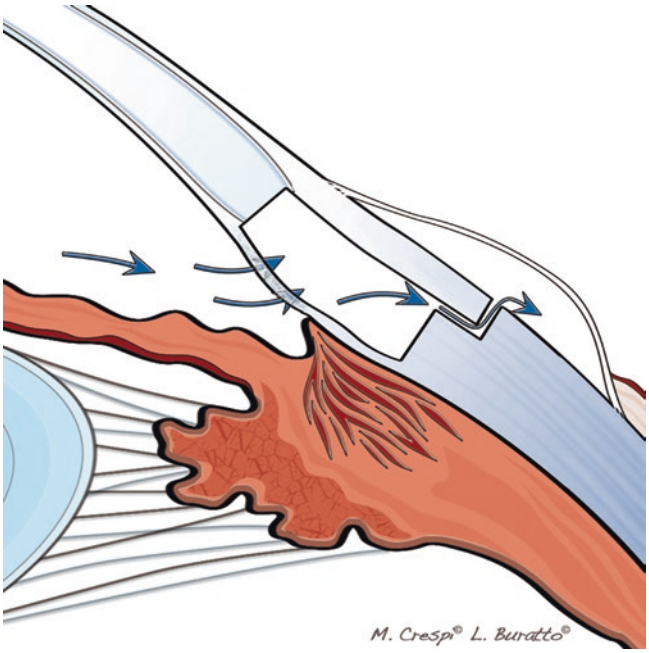

Fig. 4.13 Deep sclerectomy: possible filtration pathway for the aqueous humor. The procedure involves the removal of a portion of the sclera, including the part that covers the opened portion of the Schlemm Canal, and a more anterior portion that lies immediately above the Descemet membrane. The endothelial wall of the canal itself is removed towards the corneo-scleral trabeculate. Therefore, there will be no fistula between the AC and the subconjunctival space. The Schlemm Canal is expected to be in a slightly more scleral position with respect to the surgical limbus (Fig. 4.14). As with the viscocanalostomy, drainage is facilitated by the aqueous humor seeping through the thinned eye bulb wall in correspondence with the corneo-scleral trabeculate. The aqueous humor is collected in an intrascleral drainage chamber where it is transported by the uveoscleral discharge (*blue arrows*). The bleb almost appears to be almost an unintentional additional tool for reducing the IOP, transforming the procedure almost into a classical filtering surgery. As with the other glaucoma procedures, the deep sclerectomy can also be combined with phacoemulsification

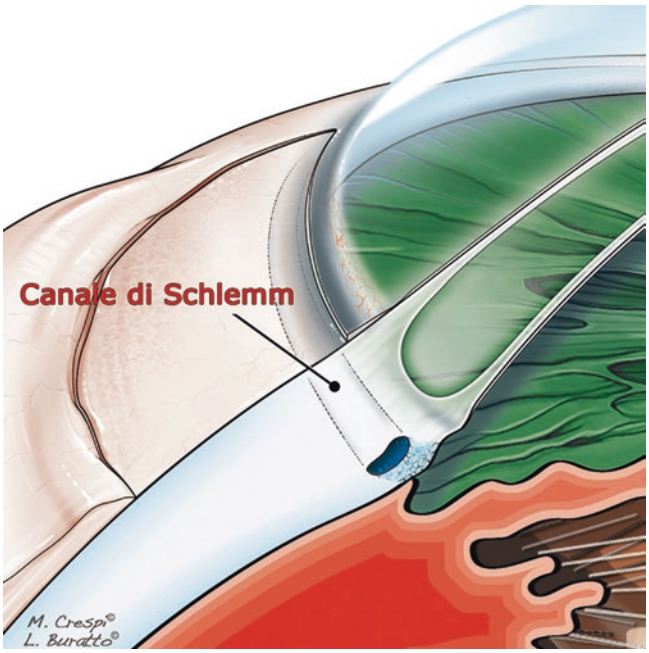

Fig 4.14 Deep sclerectomy: schematic representation

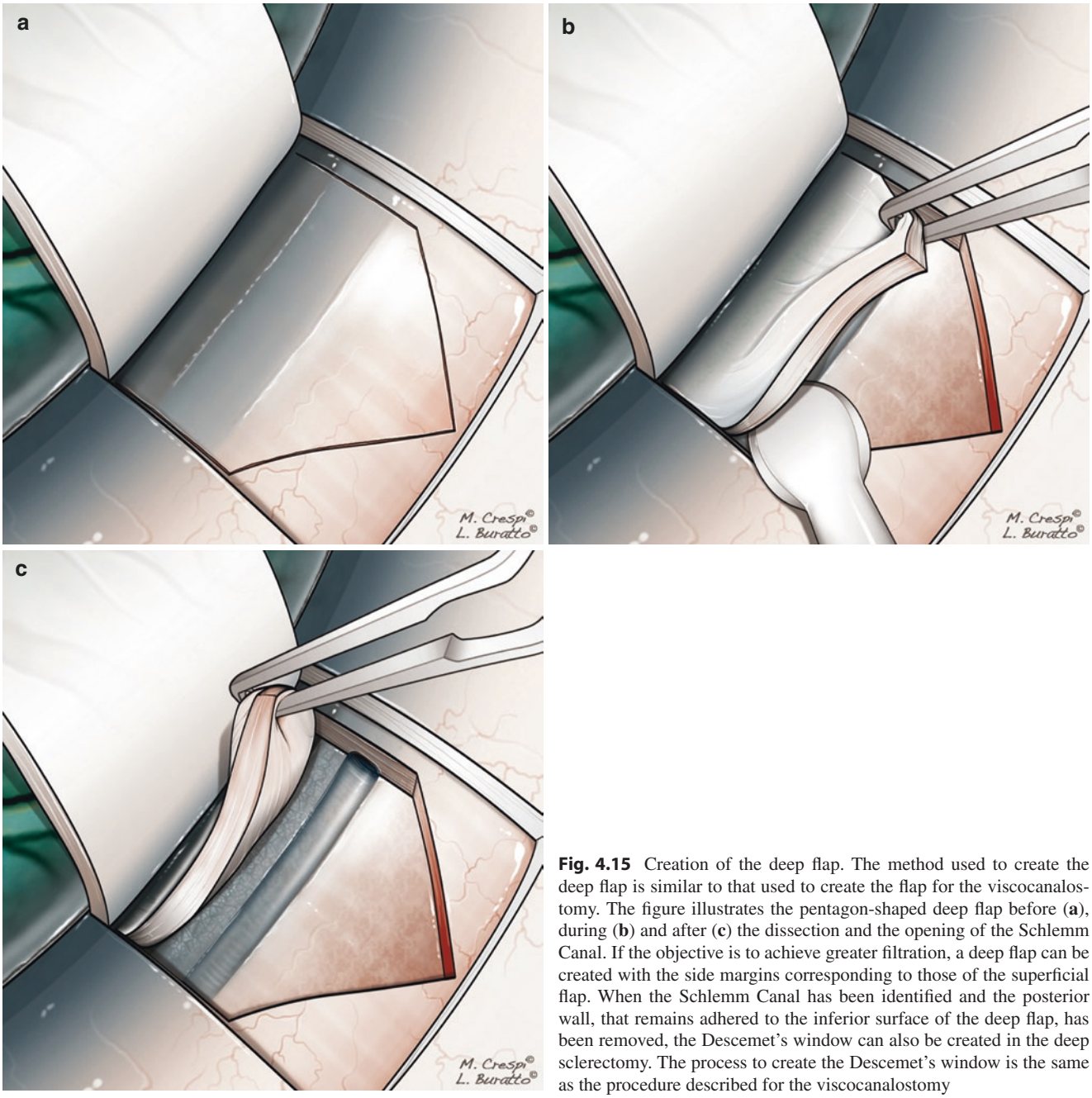

Fig. 4.15 Creation of the deep flap. The method used to create the deep flap is similar to that used to create the flap for the viscocanalostomy. The figure illustrates the pentagon-shaped deep flap before (**a**), during (**b**) and after (**c**) the dissection and the opening of the Schlemm Canal. If the objective is to achieve greater filtration, a deep flap can be created with the side margins corresponding to those of the superficial flap. When the Schlemm Canal has been identified and the posterior wall, that remains adhered to the inferior surface of the deep flap, has been removed, the Descemet's window can also be created in the deep sclerectomy. The process to create the Descemet's window is the same as the procedure described for the viscocanalostomy

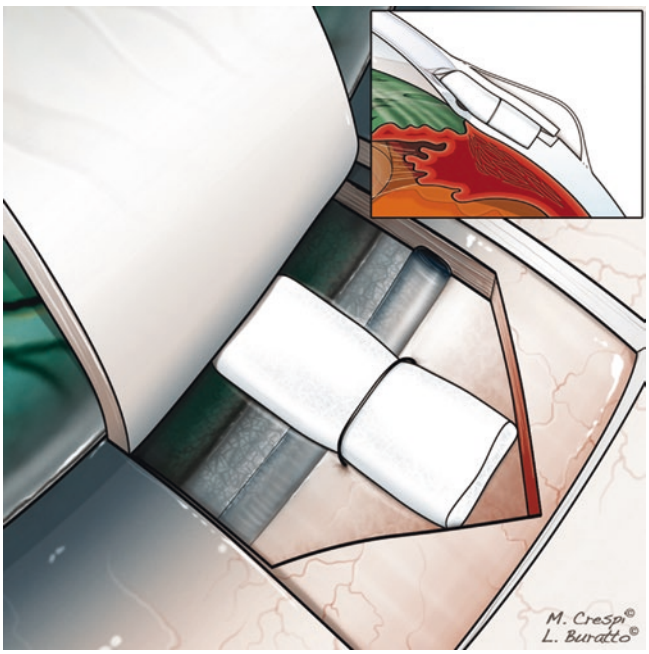

Fig. 4.16 Positioning of the inserts in the scleral lake. To ensure better filtration in the medium- and long-term postoperative period, the surgeon can position two inserts in the scleral lake following removal of the deep flap; this will facilitate maintenance of the intrascleral space and prevent occlusion by scar processes. An insert in collagen (Aqua-Flow, Staar Surgical AG, Ch-2560 Nidau, Switzerland) consists of a cylinder of lyophyllized pig collagen (see the figure). This substance has a considerable degree of hydration and excellent biocompatibility. The cylinder is positioned radially at the bottom of the scleral lake, and is sutured with 10-0 nylon; the anterior tip of the cylinder should lie above the Descemet's window. The insert will be slowly re-absorbed over a period of about 6 months. The insert in reticulate hyaluronic acid (SK-Gel, Corneal, Paris, France) is a solid gel. The mechanism of action is correlated with maintenance of the space of the intrascleral lake. The insert is positioned on the bottom of the lake prior to suturing the superficial flap. According to the manufacturer, the insert will be reabsorbed within 3–6 months with decomposition delayed by the reticular agent. However, the insert in reticulate hyaluronic acid is not widely used

The final phases of the procedure are the removal of the deep flap and suturing. The deep flap is removed using the same technique described for the viscocanalostomy. However, the suture of the superficial flap does not have to be watertight, it must allow sufficient filtering into the sub-Tenon space, similar to the trabeculectomy procedure. Two or three 10-0 nylon sutures are usually sufficient. The conjunctiva and the Tenon capsule are closed with two tobacco pouch sutures positioned at the two ends of the conjunctival flap (in 10-0 nylon or 8-0 vicryl).

The rational of the intraoperative use of antimetabolites is related to the surgical procedure goal: the drainage of the aqueous into the sub-Tenon space. This is the basic difference between the deep sclerectomy and the viscocanalostomy. The intraoperative use of the antimetabolites is justified by the presence of one or more risk factors for bleb failure. The antimetabolites 5-Fluorouracile (5-FU) and Mitomycin (MM-C) can be used in the isolated deep sclerectomy. At the time of writing, there are no studies that precisely define the indications, the doses and the results obtained with MM-C or 5-FU in the deep sclerectomy. The choice of the antimetabolite, its concentration and the time of application depend on the severity of risk factors associated. To achieve greater guarantee of water tightness, when an antimetabolite has been used it is advisable to apply a continuous running suture along the entire length of the conjunctival flap (in 10-0 nylon or 8-0 vicryl) to include the conjunctiva and the Tenon capsule, in addition to two sutures positioned on the ends of the conjunctival flap.

The Combined Phaco-Deep Sclerectomy Procedure

As for the viscocanalostomy, it is possible to perform the procedure in a superior position in correspondence to the sclerectomy, or in a temporal position; no significant differences in the tonometric results between the two techniques have been reported, even though some of the authors recommend a temporal incision.

Results

Numerous studies have demonstrated that the deep sclerectomy (and viscocanalostomy and canaloplasty), either when performed alone or in combination with the phacoemulsification, can result in a satisfactory reduction in the IOP, with a low complications rate compared to the trabeculectomy. Many of the papers published in the literature, that are increasing in number over the past 8 years, support the efficacy of this technique. Careful analysis of the literature, as mentioned previously, has shown that the non-penetrating surgical procedures (viscocanalostomy, deep sclerectomy, canaloplasty) are associated with a good control of the IOP in the early post-operative period but there is also a high percentage of late failures.

Even though the efficacy of the deep sclerectomy is generally considered to be lower than the efficacy of the trabeculectomy, additional techniques such as the intraoperative use of antimetabolites, implants and laser gonioperforation (see later) would appear to increase the efficacy. In the past, the addition of collagen to the deep sclerectomy provided contrasting results and it is not possible to state with certainty if it will guarantee an improvement in the filtration. In recent years, some meta-analyses have been published on the efficacy of non-penetrating surgery (isolated deep sclerectomy, with an insert of collagen, with an insert of hyaluronic acid, with antimetabolites, isolated viscocanalostomy) in the open-angle glaucoma: they report the success of these techniques, but with pressure results that have a lower validity when the target pressure is lower. As mentioned earlier, regarding the comparison between trabeculectomy and non-penetrating glaucoma surgery (with or without phacoemulsification), recent literature has reported contrasting results. However, while some authors

have underlined how the use of non-penetrating techniques have produced comparable results in terms of IOP reduction, others highlighted greater efficacy of the trabeculectomy in comparison to the nonpenetrating techniques (see the results for viscocanalostomy): recent literature underlines the better safety profile of the nonpenetrating techniques, but does not state that these techniques produce better tonometric reduction than trabeculectomy. Consequently, thanks to greater safety and further improvements in the surgical technique, these non-penetrating procedures, with or without phacoemulsification, are with no doubt a valid surgical option, particularly in cases in which the target pressure is not very low.

Complications

Intraoperative

The intraoperative complications can be comparable to those observed in viscocanalostomy and depend largely on the incorrect dissection of the deep flap.

Postoperative

As mentioned previously, the incidence of precocious post-operative complications following deep sclerectomy is greatly reduced compared to perforating glaucoma surgery. In the first post-operative month, the deep sclerectomy (and the same happens in the other NPGSs) causes less inflammation compared to the trabeculectomy because the AC is not opened and an iridectomy is not performed. On the other hand, even on the first postoperative, the eye frequently appears healthy and cases of hypotonia and/or reduction in the AC depth are extremely rare. This would suggest that visual rehabilitation is much more rapid.

The most frequent postoperative complication is hypoema; it will usually resolve spontaneously within a few days. In some extremely rare cases, the deep sclerectomy may be complicated by a ciliary block malignant glaucoma. Even in the combined procedure, a reduction in the precocious post-operative complications is observed: in particular, hypoema and an inflammatory reaction.

Another postoperative complication is the late failure of the procedure, with a IOP rise. The obstruction to the filtration can be internal or external.

YaG Laser Goniopuncture

Residual ocular hypertension may be observed at a variable time following the deep sclerectomy procedure. One of the possible causes is an obstruction to the drainage of the aqueous through the Descemet's window, in turn dependent on an intra-operative error (an excessively superficial dissection with insufficient percolation) or fibrosis of the window itself. In these cases, the filtration can be increased by perforating the Descemet's window from the inside using the Yag laser. Yag laser goniopuncture may be necessary in 40–50% of patients. The tonometric success following goniopuncture is above 80%. This procedure can be performed during the first postoperative period or 1 or 2 years later; as there are no studies that definitely demonstrate the efficacy, it is advisable to wait for at least 2 weeks postoperative to reduce the risks of ocular hypotony.

Canaloplasty

Conceptually, it is a variation of the viscocanalostomy technique with the addition of:

1. Dilatation of the canal using a catheter;
2. Placement of a permanent suture in the stretched Schlemm Canal. The mechanism of action is different to penetrating surgery, because an alternative pathway for the drainage of the aqueous humor has not been created; however, the efficiency of the natural pathway (trabeculate) has been improved without interfering with the spaces that are normally not used for these purposes (subconjunctival space, a critical point for the failure of filtering surgery).

Recently, this technique would appear to be the elective non-penetrating procedure among glaucoma surgeons; canaloplasty is a technique that is indicated in open-angle glaucoma with a moderate-high pressure target. However as with other non-penetrating procedures, its use is contraindicated in certain forms of glaucoma – such as neovascular and obviously closed-angle glaucoma, in glaucoma secondary to trauma with

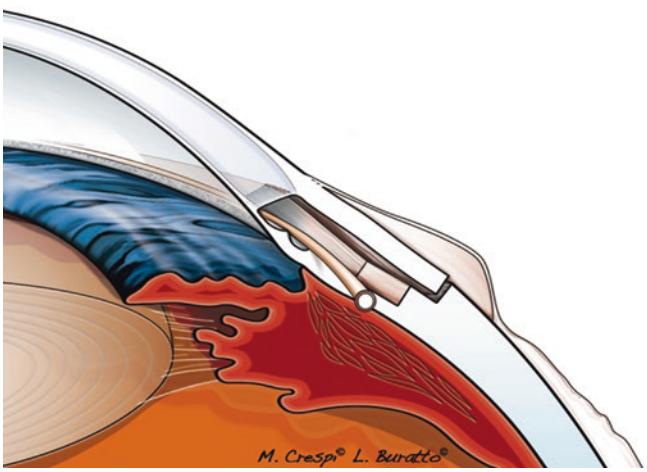

Fig. 4.17 Canaloplasty: schematic representation. Canaloplasty is a procedure developed to improve the drainage of aqueous humor and involves the insertion of a microcatheter inside the dilated Schlemm Canal. The microcatheter will carry a single or double prolene thread inside the canal where it will be tensioned, in an attempt to stretch the juxta-canicular portion of the trabeculate and improve the circumferential drainage capacity

recession of the angle, and in eyes in which the trabeculate received argon laser treatments or the trabeculectomy procedure. In theory the enormous advantage of the canaloplasty is the circumferential treatment of the Schlemm Canal, without precluding the possibility of the intraoperative conversion to a trabeculectomy, if required (due to the probe being obstructed in the Schlemm Canal, accidental perforation of the Schlemm Canal, perforation of the endothelial window, etc.). The possible disadvantages are the difficulties with the external dissection (a step that is more complex and prolonged than other procedures on the camerular angle) and the conjunctival scarring that may increase the risk of failure of the successive trabeculectomy. This procedure does not create direct access to the collector channels and the tonometric reduction is limited to the resistance of the Schlemm Canal and the episcleral vein pressure. Moreover, the long-term effects of the foreign body (prolene thread) in the Schlemm Canal are not known. As with the other NPGS, this procedure can also be performed in combination with phacoemulsification, and results to date have been positive. Regarding the tonometric results, the available literature on canaloplasty still does not offer comprehensive information even though the technique would appear to be the most promising of those introduced recently.

Surgical Technique

The first steps are the same as those for the viscocanalostomy: dissection of the conjunctiva with the base at the fornix, creation of a parabola-shaped superficial flap and the deep flap, paracentesis, removal of the deep flap to create the scleral lake.

These are followed by the dilatation of the Schlemm Canal ostias with a dedicated cannula; these are found slightly posterior to the limbus,; the surgeon then introduces VES (Healon GV) into the ostias of the canal to facilitate the passage of the microcatheter.

The next phase of the procedure involves the insertion of a flexible microcatheter (in a direction indicated by the red arrow) into the Schlemm Canal. The first microcatheter was produced by iScience Interventional, Menlo Park, CA. The surgeon can facilitate this maneuver catching the catheter with one or preferably two toothless forceps (tying or Duran forceps). The tip of the catheter has a diameter of 250 μm and an internal lumen of 200 μm. Through this the surgeon can inject the VES. The diameter of the Schlemm Canal varies between 190 and 370 μm. Other commercially available microcatheters are: Glaucolight (DORC, The Netherlands) and Onalene (Onatec, Germany).

This device includes an optic fiber with an illuminated tip: considering the absence of direct vision, the tip illumination assists the correct insertion of the microcatheter. If the microscope light emission is reduced, it will be easy for the surgeon to follow the route of the optic fiber (indicated by the red arrow) for 360° inside the Schlemm Canal (trans-scleral illumination).

During this maneuver, the surgeon must avoid going off-line—into the AC on the one side and the suprachoroidal space through the large collector channels on the other. If the catheter is obstructed along its path, it can be withdrawn and

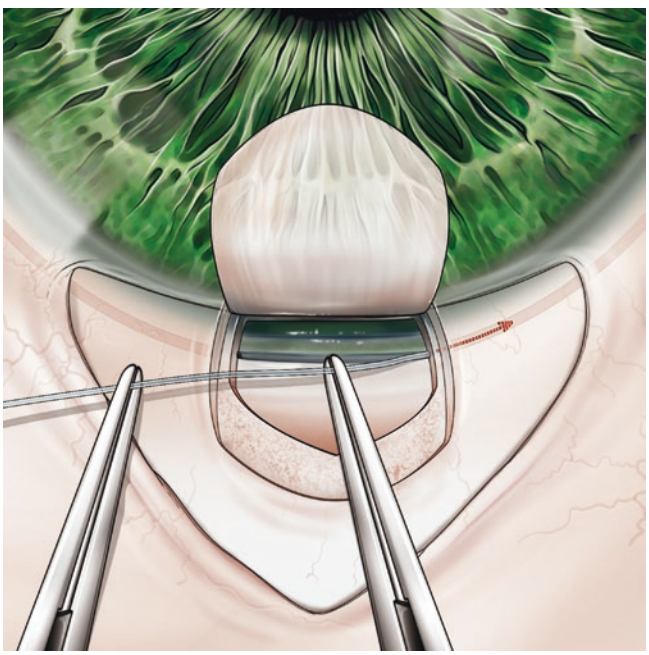

Fig. 4.18 Insertion of the microcatheter into the Schlemm Canal

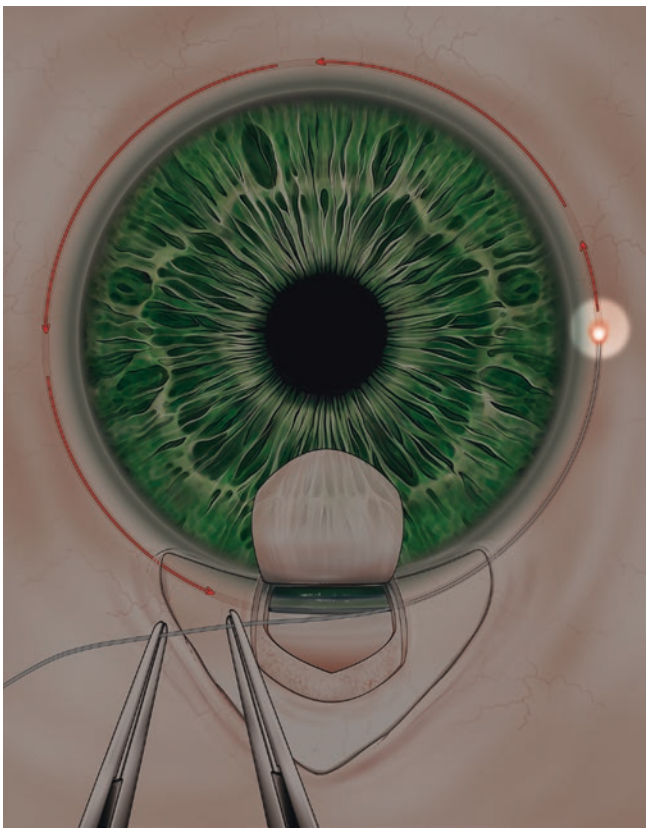

Fig. 4.19 Visualization of the fiber optic inside the Schlemm Canal

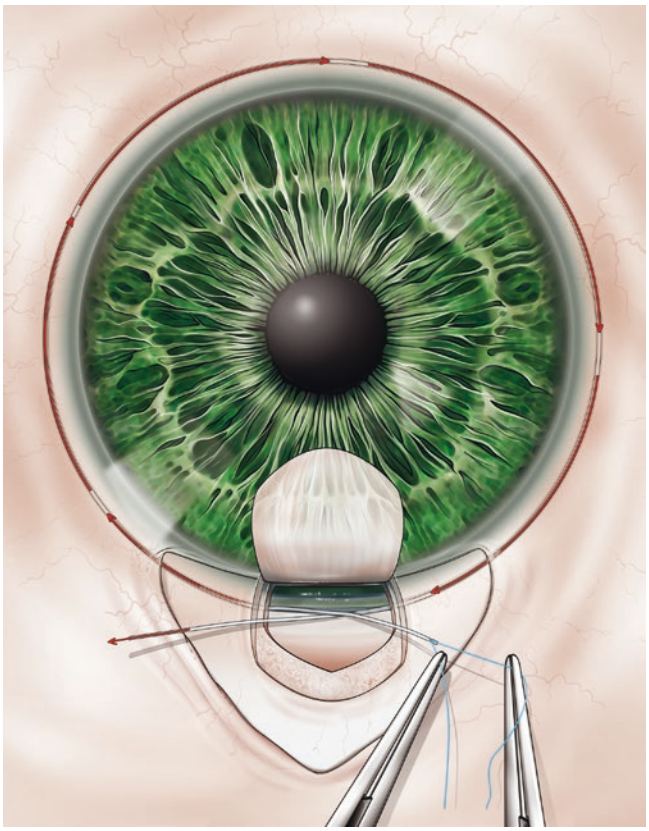

Fig. 4.20 Anchoring of the prolene 10.0 suture thread on one end of the microcatheter. Removal of the microcatheter

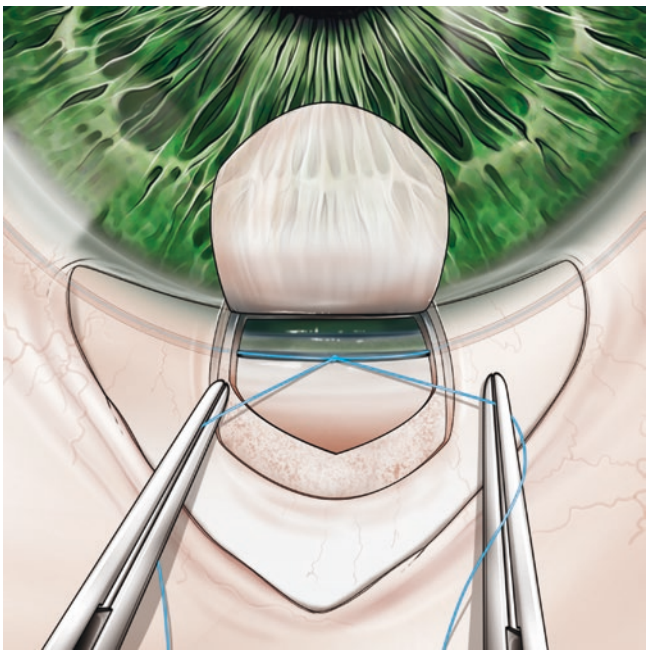

Fig. 4.21 Prolene suture

another attempt to insert it into the canal can be made through the opposite ostia: this will normally be successful.

When the microcatheter is visible outside the distal ostium of the canal, the surgeon will anchor the 9.0 or 10.0 prolene thread to the terminal of the device, a 2.1.1 knot is recommended: it is important to create a small flat knot for each of the three passes. On the return route (red arrows), the surgeon must avoid damaging the Schlemm Canal with the knot; he may wish to introduce a tiny quantity of VES through the microcatheter for the entire return phase (0.5 μL for every 2 h for the 360° −12 h of the Schlemm Canal, corresponding to 1/8th turn of the Healon GV injector) as it will widen the canal, the viscoelastic will reduce the risk of damaging the canal.

Once the microcatheter has been withdrawn, the prolene 10.0 thread is released (usually a single thread, though a double thread may be used); the surgeon separates the two thread ends and positions the suture. The knot may have a 4.1.1 format that involves four passes; both suture ends are then raised and the knot is tightened. The knot is recessed close to either the right or the left ostia under appropriate tension. The surgeon then slowly performs the second and third passes.

Another elegant and extremely valid means for creating the knot is Siepser's 1.1.1 slipknot; in this case, the first maneuver is simple a pass, the second adjusts the final tension and the third closes the knot. In both cases, the tension given to the thread will be proportional to how much the Schlemm Canal, and consequently the trabeculate, have been stretched. As the IOP in this eye will be very low, it is very easy to exceed with the thread tension; in extreme cases this may inadvertently create an undesired trabeculotomy. Correct suture tension is essential as this will determine the circumferential tension in the Schlemm Canal and the trabeculate, responsible for restoration of natural drainage of the aqueous humor. Adjusting the tension of the prolene thread may reduce visual acuity (more than 12% patients initially lose 2 or more Snellen lines), linked to astigmatism induced by the closure of the suture; however, some authors believe that it is more linkly due to the sutures positioned on the superficial scleral flap. Astigmatism generally appears between 1 and 10 days postoperative and is generally resolved within 6–10 weeks. Once the tension in the prolene suture has been appropriately adjusted, the surgeon quickly closes the superficial flap and checks that there is no filtration (similar to viscocanalostomy). Finally, the conjunctiva is sutured with the standard method.

Results

The currently-available literature on canaloplasty does not yet provide us definitive informations because there are no long-term results available. Positive results for the combined canaloplasty/phacoemulsification procedure were reported by Shingleton in 2008.

Recent long-term studies have reported that canaloplasty on its own can significantly reduce the IOP in open-angle glaucoma, with a small percentage of serious postoperative

complications in the short- and long-term. However, these studies also demonstrate that this procedure can sometimes lead to a modest reduction in the IOP and consequently should be indicated only for those patients with mild perimetric alterations and a higher target pressure.

The use of MM-C has proved to be safe and efficacious in the canaloplasty procedure proposed by some authors.

In a study by Grieshaber, the use of 10.0 prolene thread has proved to be slightly more efficacious in reducing the IOP compared to the use of 6.-0 prolene.

Complications

This surgical procedure requires the surgeon to have good manual skills. A brief description of the intra- and postoperative complications associated with the technique follows:

Intraoperative Complications

These may appear:

1. Due to lack of exposure of the canal
2. During the creation of the Descemet's window: (a) microperforation (b) macroperforation with or without iris prolapse
3. During insertion of the catheter and dilation of the canal: (a) detachment of the Descemet's membrane; (b) suprachoroidal pass

Post-operative Complications

1. Precocious (1–10 days post-surgery):
   (a) Increase in the IOP (the surgeon should exclude entrapment of the iris, angle closure, the formation of peripheral iris synechias, the presence of residual viscoelastic in a combined procedure, hypoema, response to steroids)
   (b) Reduction of the visual acuity (more than 12% patients initially lose 2 or more Snellen lines) linked to the astigmatism induced by the closure of the sutures and resolves within 6–10 weeks
   (c) Hypoema: this is a very frequent complication and can be classed as physiological because it is caused by the reverse flow in the Schlemm Canal (observed more frequently in patients previously subjected to ALT or SLT laser treatments)
   (d) Detachment of the Descemet membrane: this occurs when an excessive quantity of Healon GV has been injected
   (e) Hypotonia—this complication is almost always resolved spontaneously and rapidly.
2. Late onset (2–5 weeks):
   (a) increase in the IOP due to insufficient trabecular filtration or micro/macro perforations that lead to iris prolapse.

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Glaucoma Drainage Implants

5

Luigi Caretti and Lucio Buratto

Introduction

Glaucoma Drainage Devices (GDDs) or shunts were proposed by Molteno and coll in 1968 for the treatment of refractory glaucomas, meaning those cases at a high risk of failure following filter surgery or in cases in which surgery was already not successful.

GDDs are devices designed to deviate the aqueous humor away from the anterior chamber (AC) to an external reservoir (bleb) in the subconjunctival space, where it forms a fibrous capsule that will be responsible for flow regulation. The formation of the fibrous capsule generally occurs 4–6 weeks after surgery.

These devices are available in different sizes, materials and shapes; they may be equipped (or not) with a valve that regulates the flow of aqueous humor that drains from the eye bulb and consequently regulates the intraocular pressure (IOP).

Over the past 40 years and especially in the last decade, new shapes of shunts and improvements in the surgical techniques have resulted in better efficacy with a lower rate of complications. These new devices are also easier to implant compared to the past and the indications have been modified. For all of these reasons, today, their clinical use has increased considerably.

However, despite these technical improvements, the IOP is often not predictable immediately after surgery and many patients need to continue using topical hypotonic therapy to maintain satisfactory pressure control.

In the past, some authors have suggested an association of the implants with antimetabolites; nevertheless, at the time of writing these have been nearly abandoned because in the literature, no evidence of their effective clinical use has been reported.

Types of Drainage Implants

A number of GDDs are commercially-available; they differ in terms of type, shape and material. The implants consist of at least one plate and a tube. One of the main features that differentiates the various types of implant consists of the presence or absence of a valve fitted inside the implant. The devices with the 'valve' or with 'flow restriction' consent an exclusively unidirectional flow of liquid from the AC to the subconjunctival space with minimal activation pressure. On the other hand, the non-valved implants do not restrict the flow: these necessitate the intra- and post-operative application of some additional maneuvers to prevent hypotonia (see successive paragraphs on the surgical technique). The GDDs by Ahmed (AGV; New World medical, Rancho Cucamonga, CA) (Fig. 5.1) and Krupin (production has been interrupted) are two examples of valved implants. Non-valved GDDs are produced by Molteno (IOP Inc., Costa Mesa, CA and Molteno Ophthalmic Ltd., Dunedin, New Zealand) (Figs. 5.2 and 5.3), Baelverdt (Abbott Medical Optics, Santa Ana, CA) (Fig. 5.4) and Eagle Vision (Eagle Viono Inc., Memphis, TN) (Fig. 5.5) (also see Table 5.1).

Clinical Indications for the Use of Shunts

As mentioned previously, the GDDs were traditionally indicated for the treatment of refractory glaucoma, meaning cases in which filter surgery is associated with a high risk of failure (for example, neovascular or uveitic glaucoma), with a high rate of complications or in cases with previous failure of filter surgery for glaucoma. Moreover, the shunts appear to be effective in patients in which a previous intraocular sur-

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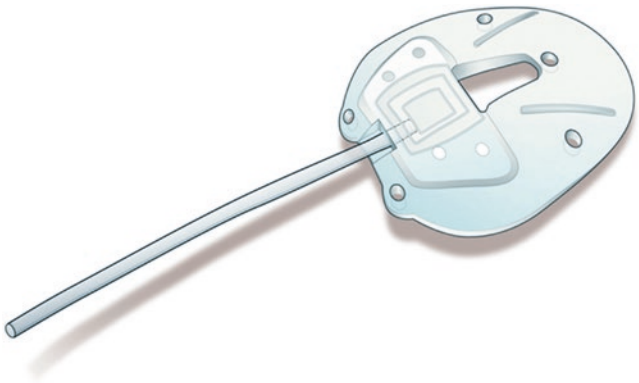

Fig. 5.1 Ahmed implant

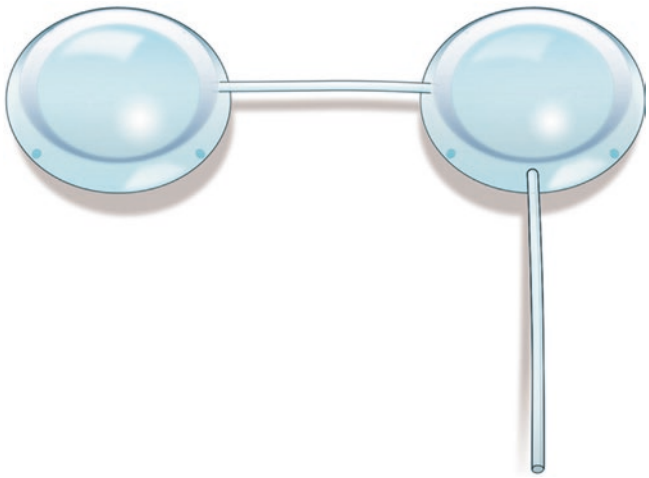

Fig. 5.3 Molteno implant (double plate)

Fig. 5.2 Molteno implant (single plate)

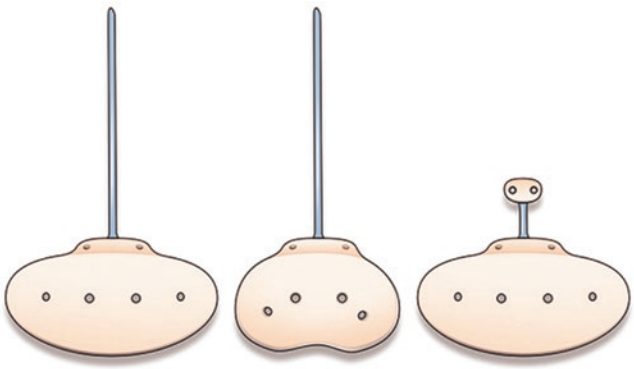

Fig. 5.4 Baelverdt implants

Fig. 5.5 Eagle Vision implant

gery (vitreo-retinal or corneal) led to the formation of conjunctival scar tissues that reduce the amount of intact conjunctiva, precluding the trabeculectomy procedure or function. In recent years, the indications for these devices have expanded quite considerably, and now include congenital/juvenile glaucoma, traumatic glaucoma, glaucoma in the aphakic/pseudophakic eye, glaucoma post-keratoplasty, other secondary glaucomas (Irido-Corneal-Endothelial syndrome, Epithelial downgrowth). Moreover, in eyes with residual visual function, the shunts may be preferred over the cyclodestructive procedures that run a high risk of blindness and Phthisis bulbi (end-stage eye) (see Table 5.2). Lastly, in

Table 5.1 Commercially-available glaucoma drainage implants

	Type of plate	Size range (mm^2)	Type of material
Valved implants			
Ahmed	Single, double, for pars plana, pediatric	96–364	Polypropylene or silicone
Non-valved implants			
Baerveldt	Single, for pars plana	250–350	Silicone
Eagle vision	Single	365	Silicone
Molteno	Single, double, for microphthalmia	50–274	Polypropylene

Table 5.2 Clinical indications for the glaucoma drainage implants

• **Previous failure of filtering surgery**
• **Patients in which filtering surgery is associated with a high risk of failure or complications**
– Neovascular glaucoma
– Uveitic glaucoma
– Previous intraocular surgery (vitreo-retinal or corneal surgery) with the formation of conjunctival scarring that preclude trabeculectomy
• **Eyes with residual useful function, for which the cyclodestructive procedures have a high risk of blindness and *Phthisis* bulbi (end-stage eye)**
• **Post-traumatic glaucoma**
• **Congenital/juvenile glaucoma**
• **Glaucoma in the aphakic/pseudophakic eye**
• **Post-keratoplasty glaucoma**
• **Other secondary glaucomas (Irido-corneal-endothelial syndrome, epithelial downgrowth**

recent years these devices have been proposed as the elective procedure for cases of primary open-angle glaucoma: a number of authors have suggested their use in the primary surgical management of non-complicated glaucoma—the most precocious cases—thanks to their better result predictability compared to the trabeculectomy with MM-C and the lower incidence of complications (see results and complications below).

Preoperative Evaluation

It is essential that the surgeon performs a meticulous preoperative evaluation of the eye and devises an appropriate surgical plan to ensure the good outcome of the implant and minimize the risk of complications. First of all, the mobility of the conjunctiva must be examined to allow the surgeon to choose the best quadrant for the implant. In children affected by buphthalmos or in patients with vascular collagen disorders, the surgeon should attempt to identify thinned areas of the sclera where the implant should be avoided: under these clinical conditions, the surgeon must use certain techniques to anchor the plate of the device to the sclera to avoid possible perforations. The surgeon should examine the patient's cornea for marked peripheral gerontoxons or leukomas that could obstruct the visualization of the tube and cause problems with its insertion and correct positioning in the AC. Moreover, in the event of damage to the corneal endothelium, the implant in pars plana is preferable to the implant in AC. If the endothelial damage is evident (corneal insufficiency), and a clinically important cataract is observed, a triple procedure may be considered (phaco + IOL + GDD). The iris should be examined under high magnification to identify new blood vessels that may be treated with a preoperative intravitreal injection of anti-VEGF drugs to reduce the risk of intra- and post-operative bleeding. The depth of the AC must be measured to avoid exclude lesions to the cornea or the iris induced by the tube in the AC. The condition of the lens must also be considered: the tube can be positioned in the ciliary sulcus of pseudophakic eyes or in pars plana in aphakic eyes. It is extremely important that gonioscopy is performed on patients who are candidates for the GDD implant; this will identify neovessels in the camerular angle (in neovascular glaucoma) and peripheral anterior synechias (frequently present in neovascular, uveitic and traumatic glaucoma). The surgeon must take note of the areas that are free from anterior peripheral synechias as this will allow him to correctly choose the site for the implant. In the event of anterior peripheral synechias of recent appearance, the tube can be positioned anterior to the synechias. If synechias are observed in an extremely anterior position, it may be necessary to perform an intraoperative iridectomy to facilitate the insertion of the tube. Alternately, the surgeon must plan the implant of the tube in the ciliary sulcus or in pars plana.

Surgical Technique

In most cases, the tube of the GDDs will be positioned in the AC. However, it can also be positioned in the ciliary sulcus of a pseudophakic patient or in pars plana in vitrectomized eyes. The implantation of GDDs in AC will be examined more in detail later. Each surgical step of this procedure requires maximum attention to achieve good results and reduce the post-operative complications. The first thing to do is to select the quadrant for the implant. Most of the GDDs are positioned in a single quadrant, with the exception of the implants with two plates. When possible (due to the conditions of the conjunctiva, sclera, etc), the implant with a single plate should be positioned in the supero-temporal quadrant: this site consents the easiest access to implant the plate and leads to a lower rate of disturbance of

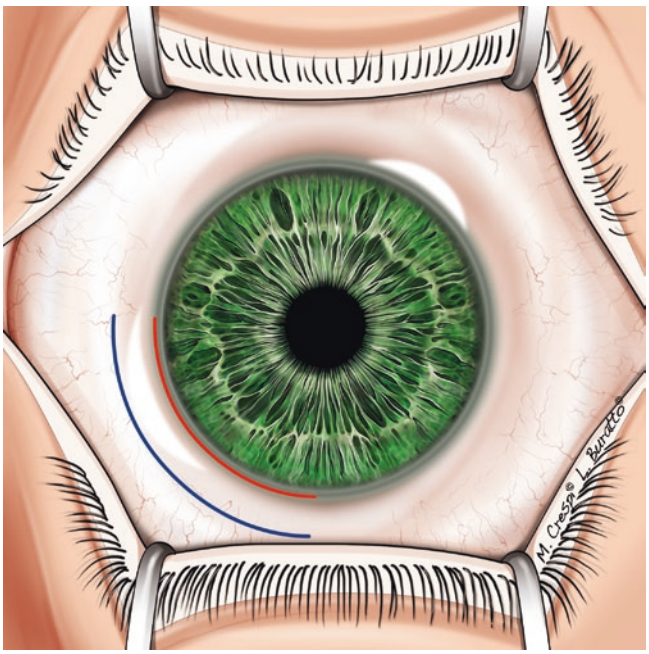

Fig. 5.6 Conjunctival incision (limbus based flap). Once the surgeon has selected the site for the implant, the first maneuver in this type of procedure is to perform the conjunctival incision (peritomy or peritectomy). Westcott scissors are generally used for this procedure. We prefer to perform a capsule-conjunctival incision with the hinge at the limbus (curved blue line in the drawing) rather that the fornix based flap (curved red line in the drawing). It must extend for 90–110° and be centered between the two rectus muscles (the distance is greater for the implant with two plates). The flap should include the conjunctiva and the Tenon because it should be a capsulo-conjunctival flap: this will ensure better closure and consequently a lower risk of exposing the implant. The advantages associated with the limbus based flap are the excellent posterior exposure (the implantation of the plate is easier), the reduced risk of leakage from the scar in the limbal position, lower conjunctival retraction and preservation of the stem cells of the limbus. The disadvantages are that the suture is more complex (compared to the incision when the hinge is at the fornix), and the scar will be positioned above the plate of the shunt, with the consequent risk of dehiscence of the wound, leakage and epithelial downgrowth

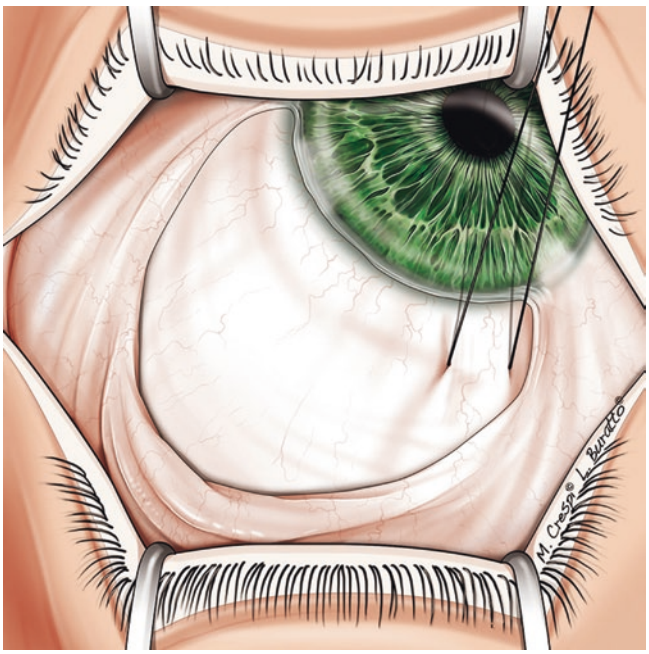

Fig. 5.7 Exposure of the quadrant for the implant. To create good exposure of the quadrant for positioning the shunt it is recommended to place of a scleral or corneal suture in silk 6.0 or 7.0 and then to tension the thread. The conjunctiva and the Tenon are detached, with the formation of a pouch. The surgeon should avoid an excessively wide dissection as the space created should not be greater than the diameter of the plate: there is a risk of acute post-operative hypotonia, particularly when non-valved shunts are used

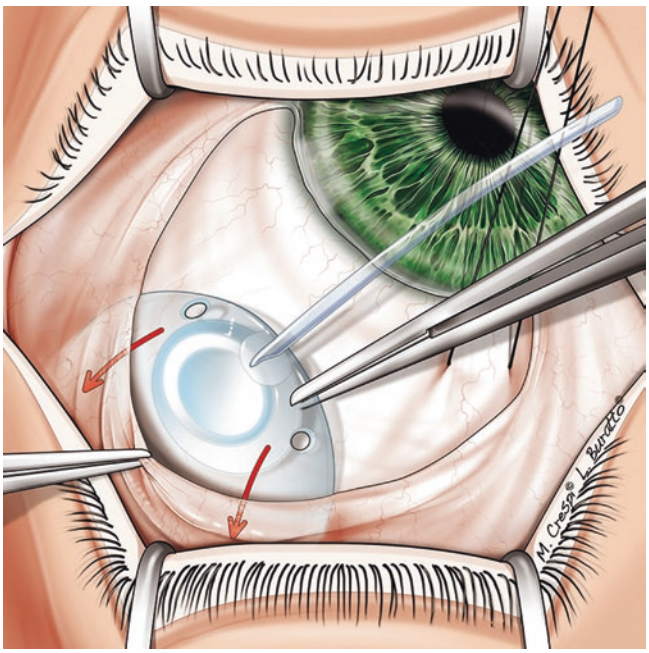

Fig. 5.8 Anchoring of the plate of the shunt to the sclera. The conjunctiva and the Tenon are retracted using forceps (or a retractor) to expose the bare sclera below. Now the surgeon proceeds by positioning the implant in the capsule-conjunctival pouch, between the two rectus muscles, so that the anterior edge lies approximately 8–10 mm posterior to the limbus

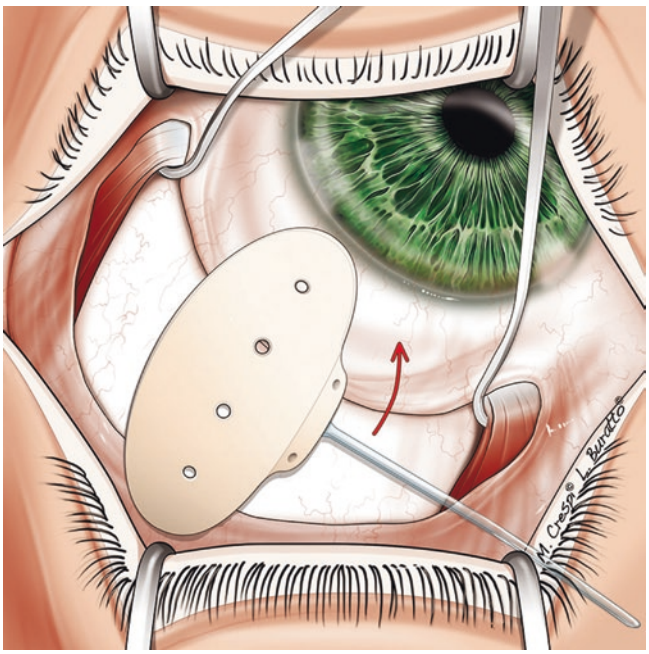

Fig. 5.9 Maneuvers to correctly position large shunts. The large implants (for example, the Baelverdt) should initially be inserted with the greater axis directed towards the apex of the eyeball and then rotated horizontally of approximately 90°, so that the tube is directed towards the AC, and the wings of the shunt slide under the rectus muscles (red arrow in the drawing). The surgeon should isolate the adjacent rectus muscles using a hook and mark the muscular insertion to allow correct positioning of the plate between or below the muscles

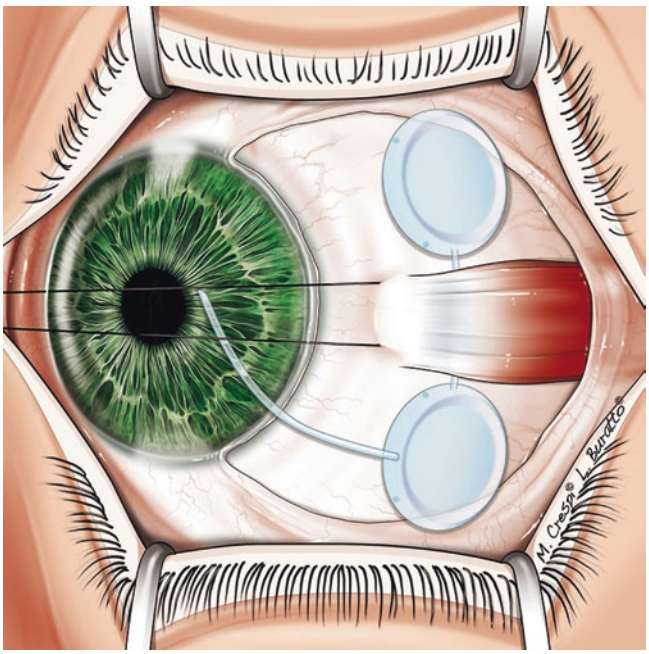

Fig. 5.10 Correct positioning of shunts with two plates. When shunts with two plates are inserted, one of the plates is positioned in one quadrant and the second plate is positioned in another quadrant. The connecting tube of the two plates can be positioned below or above the rectus muscle that separates the two quadrants

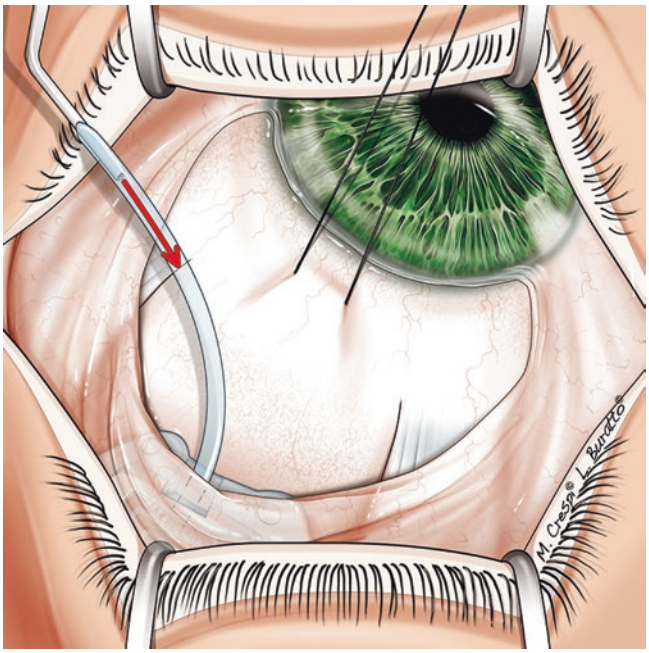

Fig. 5.11 Control of the patency of the tube of the valved shunts (priming). When valved shunts are inserted, prior to anchoring it on the sclera, it is advisable to irrigate the drainage tube (priming) using a syringe filled with BSS (Balanced Saline Solution) or sterile water with a 30G cannula; this can be used to control the correct movement of the internal valve (patency of the shunt); the valve can sometimes melt during the sterilization processes. The valve should not be touched with the forceps as it could be damaged producing a malfunction

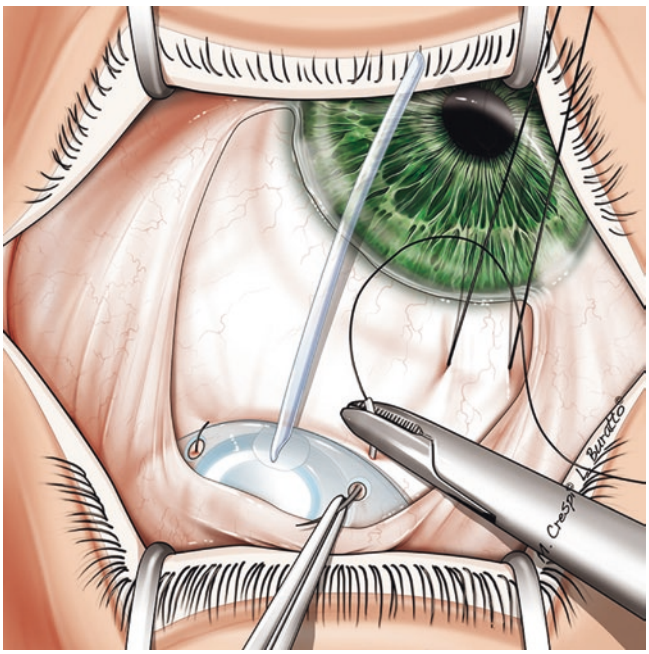

Fig. 5.12 Anchoring the shunt to the sclera. The plates of every type of shunt have small holes. Permanent/non-absorbable nylon 8.0, 9.0 or 10.0 sutures are passed through the holes and this consents firm anchoring to the sclera. As mentioned before, the surgeon should aim to anchor the anterior edge of the plate approximately 10 mm from the limbus. A spatulate needle is advisable as it reduces the risk of accidental scleral perforations. After passing the first suture, the surgeon must control that the GDD has been positioned correctly. Then, a second suture is passed through a second hole in the plate (there are normally two or three holes on each plate). It should be remembered that the knots must be recessed to avoid conjunctival erosion. It is also essential that the shunt is firmly anchored to the underlying sclera to prevent its postoperative migration in an anterior, posterior or lateral direction

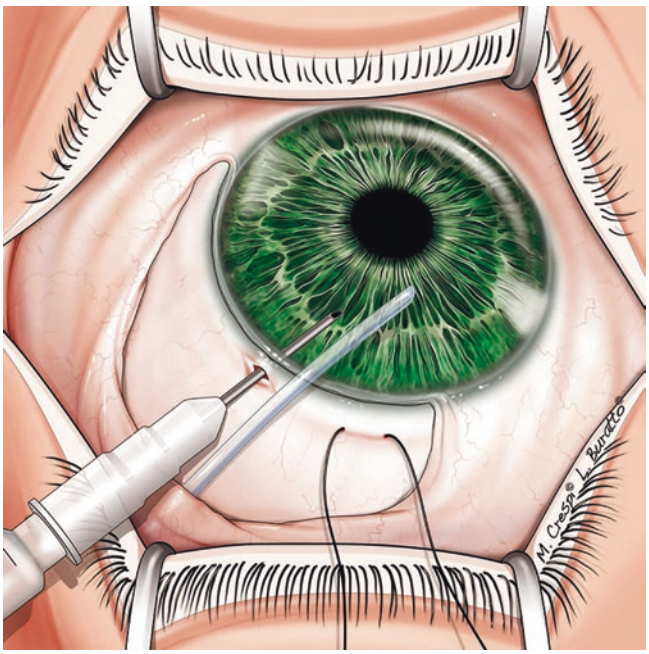

Fig. 5.13 Creation of a sclero-corneal opening. Now the surgeon makes a scleral incision, at about 1–1.5 mm from the limbus, with a 23G needle, that can be mounted on an insulin needle: the incision must be the right size to allow the insertion of the tube in the AC, it must be straight, positioned just above the iris and parallel to the iris itself. The needle is inserted immediately behind the limbus. It is important to stabilize the eye bulb with forceps when the surgical connection is being created and avoid lateral movements of the needle as this could induce hypotonia in the postoperative. Before the tube is insert in the AC, its distal portion must be cut with scissors to create a chamfered tip. It is extremely important to choose the incision site carefully: the tube must extend into the AC for approximately 2–3 mm, almost to the pupil margin. Its position should avoid the risk of any contact with the cornea or the iris, and the possible retraction that may cause the tube to exit the AC

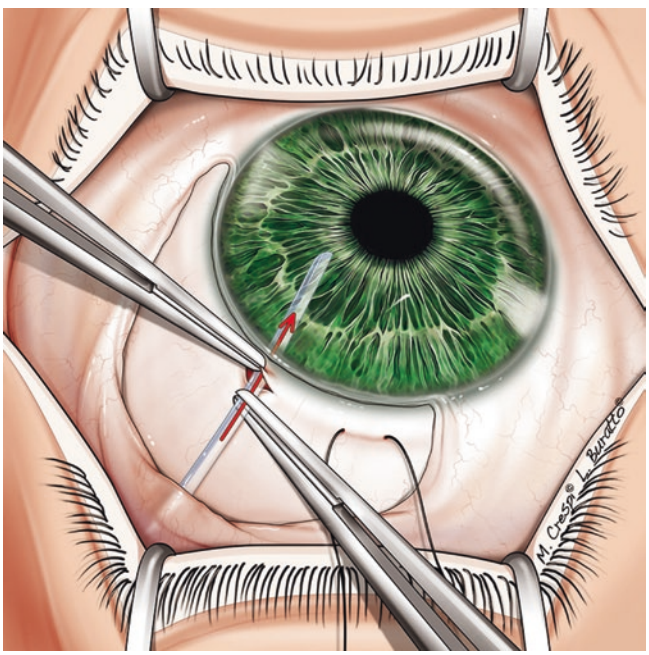

Fig. 5.14 Insertion of the chamfered tube in the AC. There will usually be no difficulty inserting a chamfered tube, with a 30°–45° bevel, into the AC. In order to facilitate the maneuver, the surgeon will normally use one or two toothless forceps

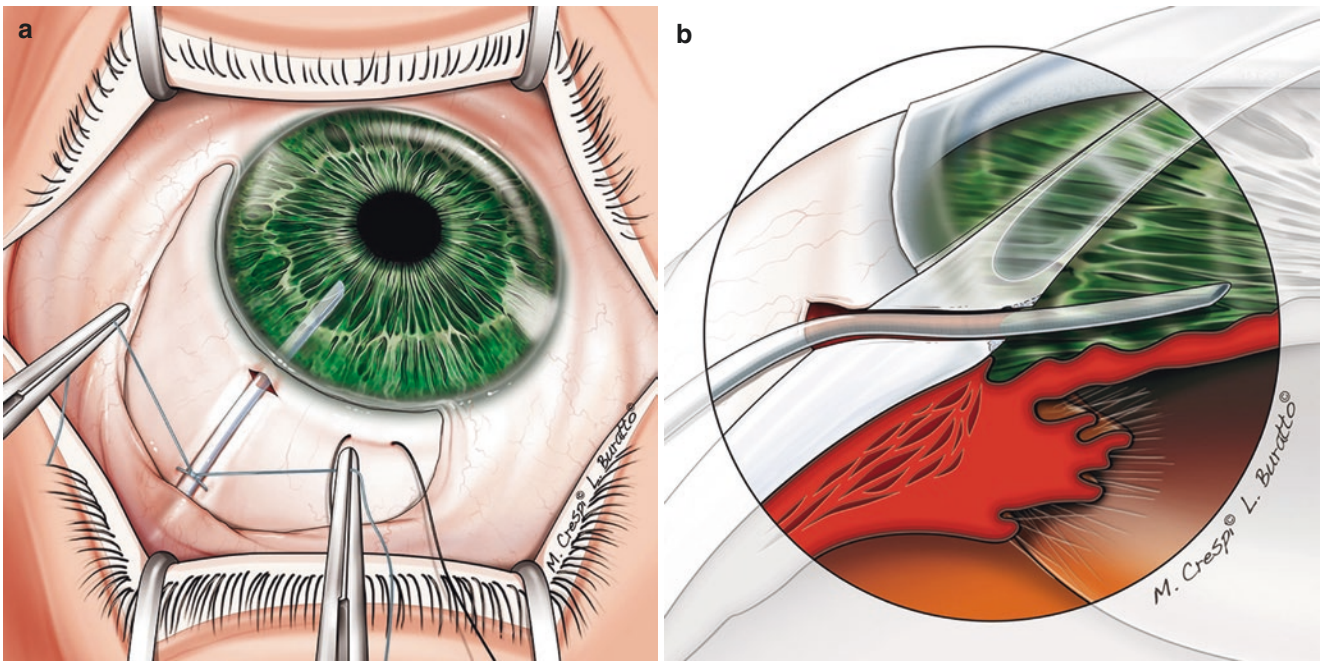

Fig. 5.15 (**a**–**b**) Correct positioning of the tube in the AC. Once the tube has been inserted, the surgeon must carefully control that it has been positioned correctly in the AC; contact with the cornea and the entrapment of the iris must be avoided. (**a**) Illustrates the correct position of the tube from above and (**b**) provides a side view of the tube in the correct position. The tube will now anchored to the sclera with a suture positioned just a few millimeters in front of the plate. The suture thread can be vicryl 8.0 or 10.0 (though some surgeons prefer nylon): the purpose of the suture is to stabilize the tube; it should not be excessively tight as this would obstruct the liquid flow in the valved shunts. If the tube is not positioned correctly, the surgeon should create a second paracentesis adjacent to the first and insert the tube through this second opening. The surgeon must pay attention to any leakage from the paracentesis: if leakage is observed, he must position a suture to maintain the intraoperative depth of the AC and reduce the dangerous risk of postoperative hyperfiltration and hypotonia

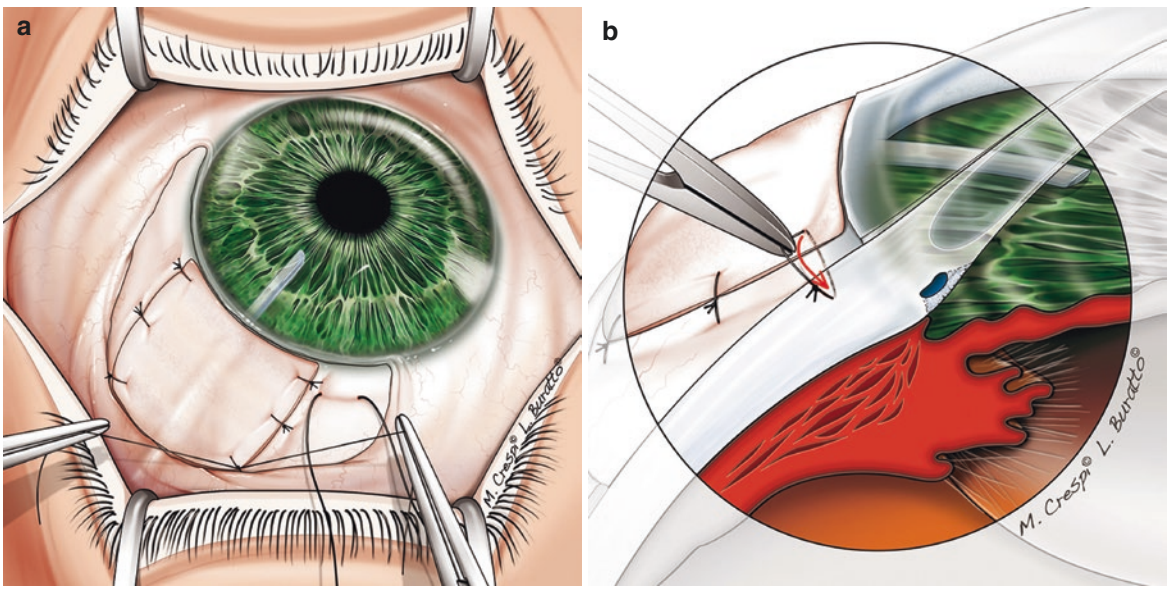

Fig. 5.16 (**a**–**b**) Covering the tube of the shunt. In recent years, many surgeons believe that the tube of the shunt must be covered with a patch or graft. This patch will reduce the incidence of conjunctival erosions, a dangerous and occasional occurrence. The patch is positioned to cover the extraocular portion of the tube of the shunt, from the plate to the insertion point in the AC. Single sutures in nylon 8.0 or 10.0 are used to anchor the patch to the bulb. Some surgeons prefer to use vicryl thread (see **a**). All sutures must be recessed in the scleral tissue to avoid late-onset erosion of the conjunctiva (see **b**). To avoid Dellen formation, the surgeon should thin the limbal edge of the patch prior to implanting it. Several materials can be used to cover the tube: scleral tissue, cornea, bovine pericardium, fascia lata and dura. However, the sclera and the cornea are the materials that are used more frequently and this can be sourced at the Eye Bank. Normally a patch measuring 6 × 6 mm or 4 × 6 mm will guarantee good cover. Some surgeons prefer corneal tissue (not suitable for keratoplasty) to the sclera. This is because the cornea is thinner than the sclera and will occupy a smaller volume. As an alternative, if the patch is not available, the surgeon can create a scleral flap that is not full depth: below this he can create the pass the tube with a 23G needle. The flap is then sutured with vicryl 10.0. However, this method would appear to be less secure than applying a patch

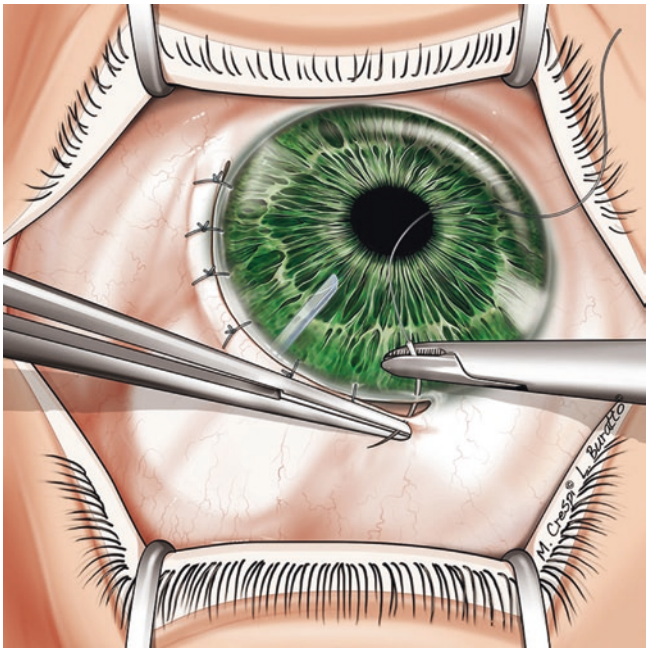

Fig. 5.17 Suture of the conjunctiva and the Tenon capsule. Final stages of the procedure. After having positioned the patch correctly above the tube of the shunt and sutured it, the surgeon must suture the conjunctiva and the Tenon capsule to cover everything completely. These two tissues must be stretched to cover the plate, the tube and the patch. An 8.0 vicryl suture—continuous or single—is normally used (as shown in figure). Everything the surgeon has done during the procedure should be controlled at the end of surgery: he should examine the position of the plate and the patch, and the correct position of the tube in the AC. Fluorescein drops or strips are useful when checking for leakage of the conjunctiva. Any continuous solutions of the conjunctiva must be closed and sutured with vicryl. Finally, a subconjunctival injection of an antibiotic-steroid combination is recommended

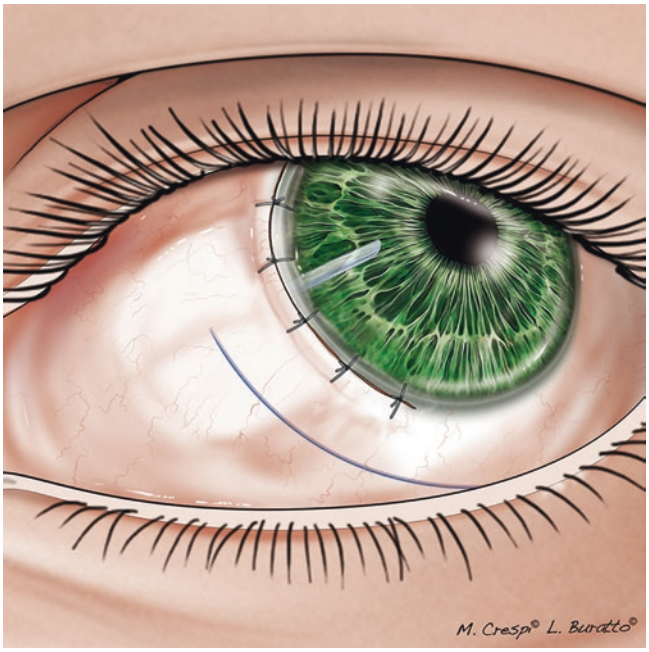

Fig. 5.18 Prolene stent in the infero-temporal quadrant of an eye with a non-valved implant Another system that reduces the flow of aqueous humor through non-valved implants is external occlusion of the tube (binding): this consists of a suture that is applied around the tube to reduce the size of the lumen. A non-resorbable 7.0 nylon suture with a slipknot or resorbable vicryl are usually used. Like the stent, the release or the resorption of the suture thread occur 4–6 weeks from surgery, the period necessary for the fibrous capsule to form around the implant. This technique is not particularly indicated for eyes affected by important preoperative hypertonia due to the long period required to normalize the IOP

ocular motility (see the paragraph on the complications below). With a silicone oil tamponade added to the eye, the implant is positioned in the temporal-inferior quadrant to prevent oil escaping; it is lighter than aqueous humor and will tend to rise.

Surgical Tips to Prevent Hypotonia with Non-valved Implants

When non-valved implants are used, two surgical maneuvers can be added to avoid hypotonia in the precocious post-operative period: both involve the use of suture thread that can be applied either inside or outside the tube of the implant.

The first of these additional maneuvers involves positioning an obstruction inside the tube (stent): it consists of a prolene or 3.0, 4.0 or 5.0 nylon thread, positioned inside the tube's lumen. This will reduce the patency and consequently decrease the drainage of the aqueous humor: the thread acts as a temporary valve. The piece of thread is approximately 15–20 mm long; it is inserted in the tube for 6–10 mm through an opening on the tube close to the plate. The free end of the prolene or nylon thread that exits the tube is positioned in the subconjunctival space of the quadrant adjacent to the implant, close to the limbus. Once the fibrous capsule has formed around the plate (4–6 weeks from surgery), the suture can be removed under the slit lamp and topical anesthesia. At this point, the aqueous humor can drain freely into the fibrous capsule around the plate, with the capsule providing resistance to the flow. However, even though this technique is efficacious for preventing precocious postoperative hypotonia, it may be necessary to remove the suture immediately in the event of precocious postoperative hypertonia caused by occlusion of the tube. So there is again a risk of hypotonia, a reduction in the depth of the AC and the associated complications.

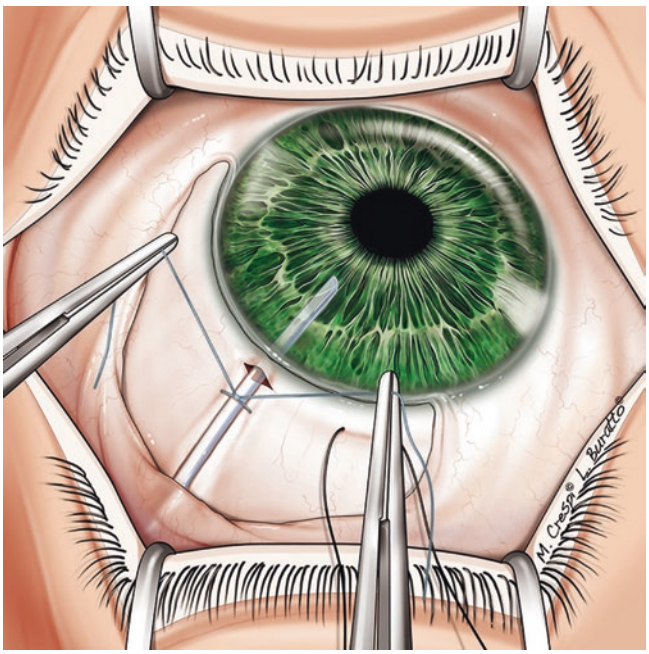

Fig. 5.19 External binding of the tube of the non-valved shunt with suture thread. Another system that reduces the flow of aqueous humor through non-valved implants is external occlusion of the tube (binding): this consists of a suture that is applied around the tube to reduce the size of the lumen. A non-resorbable 7.0 nylon suture with a slipknot or resorbable vicryl are usually used. Like the stent, the release or the resorption of the suture thread occur 4–6 weeks from surgery, the period necessary for the fibrous capsule to form around the implant. This technique is not particularly indicated for eyes affected by important preoperative hypertonia due to the long period required to normalize the IOP

Results

Most of the published studies report a mean percentage of success with the four types of implant of approximately 70% (range 50–80%), with an average postoperative reduction in the IOP of at least 50% over the preoperative values 2 years from surgery: the variation of the range depends on the type of glaucoma and the type of implant chosen. Unfortunately, failures account for 10% per year, with a consequent 50% function of the drainage implant after 5 years. One-year results of a comparative study for the Ahmed and Baerveldt implants did not clearly demonstrate any clear superiority of one over the other: even though the mean IOP was slightly higher in the eyes with the valved implant (Ahmed), this implant was associated with a lower incidence of precocious complications that are less severe than those observed with the Baerveldt implants. Recently an update with 5-year follow-up was published. It referred to an important study called 'Treatment Outcomes in the Tube Versus Trabeculectomy" (TVT). It reported that 5 years from surgery, IOP was a slightly greater (though not significant) when shunts were used compared to trabeculectomy: in the postoperative, both types of procedure are associated with a fairly similar reduction in the IOP and comparable use of a topical pressure-reducing therapy. GDDs have a greater success rate compared to the trabeculectomy procedure associated with MM-C: the cumulative probability of failure during 5 years of follow-up has been reported as 29.8% for the GDDs and 46.9% for the trabeculectomy. By the same measure, the percentage of repeating surgery is greater for trabeculectomy. These important findings have driven numerous surgeons to increase the number of implant procedures performed and to propose this surgery in cases of simple, not complicated, chronic glaucoma. Barton et al concluded their study by stating that the Ahmed valves would appear to improve the predictability of the precocious postoperative control, and that the Baerveldt valves have a lower percentage of late encapsulation. The authors believe that the main obstruction to the diffusion of these devices in uncomplicated cases of glaucoma is the lack of data available on the long-term effects on the endothelium, an issue that has not been fully clarified. In conclusion, GDDs would appear to be associated with an efficacy that is comparable, and sometimes superior, to the trabeculectomy in the management of complicated glaucoma. Given that, traditionally, these devices were suggested for refractory cases of glaucoma, they have always been associated with poor results. Their use should be reviewed—something that is already happening to some degree—in the primary surgical management of uncomplicated glaucoma (the more precocious cases), even taking in consideration the greater predictability compared to the trabeculectomy with MM-C, combined with a lower incidence of complications.

Complications

There are numerous possible complications associated with GDDs; the surgeon must necessarily construct a precise preoperative plan and have learned a meticulous technique (for all phases of the procedure) to achieve a valid result.

The complications are divided into:

- intraoperative
- precocious postoperative (within 3 months)
- late onset postoperative (after 3 months)

Intraoperative Complications

One complication is the formation of 'Button Holes' or lacerations in the conjunctiva. These are observed more frequently in patients who were previously subjected to surgery that involved manipulation of the conjunctiva. To suture the conjunctiva, many surgeons prefer to use a single filament of 9.0 vicryl because this thread has greater tensile strength and is equipped with an extremely fine needle that reduces the risk of button holes forming when used on a very thin conjunctiva. If

the surgeon notices a tear during the surgery, it must be repaired with a 10.0 vicryl suture positioned with a fine needle. If the rupture cannot be closed, it is essential that the surgeon controls that the patch covers the entrance of tube into the AC and that there is no leakage through the conjunctival hole. If leakage is absent, the conjunctiva will heal at a later stage (thanks to the vascularization of the patch below). However, if leakage is observed, the implant must be removed, the conjunctival suture must be tightly sutured and the tube must be positioned in another quadrant. Other intraoperative complications are associated with the tube: it may be too short (the surgeon's error), its position may be excessively anterior or posterior causing it to touch the ocular structures (corneal endothelium, iris, crystalline) and this may lead to bleeding the AC in the case of an implant in eyes affected by iris rubeosis. This complication is often linked to acute hypotonia that appears during the insertion of the tube; it can be avoided by injecting VES into the AC prior to the procedure or by applying a maintainer. Scleral perforation is a serious complication that is rarely described. It occurs when the surgeon anchors the shunt to the sclera. He must pay maximum attention when inserting an implant into eyes affected by buphthalmos and in patients with vascular collagenopathies that may be associated with localized or widespread thinned areas. If scleral perforation is observed, the surgeon had to do an *in situ* cryopexy, followed by an attentive vitreoretinal follow-up examination.

Precocious Post-operative Complications

The complications are similar to those observed with other techniques, namely hypothalamy, hypotonia and associated consequences such as choroidal effusion and choroidal haemorrhage. Hypotonia with hypothalamy is possibly the most frequently observed complication. Hypotonia and associated consequences are observed most frequently with the non-valved shunts. Precocious hypotonia is normally caused by leakage from the wound, inflammation, incomplete occlusion of the tube or excessively large drainage fissures with non-valved implants. With the valved implants, hypotonia is observed less frequently and can be related to hyperfiltration. There may be leakage around the tube if the pathway that communicates with the AC is created with an excessively large needle or if it is widened unintentionally when the surgeon withdraws the needle. Consequently, as mentioned previously, it is important that the surgeon stabilizes the bulb with forceps when he creates the pathway and that he avoids any lateral movement of the needle. Hypotonia is treated conservatively for as long as it is observed in the AC: it may actually resolve spontaneously after just a few days. However, if the AC is lost or is very flat after 7–10 days, and there is contact with the endothelium, the AC must be reformed with the introduction of air or preferably cohesive, low resting molecular weight VES under the slit lamp. It is introduced using the paracentesis created during the procedure. If choroidal effusion is observed, it is usually treated with systemic corticosteroids and cycloplegics. In the event these measures are not successful, surgical revision may be necessary, possibly with the removal of the implant and drainage of the choroidal effusion. Complications may also be linked to the presence of the tube, and these may also appear in the early postoperative period. The surgeon must take extra care to position the tube correctly in the AC: the tube must extend in the AC for approximately 2.5–3 mm. If the tube is excessively close to the cornea or if there is extensive contact, endothelial dysfunction may result: in this case, the tube must be repositioned. If there is contact with the peripheral cornea, the damage will usually be localized and the implant can be left in position. However, if the position of the tube is excessively posterior, it may touch the iris causing rubbing iritis, or if it touches the crystalline, a cataract might result. Iritis is a common occurrence. If it is mild, the tube can be left in position and the inflammation treated with low doses of topical steroids. In the event of severe iritis, the implant must be repositioned or replaced. The cause of the iritis may not always be identified; consequently, it must be treated like all iritis inflammations observed in glaucoma patients. The tube may occlude precociously due to the presence of blood, vitreous, fibrin exudate or iris entrapment with consequent ocular hypertonia: on occasion these can be treated with a delicate manual massage, with steroids, by washing with BSS or using the Nd:Yag; or it may be necessary to unblock the tube. Lastly, the tube may be withdrawn and moved in an anterior direction—this is indicated in children. Corneal edema (corneal swelling) may result from contact between the tube and the endothelium or persistent hypothalamy from hypotonia. The risk of this complication is reduced if valved implants and stents are used as the AC depth will be maintained more successfully. Even the implantation of the tube on Pars plana will reduce the risk of this complication. If there is evident and irreversible corneal swelling, the tube must be repositioned, possibly in another quadrant, preferably prior to starting the keratoplasty. The keratoplasty procedure may be performed when the tube is being repositioned; the surgeon has the option of performing a perforating keratoplasty or an endothelial keratoplasty. As the endothelial keratoplasty requires air to be present in the AC, it may prove to be difficult as the tube may allow the air to escape more rapidly. In the 1–6 weeks postoperative, there may be hypotonia, most frequently observed between weeks 4–7; the IOP range lies between 30–50 mmHg. This condition has been reported for all types of drainage and is more frequently observed with the valved implants. The tube is not occluded by blood, vitreous, fibrin or the iris; hypertonia would appear to be associated with a pluri-compartmentalized bleb (containing many septums); these reduce the permeability of the aqueous humor through the conjunctiva. This complication is frequently observed with the smaller valved implants (in terms of filtration area) with a polypropylene plate (as opposed to silicone). The therapy options in the hypertensive phases are: IOP-reducing

medical therapy, digital massage, needling of the bleb, with or without 5-fluorouracile and surgical excision of the bleb. Needling is performed under topical anesthesia at the slit lamp: it involves penetrating the conjunctiva with a 30G hypodermic needle 5–10 mm from the bleb and cutting the wall of the bleb with lateral movement. A small quantity (between ¼ and ½ cm^3) of aqueous humor is allowed to escape, but care must be taken to avoid losing the AC. This maneuver is considered successful when localized chemosis and a soft eye bulb are observed. The maneuver can be repeated once a week until the IOP has normalized. If these options are unsuccessful, the surgeon should consider the application of a new shunt or the cyclodestructive procedures. A malfunctioning valve, linked to the sterilization processes that may cause adhesion of the internal membranes, is a rare event. Nevertheless, prior to the definitive anchoring of the eye bulb, the surgeon should always check the patency of the tube with BSS. Sometimes hypoema may be observed in eyes with neovascular glaucoma; it is normally of minor importance and resolves spontaneously. This complication is extremely rare since anti-VEGF drugs have been used in the preoperative period.

Late-Onset Postoperative Complications

The most fearsome complication is the unsuccessful implant linked to fibrosis of the bleb. The Tenon capsule is the tissue responsible for the formation of the bleb. Several options have been proposed to prevent the onset of this phenomenon. Some authors inhibit the formation of fibrosis with a cocktail of Nsaids, colchicine and topical adrenalin associated with systemic steroids, in the postoperative (1–6 weeks from surgery) as suggested by Molteno. As the antimetabolites have no effect in preventing the formation of fibrin, their use is not recommended. In the event hypertonia from fibrosis is observed, needling or the implantation of a second GDD in another quadrant may prove useful. In recent years, some authors have suggested the implantation of a shunt above the Tenon capsule; the reason for this procedure is to exclude the Tenon capsule from the bleb formation process, given that it is considered to be the main protagonist in this process. The positioning of a second GDD above the Tenon has also been suggested to prevent fibrosis above the plate. Erosion of the capsular-conjunctival tissue above the tube is a frequent consequence of conjunctival melting and can be associated with the inadequate preparation of the patch, its incorrect positioning or it may be assisted by the blockage of the tube. To reduce the increase in volume associated with the patch that can lead conjunctival erosion, some surgeons use a half-depth cornea as opposed to sclera or full-depth cornea. This will expose the tube and the plate of the shunt and may also occur in the event of a perfect surgical outcome. Erosion will be more frequent when the flap has its hinge at the limbus, as the incision will lie closer to the plate of the implant. Sometimes the erosions can be associated with epithelial growth on the plate: this epithelial downgrowth can be extremely dangerous as it may prevent the scarring of the conjunctival wound. Exposure of the tube or the plate of the shunt are surgical emergencies that must be treated immediately to prevent endophthalmitis. If erosion is present, the bulb may become extremely hypotonic and consequently at a risk of endophthalmitis—a phenomenon observed more frequently in children. This tissue defect must be repaired by replacing the patch and bringing the conjunctiva forward. If this displacement of the conjunctiva is not sufficient, a conjunctival allograft removed from another quadrant may resolve the problem. And if the problem is still not solved with this procedure, the implant should be removed. A rare possible complication is the migration and the expulsion of the plate: this is associated with an excessively anterior position of the plate. If the patch is too thin or in an excessively anterior position, the bleb may protrude and this can lead to chronic Dellen or persistent ocular irritation. Strabismus may also appear. Changes in the equilibrium of the extrinsic muscles may lead to very serious diplopias; this is a frequent occurrence with implants in the inferior quadrants. It is also extremely frequent with the larger implants. This may limit the supero-version eye movements, given that the shunt is frequently implanted in the superior quadrants; however, there will also be limits to the infero-version eye movements with inferior implants. These are the more frequent cause of diplopia and is extremely uncomfortable for the patients. Diplopia is observed more frequently when larger implants are used (despite the fact that these can lead to a better outcome on the IOP). The onset of pseudo-Brown syndrome and hyperopia have also been observed. These disturbances of the eye movements may appear in both the early and late post-operative period; they may be caused by the volume of the plate, scar tissue below the rectus muscles, entrapment of the oblique muscle or fibrotic retraction of the orbit fat (caused by accidental manipulation of the orbit fat). Diplopia induced by GDDs is sometimes difficult to treat with either prisms or surgery and sometimes it cannot even be resolved by removing the shunt. A meta-analysis on shunts dating 2008 highlighted the most serious long-term complication is corneal endothelium deficiency. The most frequent complication is the erosion of the conjunctiva above the GDD. This study also reported a 10% annual failure rate that is similar to the value for trabeculectomy. The TVT study with 5-year follow-up reported that despite the large number of complications, the majority are transitory and resolved spontaneously. Moreover, with respect to the trabeculectomy with MM-C, there was a lower incidence of precocious complications. Both methods (GDD and trabeculectomy with MM-C) are associated with a similar incidence of late-onset complications, repeated surgical procedures because of complications and a need for cataract surgery, all reasons that have driven a significant increase in the use of these devices.

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Surgical Iridectomy

6

Luigi Caretti and Lucio Buratto

Introduction

The surgical iridectomy was introduced in the nineteenth century (1855–1860) by Albrecht Von Graefe, who treated open-angle glaucoma through a scleral incision with no conjunctival flap. At the time of writing, this procedure is no longer frequently used and is normally reserved for the treatment of closed angle glaucoma secondary to pupillary block. The procedure is designed to create communication between the anterior chamber (AC) and the posterior chamber (PC) to balance the pressure between the two chambers, reducing the risk of angle closed glaucoma (Fig. 6.1). In modern clinical practise, the laser iridotomy (with the Nd:YAG or Argon laser) is preferred over the surgical iridectomy for a number of reasons: the laser procedure is simple, rapid, with a high percentage of success and a low rate of complications. Moreover, the patient does not need to enter an operating room, something that will pleases both him and the surgeon. Even though it has been replaced by the laser iridotomy to a large degree, the surgical iridectomy may still be the elective choice in some clinical situations such as:

- Corneal opacity that reduces the vision in the AC
- Non-compliant patients that are unsuitable for a laser procedure (due to decubitus or dementia)
- occlusion resulting from laser iridotomy performed to treat inflammatory membranes
- the laser machine is not available (for example, in the developing countries)

Moreover, the surgical iridectomy is performed during other procedures, such as:

- trabeculectomy (to avoid the iris occluding the fistula)
- implantation of phakic IOLs or IOLs for the AC (to avoid pupillary block by air; however, many authors consider the iridectomy to be useless in these cases)
- intracapsular extraction of the cataract (to avoid pupillary block by the vitreous)
- vitrectomy with silicone oil tamponade in aphakic patients

Finally, the iridectomy is also performed in some rare situations such as:

- incisional or excisional surgical biopsy of lesions of the iris or the ciliary body
- creation of an iridectomy for optical purposes in patients with clinically significant corneal opacity

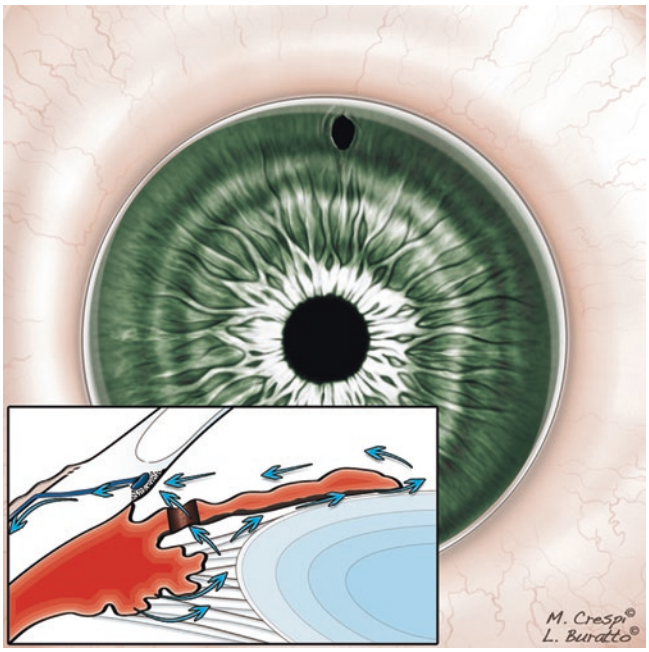

Fig. 6.1 Mechanism of Action of the iridectomy. The iridectomy is visible in the superior portion of the peripheral iris. The new pathway for the aqueous humor through the iris fissure can be seen in the lower left section (*blue arrows*)

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Surgical Technique

One hour before starting the iridectomy, the surgeon should instil 2% pilocarpine eyedrops three times at 5-min intervals: the cholinergic action of the drug produces miosis, distending the iris and facilitating the peripheral iridectomy procedure. A subconjunctival injection of 1% lidocaine usually provides sufficient anesthesia. 0.2–0.4 ml of anesthetic is injected under the conjunctiva using a 30G needle in the site selected for the conjunctival incision. Many surgeons, ourselves included, prefer a simple topical anesthesia. A number of different approaches are possible: some surgeons prefer the limbal approach, others opt for an approach in clear cornea, while another group prefers to create a sclera-corneal tunnel. The most popular approach is an incision in pure cornea that will leave the conjunctiva intact (Fig. 6.2).

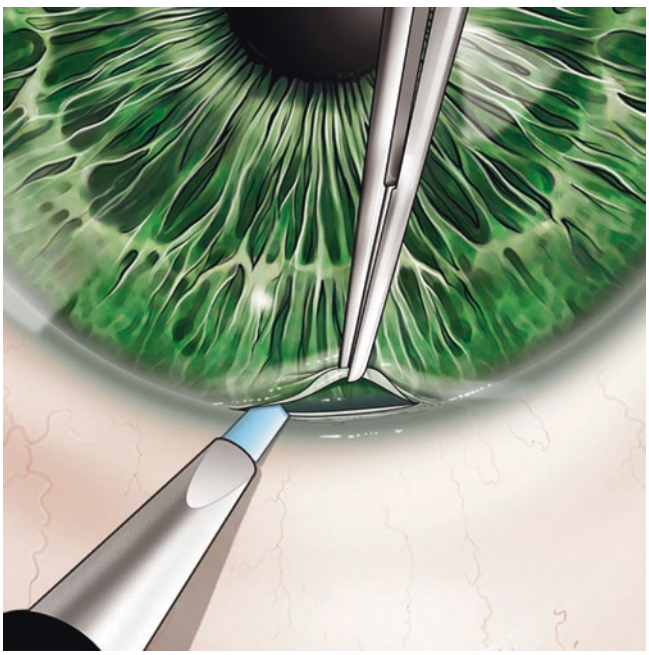

Fig. 6.2 Construction of the corneal incision during the iridectomy. The incision is created just in front of the limbus (0.5–1 mm) at the anterior edge of the limbal vessels. It is created with a 15° knife and must be 3 mm long. It is recommended to initially extend the incision to the Descemet membrane and then penetrate the AC for the 3 mm of the incision, slightly detaching the corneal tissue upwards with toothed forceps. With the approach in clear cornea, the surgeon must enter the AC perpendicular to the cornea to allow access to the root of the iris; nevertheless, the basal iridectomy can sometimes prove difficult in technical terms. Prior to the iridectomy procedure, the surgeon can opt to inject 0.5–2 ml of acetylcholine hydrochloride into the AC. This will assist the contraction of the iris sphincter and stimulate miosis. The injection can be performed through this or a second incision created in the temporal sector of clear cornea (paracentesis). Some authors recommend an additional injection of 1% lidocaine anesthetic in the AC with a 30G cannula. The iridectomy can now be performed (Fig. 6.3)

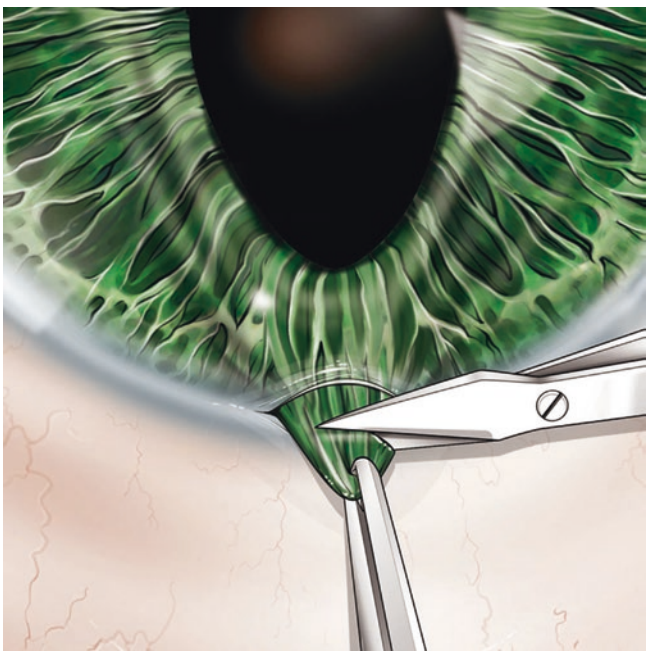

Fig. 6.3 Basal Iridectomy. In the basal iridectomy procedure, the iris is caught and carried outside of the AC through the scleral opening, with dedicated toothed forceps with fine arms (iris forceps) or with Colibrí forceps. Sometimes, once the AC has been opened, the iris will tend to prolapse spontaneously through the incision. The iris is cut peripherally, in parallel to the limbus, using Vannas or DeWecker scissors. The surgeon must pay attention to the position of the stroma and the pigmented layers of the iris when he is creating the full-depth iridectomy. Ideally, the peripheral iridectomy should lie between the external third and the middle third of the iris: the surgeon must avoid cutting the larger iris vessels in this area. During the iridectomy, it is essential that the surgeon checks the position of the pupil to avoid an excision that lies excessively close to the pupil. The surgeon must not remove tissue that is excessively posterior: this should prevent rupture of the base of the iris, creation of an iridodialysis, damage to the ciliary body or intraocular bleeding

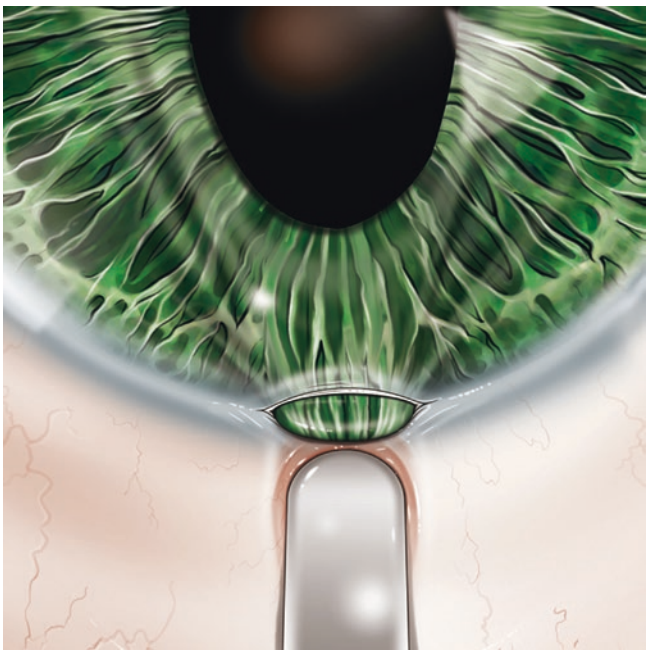

Fig. 6.4 Manoeuvre that facilitates iris prolapse prior to the iridectomy Prior to performing the iridectomy, some surgeons recommend delicately prolapsing the iris through the incision, exerting slight pressure on the posterior lip of the incision with a blunt instrument. Once the iridectomy has been completed, in most cases, the iris will spontaneously tend to return into the AC through the incision and the peripheral iridectomy can be visualized through the cornea. In the event the iris remains trapped in the incision, the problem will be often be resolved by applying light pressure on the scleral side of the incision with an iris spatula. If this maneuver is unsuccessful, the iris can be repositioned in the AC by delicately touching the cornea with a blunt instrument (for example, an iris spatula or a muscle hook), smoothing the tissue with a centrifugal movement from the center of the cornea to the limbus. In the event of further failure, injecting BSS in the direction of the incision should return the iris to its rightful position. Generally-speaking, the AC is not lost during this procedure and consequently, does not need to be reformed. Once the surgeon has repositioned the iris in the AC, he must check that the iris is circular and that the iridectomy has included the pigmented layer: he must identify the red reflex through the iris fistula with back lighting, using the co-axial light of the operating microscope or by directly observing the presence of pigment on the piece of tissue removed. Some authors have suggested an iridectomy with a vitrectome as an alternative to the traditional procedure we described above. The final phase of the procedure involves placement of the sutures. As the incision in clear cornea is not a tunnel, the closure of the incision will be a more critical phase and will often require a suture in 10.0 nylon to seal the incision and prevent leakage. One or two suture points are passed full-depth at the center of the cornea. These will be tightened to ensure the correct positioning of the incision edges, without pulling excessively on the tissues. The sutures are then recessed in the tissue. The advantage of the approach in clear cornea is that the cornea itself is not manipulated, an extremely important factor in view of a potential filtering procedure at some stage in the future. Variations of this technique include the creation of an incision; as mentioned previously, some authors prefer a limbal approach, others prefer the approach in clear cornea and others prefer the sclera-corneal tunnel. Charleux described a variation of the corneal approach: the incision is created in a slightly anterior position with respect to the limbus, though at a different angle. The cut is described as "inverted" because the blade resting on the peripheral cornea is tilted in an antero-posterior direction to direct the lip towards the irido-corneal angle, and creates a chamfered connection. The iris is caught with forceps and, given the orientation of the cut, the surgeon will be certain he is correctly performing the basal iridectomy. Moreover, it will not be necessary to close this cut with a suture as it is valved and self-sealing

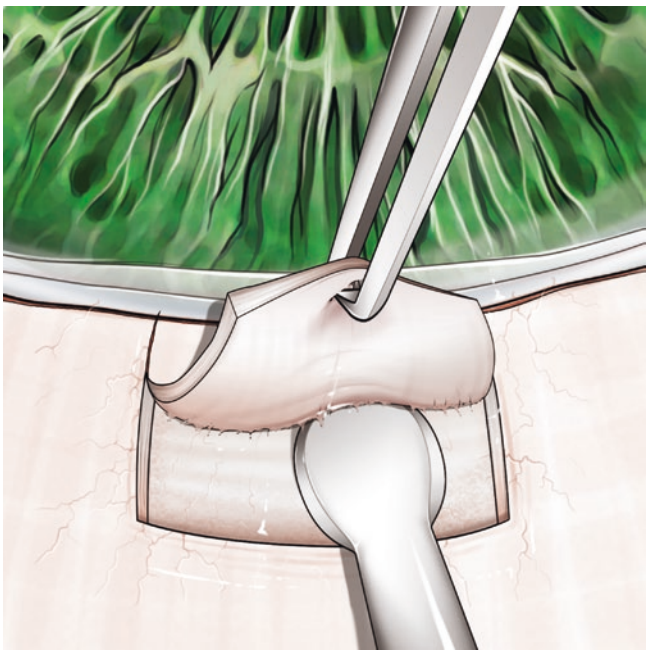

Fig. 6.5 Creation of the Sclero-Corneal tunnel. Chandler proposed a sclero-corneal approach; the procedure begins with a superior conjunctival peritomy, approximately 3 mm wide. This cut is performed with blunt Westcott scissors. A fornix based flap is created. If there is bleeding, hemostasis will be activated that will be more effective if the operating field is slightly moist. The surgeon will then proceed to carve the sclero-corneal tunnel (Fig.6.5). The surgeon initially creates a scleral incision, of depth approximately 350 μm and length 2 mm, positioned posterior and tangential to the limbus. It is important that the incision is not cut in an excessively posterior position; it should not be positioned more than 1.5 mm from the limbus to avoid cutting the ciliary body instead of the iris. During this maneuver, the bulb should be stabilized with toothed 0.12 mm forceps (Colibrí forceps, for example) held in the non-dominant hand. Then the surgeon creates the tunnel just beyond the limbal vessels using trapezoidal blades or a crescent knife. At this point he enters the AC with a 15° blade: the opening is created in the most distal portion of the tri-planar sclero-corneal tunnel. It must be fairly vertical so that the entrance angle will consent relatively easy access to the root of the iris. The scleral incision is closed with 2 suture points in 10.0 nylon using a spatulate needle; these are placed at the corners of the scleral flap. The sutures are then recessed in the tissue. Finally the conjunctiva is sutured with 8.0/9.0 vicryl

Position of the Iridectomy

The position of the iridectomy is determined by the clinical conditions. The preferential site is above the 12 o'clock position; at the end of the procedure, the iridectomy will be covered by the upper eyelid and this will reduce the incidence of visual disturbances. The iridectomy should be sized so that it will be completely covered by the upper eyelid. In theory, the iris fistula should measure at least 150–200 μm to prevent closure of the camerular angle. These dimensions are easily obtained with a surgical iridectomy. Partially-exposed iridectomies can cause visual disturbances such as monocular diplopia, half-moon vision, shadows or ghost images. At the end of the vitrectomy procedure in aphakic patients that involved the use of silicone oil, an inferior iridectomy at 6

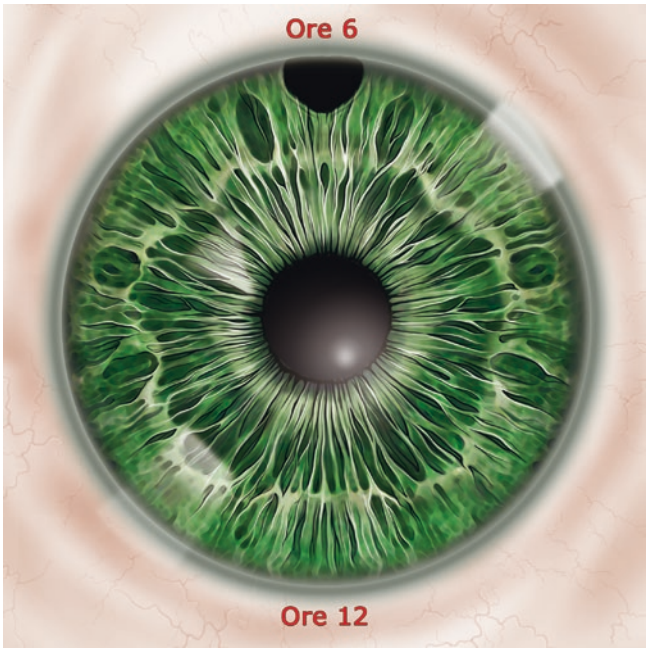

Fig. 6.6 Aphakic bulb subjected to vitrectomy with silicone oil and an Ando iridectomy. Silicone oil floating on the aqueous humor can potentially occlude the superior iridectomy. As an inferior iridectomy allows the passage of the aqueous humor between the AC and the PC, this type of occlusion will be avoided. A basal iridectomy at 12 o'clock is indicated when heavy silicone oil is used in aphakic patients

o'clock will be necessary to prevent pupillary block caused by the oil (Ando iridectomy) (Fig. 6.6).

Results

The iridectomy is an extremely successful procedure in the vast majority of cases and more importantly, it is extremely safe. Normally, one iridectomy procedure will resolve the clinical problem; however, in chronic cases of closed angle glaucoma, two iridectomies may be required—one in each of the superior quadrants, as this arrangement will facilitate better drainage of the aqueous humor and open the angle more than a single iridectomy. The rare cases of ocular hypertension observed after the peripheral iridectomy may be due to either a chronic closure of the angle or a primary or secondary open-angle mechanism.

Complications

Complications are rare. However, the iridectomy may be incomplete—with only the anterior layers of the iris tissue removed and not the posterior pigmented layer. An incomplete iridectomy is the most frequent complication; this may lead to the occlusion of the sclerotomy and an increase in the IOP. As recommended previously, the surgeon should always control the patency of the iridectomy during the procedure and check for the red reflex through the iridectomy, or examine for pigment present in the piece of tissue removed. If the posterior pigmented layer persists in the postoperative period, the fistula can be completed using an Argon or Nd:YAG laser. Hypothalamy (reduced or loss of AC) due to leakage is another complication that may be observed in the post-operative period. The wound must always be checked for leakage at the end of surgery using the Seidel test, involving a fluorescein strip. A meticulous surgical technique will contribute to preventing leakage of the wound and the formation of a conjunctival bleb. Leakage from the wound is associated with relaxed sutures. It follows that leakage will be observed more frequently when sutures are not applied. Leakage can be managed with drug treatment: eyedrops that inhibit the production of aqueous humor, in association with cycloplegics and antibiotics; these must be prescribed immediately. The AC must be reformed within a short period of time. Moreover, a watertight re-attachment of the conjunctiva to the limbus can be facilitated by using a contact lens or a patch to eliminate the leakage. If the leakage persists, surgical repair may be necessary; the surgeon must always check that the wound is fully sealed and watertight. In the case of hypothalamy, measurement of the IOP is extremely important for management of the cornea. If the AC is flat and the IOP is low, the surgeon may observe a conjunctival bleb with hyperfiltration or leakage from the wound. Moreover, choroidal effusion may also be associated. If the AC is flat and the IOP is high, differential diagnosis between choroidal hemorrhage and aqueous misdirection with malignant glaucoma should be taken into consideration. In these cases, the iridectomy is patent and there will be no leakage from the wound. On occasion, choroidal effusion, choroidal hemorrhage and aqueous misdirection will not be resolved with local or systemic medical therapy; vitreo-retinal surgery will therefore be necessary. Another possible late-onset complication of the iridectomy is the appearance of a cataract: this may be associated with unexpected trauma to the crystalline or rupture of the capsule. 'Wait and see' observation may be sufficient unless there is significant inflammation or a reduction in visual acuity, situations that will necessitate surgical intervention. Hypoema appears when the iris vessels or the ciliary body are cut. Cauterization may reduce the bleeding, though it is not always essential. If required during surgery, the AC can be washed with BSS, and high molecular weight VES can be used to stop the bleeding. Nevertheless, hypoema will usually be minimal and will resolve spontaneously. However, if the bleeding originates from a lesion of the ciliary body (in the event of the sclero-corneal access or incisions that are excessively posterior), it will usually be abundant and may extend into the AC and the vitreal chamber. Finally, complications such as malignant glaucoma, the various forms of iritis and endophthalmitis are extremely rare.

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Pediatric Glaucoma

7

Luigi Caretti and Lucio Buratto

Introduction

Traditional surgical approaches to glaucoma in pediatric patients are substantially angle-based procedures: trabeculotomy and goniotomy. These two surgical procedures are performed to facilitate the outflow of aqueous humor from the eye bulb, thanks to the creation of openings in the altered trabeculate of these patients. These apertures create an easy outflow pathway between the anterior chamber (AC) and the Schlemm Canal as opposed to an alternative discharge pathway, as is the case in the trabeculectomy or when draining implants are used. Angle surgery is generally performed under general anesthesia, in consideration of the young age of these patients.

Trabeculotomy

Introduction

The trabeculotomy is the progenitor of the non-penetrating antiglaucoma surgical techniques; it was originally developed in the early Sixties. As mentioned previously, the mechanism of action involves the creation of direct communication between the anterior chamber (AC) and the Schlemm Canal, by-passing the main obstacle to the filtration of aqueous humor, namely the trabeculate. This procedure is similar to goniotomy; the two techniques differ in terms of the access to the Schlemm Canal, *ab externo* for the trabeculotomy and ab interno for the goniotomy. At the time of writing, the use of this technique is not widespread, with the exception of cases of congenital glaucoma, for which it is considered to be an alternative to goniotomy (another angular surgery technique): it can be considered when the cornea is not sufficiently clear to allow visualization of the angle structures to performe goniotomy or when a repeat goniotomy has not normalized the intraocular pressure (IOP). It is also possible to perform the trabeculotomy procedure in combination with phacoemulsification.

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Surgical Technique

The first step of the operation consists of the correct operating field exposure that will facilitate the surgeon's access to the delicate ocular structures he will be manipulating. Positioning a traction suture, normally in 4.0 silk, on the rectus muscle may prove extremely useful. At this point the surgeon continues with a conjunctival peritomy and the preparation of the scleral bed. The conjunctiva and the Tenon Capsule can be opened with a flap, preferably limbus based or alternately with a hinge at the fornix, depending on the surgeon's preference. The peritomy is usually 3 h wide. It is normally performed with Westcott scissors and fine-toothed forceps. The temporal approach is often preferred to avoid interference from the nose and particularly to preserve the conjunctiva in the superior sector for a possible future filtering surgery procedure. The surgeon prepares a scleral flap measuring approximately 4 × 4 mm at 2/3rds of the scleral thickness; the flap can also be triangular or trapezoidal. The dissection is extended forward to include the blue-gray area corresponding to the surgical limbus (between the cornea and the sclera), with the Schlemm Canal normally found at the posterior edge. Mild cauterization may be necessary to achieve hemostasis. The surgeon now proceeds with the subsequent phases of surgery, in particular, identification of the Schlemm Canal.

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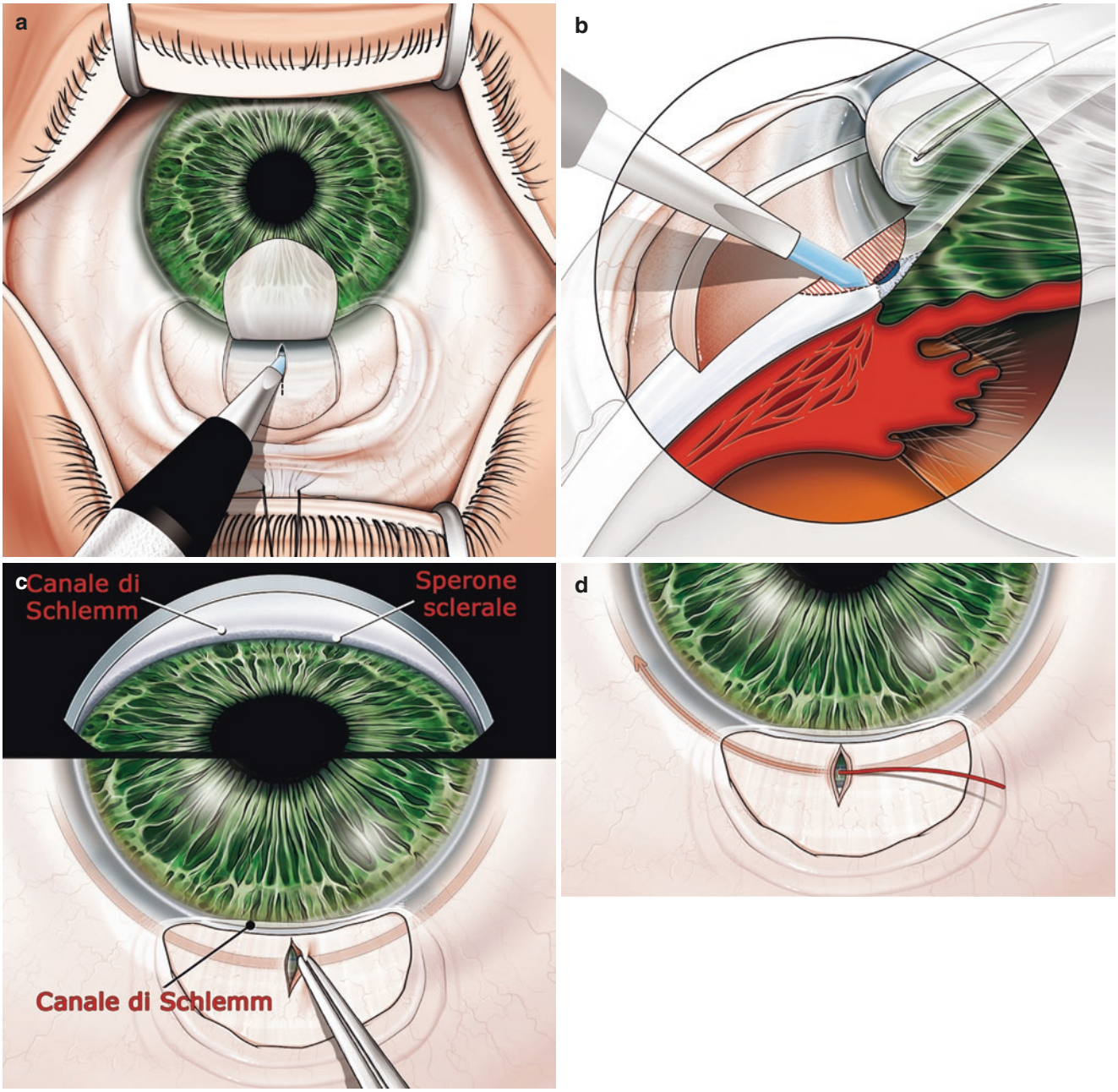
a
b
c
Canale di Schlemm
Sperone sclerale
Canale di Schlemm
d

Fig. 7.1 Creation of the radial incision of the limbus for the identification of the Schlemm Canal.
(**a**) Surgeon's view. On the bed of the scleral pouch, the surgeon creates a radial incision approximately 1 mm long with 15° blades, in correspondence with the surgical flap. In this phase, it is advisable to use strong magnification to view the details. The anterior edge of the area to be cut must correspond to the anterior projection of the Schwalbe line; the posterior margin must correspond to the scleral spur. The trabeculate and the attached Schlemm canal can be identified between these two lines.
(**b**) Side view. The initial incision is gradually and progressively deepened until the Schlemm Canal can be observed in a slightly anterior position to circumferential fibers of the scleral spur (barely posterior to the gray limbal zone). The incision is deepened delicately until the Schlemm Canal can be identified: opening the roof of the canal is generally accompanied by the escape of a small quantity of blood or a drop of aqueous humor (due to the pre-set pressure gradient), often a *pink color* thanks to the blood present.
The goal is to open the external wall of the canal without perforating the internal wall, thus avoiding penetration of the AC: the surgeon visualizes the internal wall of the canal that will appear to be slightly pigmented. If a large amount of liquid escapes after the surgeon has created the incision, he may have inadvertently penetrated the AC. If this is the case, the incision must be sutured quickly and another incision must be created just posterior to the first.
(**c**) Surgeon's view and gonioscopic view during the identification of the Schlemm Canal. In the lower part of the figure (viewed from above), the conjunctival peritomy, the small radial incision of the sclera that extends posteriorly from the limbus and the Schlemm Canal are observed. The scleral flap is not visible in the drawing.
In the upper portion of the figure (gonioscopic vision), the pigmented layer (Schlemm Canal) and the scleral spur (a *whitish color*) can be observed
(**d**) Control of the correct identification of the Schlemm Canal. The correct position and the patency of the Schlemm Canal can be controlled using a small length of prolene or 6.0 nylon suture thread (diagnostic incannulation of the canal): the thread should easily slide into the canal or present only minimal resistance, through the left and through the right sides of the radial incision. If there is considerable resistance to the pass of the thread, the surgeon must suspect that he has penetrated the wrong area, such as the suprachoroidal space; in these cases, the incision can be deepened or a second radial incision can be created parallel to the first to allow correct identification of the Schlemm Canal.
At this point, many authors suggest creating a paracentesis to allow reformation of the AC using VES if necessary. Alternately, the paracentesis should be created immediately after the scleral flap. The surgeon then proceeds with the trabeculotomy

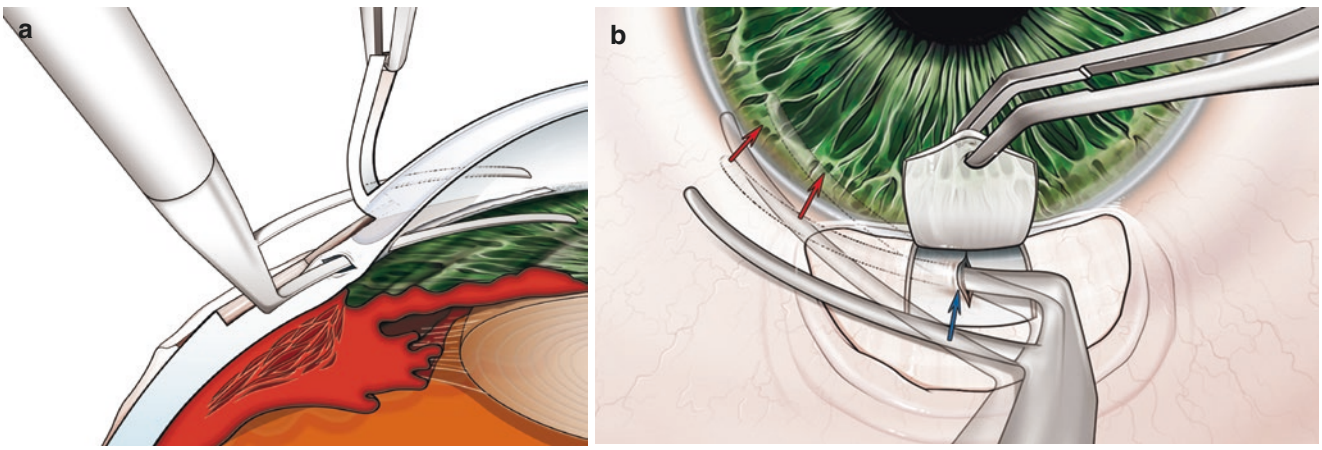

Fig. 7.2 Trabeculotomy procedure.
(**a**) Lateral vision. To facilitate the successive introduction of the trabeculotome once the Schlemm Canal has been identified, some authors suggest the creation of an incision parallel to the limbus, introducing the inferior arm of Vannas scissors into the canal. A special probe, such as Harms or a Mc Pherson trabeculotome, is delicately inserted into the end of the Schlemm Canal, and pushed as far as possible. Two curved arms, parallel to each other, extend from the handle; the lower arm is inserted into the canal, the upper arm serves as a guide and allows indirect visualization of the position of the arm inside the Canal; the wall of the trabeculate is cut (**a**). In this phase, the surgeon holds the trabeculotome in one hand and delicate toothed forceps in the other to lift the scleral flap. Right and left trabeculotomes are available.
(**b**) View from above. At this point, the surgeon rotates the two arms of the trabeculotome towards the middle of the AC (**b**, see *red arrows*), until ¾ of the two arms of the trabeculotome can be seen inside the AC: this maneuver opens the trabeculate. In this phase, the surgeon must take care not to damage the iris or the cornea. Leaving the distal tip of the trabeculotome facing the middle of the AC, the surgeon withdraws the instrument from the Schlemm Canal, opening the trabeculate as far as the point of insertion.
The trabeculectomy must extend left and right for a total angle of approximately 120°: consequently, after having extended the trabeculate incision for 60° in one direction, the surgeon then extends the cut for 60° in the opposite direction, introducing the trabeculotome on the side opposite the incision of the canal.
The trabeculotomy must not involve the point at which the scleral floor has been cut: in this position the internal wall of the Schlemm Canal must be preserved (**b**, *blue arrow*), otherwise the procedure is transformed into a perforating procedure and a basal iridectomy will be necessary to prevent the prolapse of the iris.
Following the trabeculotomy, there may be a reduction in the AC depth or hypoema (blood reflux) may be observed. Occasionally, between the first and the second trabeculotomy, it may be necessary to introduce cohesive VES through a paracentesis to reposition the iris in a posterior position and deepen the AC that may collapse when perforated due to low scleral rigidity

Suturing the Flap and the Conjunctiva

Trabeculotomy is not associated with outflow of the aqueous into the sub-Tenon space and consequently a suture is required to close the scleral flap. Five-six single sutures in 10.0 nylon are normally sufficient. The conjunctiva and the Tenon capsule are closed with the procedure used for visco-canalostomy (see Chap. 4).

Phacoemulsification

The trabeculotomy procedure con be successfully combinated with phacoemulsification. There are different options for the construction of the access tunnel to the AC: with one or two scleral flaps.

There are no significant differences with respect to visco-canalostomy, deep sclerectomy and canaloplasty (see Chap. 4) regarding the successive phases of phacoemulsification.

Results

Numerous studies have demonstrated that, by reducing resistance to aqueous outflow, the trabeculotomy leads to a decrease in the IOP with good results in cases of congenital glaucoma, open- or closed-angle primary glaucoma and particularly in pseudo-exfoliative glaucoma.

In congenital glaucoma, the results of the trabeculotomy procedure are linked to the eziology of the glaucoma. As for goniotomy, trabeculotomy will also lead to excellent results (success in 80–90% of cases), in cases of congenital glaucoma with good prognosis, for example, glaucomas that appear in the period immediately after birth and within the first year of life.

The advantage of this procedure is that it does not require the formation of a filtering bleb and consequently, it is not associated with long-term risks associated with the presence of this bleb.

In terms of disadvantages, it should be pointed out that goniotomy does not lead to the formation of a conjunctival scar typical of trabeculotomy. This would have serious consequences for a child affected by glaucoma: during the patient's life if filter surgery is necessary, a scar created by the previous trabeculotomy will reduce the percentage success of the procedure (even when antimetabolites are used).

The general opinion is that the tonometric reduction achievable with the trabeculotomy is lower than that achievable with the trabeculectomy procedure; consequently, even in the event of combined surgery, it is advisable to opt for the trabeculotomy procedure only in those eyes affected by mild glaucoma or simply with raised IOP, without advanced peripheral damage, in which case a phaco-trabeculectomy is advisable.

Complications

These are divided into intra-operative and post-operative.

Intraoperative

Errors may occur during the preparation of the conjunctival-capsular and the scleral flaps. They include lacerations of the conjunctiva or a flap that is excessively superficial (or deep), a common occurrence with other anti-glaucoma techniques. In these cases, the tissues should be carefully sutured and the position of the incision should be changed.

It is also possible that false pathways have been created in the AC or in the supra-choroidal space. There are also some complications typical of the trabeculotomy, such as the detachment of the Descemet, caused by the movement of the trabeculotome when it is rotated towards the AC with the tip pointing towards the corneal endothelium.

Another possible error caused by the trabeculotome is the creation of cyclo-dialysis. The resulting drop in IOP may necessitate further surgical treatment.

Frequently (in up to 84% of cases according to Tanihara), the laceration of the trabeculate is accompanied by modest hypoema: during the procedure, this can be controlled by injecting low resting molecular weight cohesive viscoelastic into the AC; the clot will normally reabsorb within a few days.

Damage to the crystalline or the iris is possible but rare.

Postoperative

The most common postoperative complications are:

1. Residual hypotonia
2. Anterior peripheral synechias that can reduce or eliminate the success of the procedure
3. Formation of a conjunctival bleb, that can lead to hypotonia. This necessitates a revision of the wound and a new suture of the scleral flap.

In other words, trabeculotomy is characterized by a lower incidence of postoperative complications (particularly those correlated to hypotonia) than trabeculectomy.

Goniotomy

Introduction

As mentioned previously, goniotomy creates a direct communication between the AC and the Schlemm Canal, bypassing the main barrier to the outflow of the aqueous humor,

namely the trabeculate. The access to the Schlemm Canal occurs in the AC as opposed to *ab externo* approach. Goniotomy is the elective procedure for the treatment of the majority of primary infantile congenital glaucomas; some authors perform this technique in some primary glaucomas during puberty and some secondary glaucomas (with a lower percentage of success compared to the pediatric forms). In actual fact, angle surgery is not indicated for all pediatric glaucomas. It is a relatively short procedure and preserves the conjunctiva, important if filtering procedures are necessary in the future.

Preparation for Surgery

In the preparatory phases for goniotomy, it may prove useful to administer oral acetazolamide (10–15 mg/kg/day) to reduce the preoperative IOL and help reduce any corneal edema that may be present.

Pressure-reducing topical eyedrops are useful in the preoperative period. 1–2% pilocarpine eyedrops are recommended just prior to surgery to protect the crystalline during the procedure.

Surgical Technique

For this type of surgery, the surgeon sits in a specific position. He sits opposite the portion of the angle he wishes to operate; the patient's head is rotated slightly to the side opposite the surgeon. The operating microscope is tilted 30°–45° to allow optimal visualization of the angle. Usually, the first goniotomy procedure is performed in the nasal sector with the surgeon positioned on the temporal side. The correct position is crucial for the success of surgery. Sometimes, the first maneuver of the procedure is the removal of the edematous corneal epithelium, using 70% isopropyl alcohol and a spatula (or the edge of a blade): in the majority of cases, this will greatly improve visualization. If the edema persists even after the epithelium has been removed (edema of the corneal stroma), a trabeculotomy is indicated to avoid possible damage to the cornea, the crystalline or the iris. Glycerine is only marginally useful in these cases. If necessary, the surgeon's assistant can stabilize the eye bulb using two forceps (Moody or Elschnig-O'Connor forceps, Katena Eye Instruments), that engage the insertion of the superior or inferior rectus muscles, when a temporal or nasal goniotomy is performed. Alternately, two traction sutures in 6.0 silk can be applied in the paralimbal area. At this point, the surgeon positions a goniolens on the cornea (for example, a Barkan lens, a Swan-Jacob lens, a Lister lens), following addition of VES to the cornea. He then proceeds with the preliminary maneuvers prior to performing the goniotomy procedure.

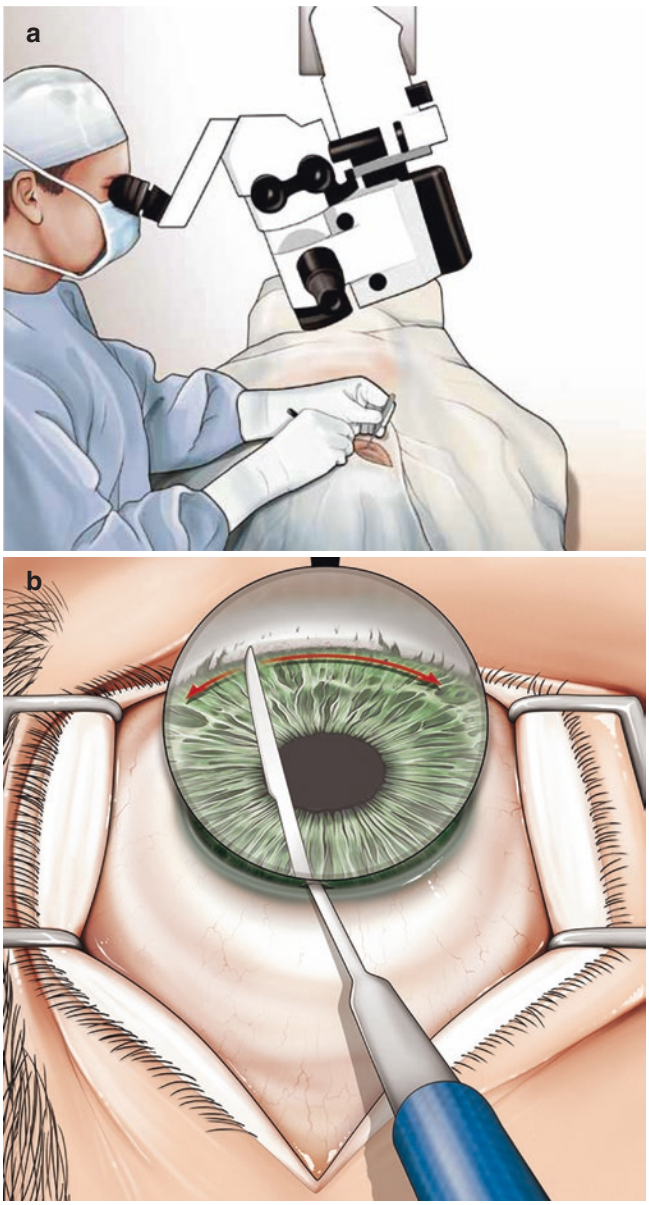

Fig. 7.3 (**a**) Specific surgeon position: patient head should be pushed away from the surgeon and the microscope should be tilted of about 30–45 grades. (**b**) Insertion of the goniotomy instruments or a 25G needle into the AC. A goniotomy instrument (several different ones are available), or a 23G or 25G needle mounted on a syringe filled with VES, is inserted in the AC through a peripheral paracentesis. Through the goniolens, the surgeon observes and monitors the slow progression of the instrument's tip in the AC to the opposite angle, parallel to the iris, avoiding the pupil. As mentioned previously, the bulb is stabilized by the assistant using 2 forceps (Moody or Elschnig-O'Connor forceps, Katena Eye Instruments), that engage the insertion of the superior or inferior rectus muscles. The *red arrows* indicate the direction of the goniotomy performed

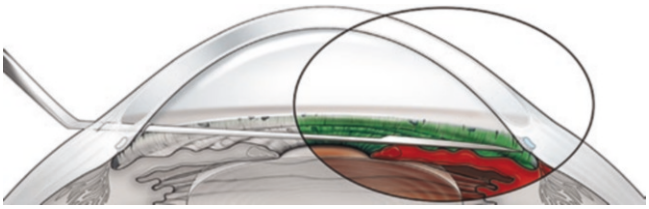

Fig. 7.4 Introduction of the instrument tip in the trabeculate. The surgeon now proceeds with the crucial phase of the procedure. The instrument's tip (blade or needle) is introduced between the anterior third and the middle third of the trabeculate, just under the Schwalbe line, in an extremely superficial position, for about 0.5 mm. If the tip is introduced in an excessively anterior position, it is unlikely that the angle tissue will be cut; moreover, it is possible that there will be damage to the corneal endothelium. If the tip is introduced in an excessively posterior position, it may engage the iris or damage the crystalline and the AC may collapse

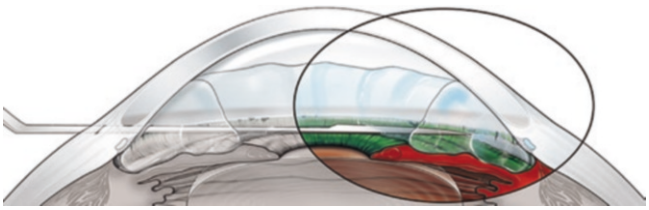

Fig. 7.6 VES-assisted goniotomy. Some authors (ourselves included) recommend the introduction of low resting molecular weight VES to the AC just prior to the goniotomy procedure: the VES will distend the iris and expand the camerular angle, improving vision of the structures and improving the safety profile of the procedure. It prevents the AC flattening and reduces damage to the endothelium and the iris. Finally, it assists hemostasis and containment of any bleeding

Once the incision has been created, the instrument is removed rapidly from the AC; then BSS, sterile air, or VES (contained in the syringe mounted with the needle) is injected into the AC to deepen it and/or displace the blood. Hypothalamy, hypotony and hypoema may appear during this phase: these problems will be more frequent if the surgeon uses goniotomy instruments (that are frequently conical) as opposed to a 25G needle (that is cylindrical). If visualization is not optimal during the maneuvers, the assistant may delicately rotate the eye bulb to produce better vision for the surgeon. Many authors recommend positioning one 10.0 vicryl suture (Ethicon, Inc., Somerville, NJ) on the peripheral corneal incision to prevent leakage; in slightly older children, a suture in nylon 10.0 can be applied. The knots for both sutures should be recessed. When a bilateral goniotomy is programmed, the entire procedure can be performed with a single anesthesia; obviously the operation on the first eye must be terminated without complications and all of the material (drapes, gloves, instruments, etc) must be replaced before starting the procedure on the second eye.

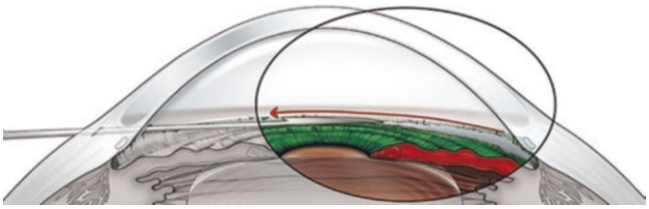

Fig. 7.5 Circumferential incision of the trabeculate. The surgeon now performs the circumferential incision, first in one direction (shown by the *arrow* in the drawing) with a very delicate maneuver and then in the opposite direction. The surgeon may ask his assistant to rotate the eye bulb. The movement is 'fan-like'. The incision plane for the trabeculate must be parallel to the iris and attention must also be paid to avoid damaging the crystalline (because of its anterior convex shape). When the incision is created, the surgeon will notice the formation of a solution of continuity; beneath this, he will observe white tissue (ciliary band and scleral spur); sometimes, he will perceive a posterior shift of the peripheral iris, the release of the iris processes and the formation of a solution of continuity. The goniotomy extends for approximately 4–5 h. Mild hypoema will generally be observed following the incision. If the incision has been created in an excessively anterior position, the correct tissue will not have been cut and it is likely that the surgery will not be successful. If the incision angle is excessively posterior, iridodialysis, cyclodialysis and hypoema may be observed; moreover, the camerular angle tissue may not have been cut

Results

The outcome of the goniotomy procedure in pediatric glaucoma will depend on the etiology of the glaucoma. Children will often require further surgery to control the IOP (for example, trabeculotomy or trabeculectomy). In some cases, the goniotomy procedure can be repeated with treatment of the angle sectors that were not involved in the primary procedure. On some occasions, a third or fourth goniotomy procedure will allow the control of the IOP. Failure of the goniotomy procedure in the treatment of infantile glaucoma may be due to an inadequate position or incorrect depth of the incision or the presence of anterior peripheral synechias that will obliterate the incision. Generally-speaking however, the best results of goniotomy (and trabeculectomy) for the treatment of congenital glaucoma (with a success rate of 80–90%) are achieved when the glaucoma appears after the child is born but before the first birthday (between 3 months and 1 year). If the cornea is transparent, goniotomy is preferable to trabeculotomy: there will be no conjunctival scar and surgery times are shorter.

Complications

Mild or moderate hypoema is frequently observed following goniotomy and normally disappears within a few days. The correct approach is to wait and see how the situation evolves. If it does not resolve, lavage of the AC may be necessary.

Possible complications, though more uncommon, are the more severe iatrogenic traumas, such as iridodialysis or cyclodialysis, that can potentially lead to hypotonia. Traumatic corneal lesions and lesions to the crystalline are also rare and may lead to the appearance of cataract and small peripheral anterior synechias in the area where the angle tissue has been cut. Corneal edema may obscure the surgeon's vision, and this can greatly increase the risk of complications.

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Mini-Invasive Glaucoma Surgery (MIGS)

8

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Introduction

The term MIGS refers to a new group of surgical procedure to treat glaucoma. The procedures are characterized by minimum invasiveness and high future potential. More specifically, these procedures have common features and involve the creation of small incisions. Regarding the mechanism of action of MIGS, these procedures reduce the intraocular pressure (IOP), by improving the outflow of aqueous humor and, to a lesser degree, reducing its production by the ciliary bodies. The MIGS procedures that increase the aqueous humor outflow can influence several physiological pathways: some procedures improve the outflow of the aqueous humor in the Schlemm Canal (SC)—by removing the resistance of the trabeculate (the traditional drainage pathway) or by by-passing it. Other procedures improve the uveo-scleral discharge by creating a connection between the anterior chamber (AC) and the supra-choroidal space.

There are six fundamental requisites associated with all of the MIGS procedures.

– First of all, micro-invasiveness: the procedure is performed through an incision in clear cornea, avoiding incisions in and scars of the conjunctiva. The advantage is that the surgeon can perform surgery that involves the manipulation of the conjunctiva at a later stage; and the micro-invasive approach will not affect the results of a subsequent second procedure. The micro-incisional approach of the MIGS procedures is largely *ab interno* even though some authors believe that an *ab externo* approach is also an option.

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Ab interno glaucoma surgery is performed through a small incision in clear cornea, avoiding incisions and scars of the conjunctiva. As mentioned before, using this approach the surgeon can perform further surgery at a later stage that will involve manipulation of the conjunctiva, without conditioning the results. Moreover, this approach will allow the direct vision of the anatomical structures to optimize the position of a device or an incision inside the camerular angle.
This approach facilitates intraoperative maintenance of the AC depth and conservation of the normal ocular anatomy; it minimizes the postoperative refractive changes and increasing the degree of safety of the procedure.
Some authors believe that MIGS can also include a different approach—that is *ab externo.* In the past, this group included canaloplasty, deep sclerectomy and the implantation of an EX-PRESS shunt. Even though these procedures are associated with fewer complications compared to traditional incisional surgery (trabeculectomy and drainage implants), they also involve manipulation of the conjunctiva, partly compromising the results of any future glaucoma surgery. As a result, not all authors agree that this group of procedures can be classed as MIGS.

– The second essential requisite of the MIGS procedures consists of minimal induced trauma on the target tissue. The non-traumatic approach reduces inflammation, accelerates postoperative recovery and conserves the anatomy and the physiological drainage pathways.

This type of approach leads to a reduction in the resistance to the aqueous humor outflow, preventing complications associated with hypotonia, possible with the traditional incisional techniques.

– The third aspect is the clinical efficacy of the procedure. The majority of the MIGS techniques are frequently associated with modest efficacy compared to incisional glaucoma procedures, that are much more invasive. Infact, given that the MIGS procedures will improve the physio-

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logical drainage of the aqueous humor rather than by-passing it, the postoperative IOP rarely drops to values lower than the pressure measured for the episcleral veins. At any rate, this frequently modest efficacy is partly compensated by the undeniably valid safety profile.
- The fourth factor that characterizes MIGS is extremely important, that is the extremely good safety profile. These procedures avoid the well-known and serious complications that may be associated with the other *ab externo* procedures.
- The fifth requisite is the relative ease and speed of the MIGS techniques, and the fact they are associated with a short learning curve.
- Finally, the MIGS procedures must consent rapid postoperative recovery with minimum impact of the patient's quality of life.

  All of the MIGS procedures can be associated with cataract surgery.

The scientific literature has highlighted that the MIGS procedures lead to only a modest reduction in IOP; as a result, these procedures are indicated only in the cases of mild and moderate degrees of glaucoma damage and modest targets for the reduction of the IOP. Given that these procedures determine a modest pressure reduction and are characterized by an excellent safety profile, they can be included in the algorithm for glaucoma treatment in a more precocious position than more invasive glaucoma surgery. In the literature, there are a number of studies that demonstrate the efficacy of the MIGS procedures associated with phacoemulsification. However, the effective validity of the isolated MIGS procedures must still be clarified through randomized clinical trials, particularly those with a long follow-up. In summary, MIGS are a group of recently-developed procedures and can determine a modest reduction in the IOP. They still need to be given an exact position in the algorithm for glaucoma treatment: at the time of writing, a number of trials (including comparative studies) are ongoing for the various tecniques to establish the effective validity of these procedures. Nevertheless, these newly-developed procedures have attracted the interest of many Opinion Leaders and important industries in this sector.

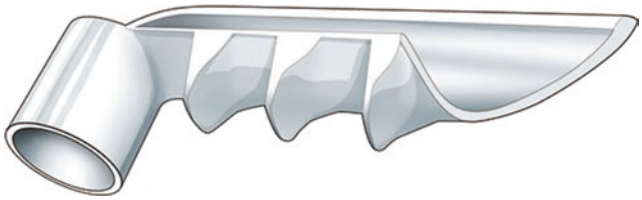

Fig. 8.1 iStent. This is a very small L-shaped device in non-ferromagnetic titanium, coated in heparin to assist self-priming. The most recent model is 1 mm long, 0.33 mm thick and weighs 60 μg

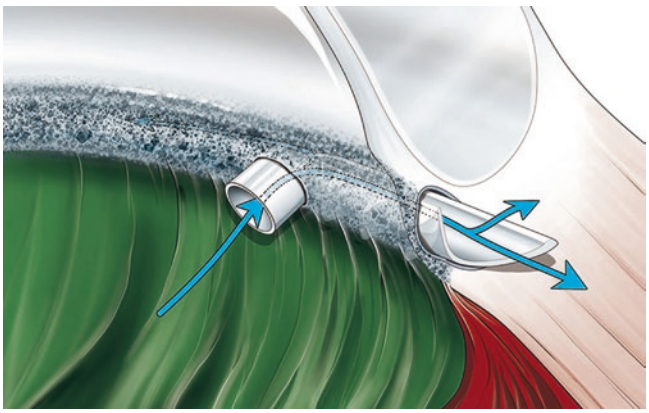

Fig. 8.2 Correct positon of the iStent and its mechanism of action. The foot plate of the iStent is positioned in the Schlemm Canal (Fig. 8.2). The distal part (shaped like a snorkel) is positioned in the AC, is 0.25 mm long with an opening of diameter 120 μm. The aqueous humor passes through the iStent (blue arrow), by-passing the trabeculate, flowing from the AC to the Schlemm Canal. It is successively drained by the collector canals into the episcleral veins, especially in the quadrant containing the by-pass

Fig. 8.3 The iStent preloaded in an injector. There are two types of iStents (Fig. 8.3). Both are preloaded in a sterile injector, one for the right eye and one for the left eye

A Device That By-Passes the Trabeculate: The iStent

Introduction

This MIGS procedure reduces the IOP by by-passing the trabeculate obstruction. The device is called the iStent Trabecular Micro-Bypass (Glaucos Corporation, Laguna Hill, CA). The iStent was approved by the FDA in 2012 for the treatment of mild or moderate open-angle glaucoma. It is believed that in these patients the juxtacanalicular trabeculate is the main resistance to conventional outflow. The iStent is indicated in these cases because it creates a by-pass through the resistance presented by the juxtacanalicular trabeculate, facilitating conventional drainage. There are studies in the literature that

examine pigmentary, pseudoexfoliative, steroid-induced and post-trauma glaucoma.

This device is used in association with cataract surgery or as an isolated procedure in pseudophakic patients: the best tonometric results are obtained when it is used in combination with phacoemulsification. The iStent is not indicated for closed-angle glaucoma (primary and secondary), in all the clinical conditions that can result in pressure increase of the episcleral veins, in turn responsible for ocular hypertonia (for example, Struge-Weber Syndrome) and in corneal anomalies that prevent gonioscopic visualization of the position of the implant. On this subject, excellent knowledge of gonioscopy (necessary for both the outpatients and for the operating room) is essential for a correct preoperative evaluation of the patient and for the efficacious performance of this technique. In the preoperative evaluation phase, gonioscopy is indispensable for identifying conditions that will prevent adequate vision of the angle (anterior peripheral synechias, rubeosis, other anomalies of the angle) and are consequently contraindications to surgery.

Surgical Technique

Even though this operation is easier to perfome compared to other glaucoma procedures, we would recommend local anesthesia (retrobulbar or peribulbar) for the first implants performed by learning surgeons. Preoperative instillation of miotic eyedrops (1 or 2% pilocarpine) is recommended to open the angle. For this type of procedure, the surgeon sits in a specific position that has already described in Chap. 8 about the goniotomy procedure: he sits on the opposite side to the portion of the angle he intends intervening on; the patient's head is rotated slightly to the side opposite the surgeon. The operating microscope is tilted 30°–45° to allow optimized vision of the angle.

The surgical steps are as follows:

- Step 1: creation of a 1.5 mm incision in clear cornea in a temporal position parallel to the iris. The incision must be diametrically opposite the chosen position for the implant and must be close to the limbus.
- Step 2: introduction of low resting molecular weight cohesive VES into the AC to encourage the successive entrance of the handle: creation of air bubbles in the AC should be avoided as these can reduce the visualization of the camerular angle.

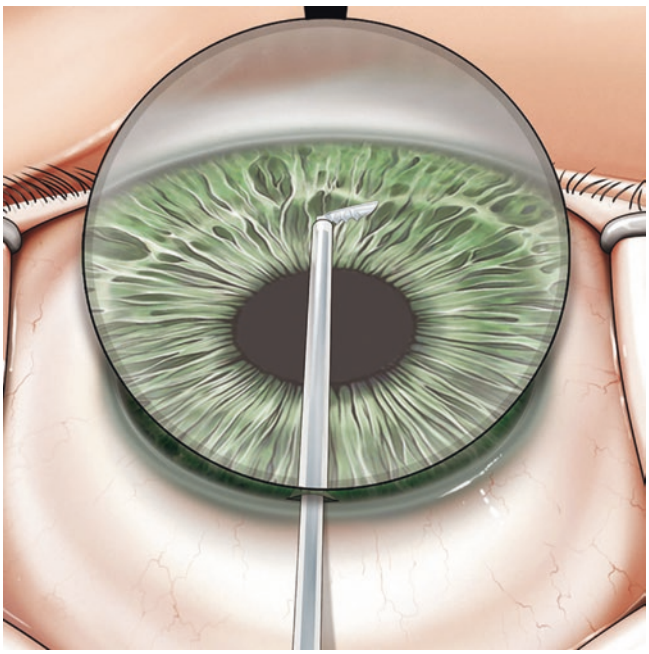

Fig. 8.4 Control of the vision of the camerular angle (step 3). Now the surgeon proceeds by placing gel on the cornea, positioning the goniolens and controlling the vision of the angle (Fig. 8.4). Normally a modified Swan-Jacobs lens is applied: high magnification is recommended (10–12×). The gonioprism is generally held in the non-dominant hand; light pressure is applied to maintain a uniform meniscus of gel on the cornea. Excessive pressure applied in this phase can cause the formation of corneal folds that can ostacle the angle visualization. In the event the surgeon cannot identify the anatomical landmarks, he may attempt to induce blood reflux in the Schlemm Canal by applying light pressure to the perilimbal sclera. As we mentioned before, two types of iStent are available. Both are preloaded in a sterile injector, one for the right eye and one for the left eye: this facilitates the insertion in the inferonasal quadrant. The surgeon identifies the trabeculate localized between the scleral spur and the Schwalbe line: this is the point where the device is inserted. The surgeon should always identify the most suitable site for the implant: the most pigmented area of the trabeculate is where there is greater drainage and a greater density of the collector canals. Generally it is localized in the inferior nasal quadrant. After identifying the surgical landmarks (the trabeculate localized between the scleral spur and the Schwalbe line), the goniolens is removed and the surgeon concentrates on the implantation of the iStent

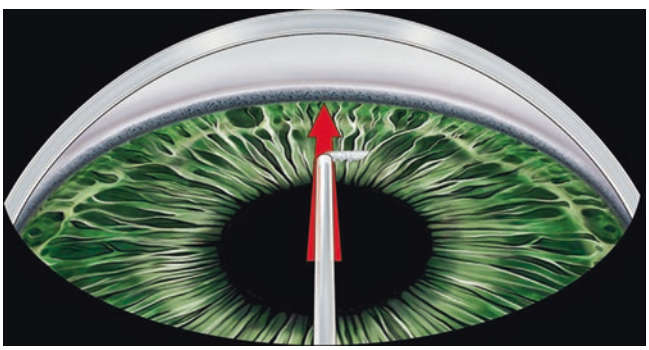

Fig. 8.5 Progression of the implant in the AC in a nasal direction (step 4). The implant is inserted in the AC parallel to the iris to avoid engaging it. The implantation procedure proceeds in a nasal direction inside the AC (Fig. 8.5) and the goniolens is repositioned

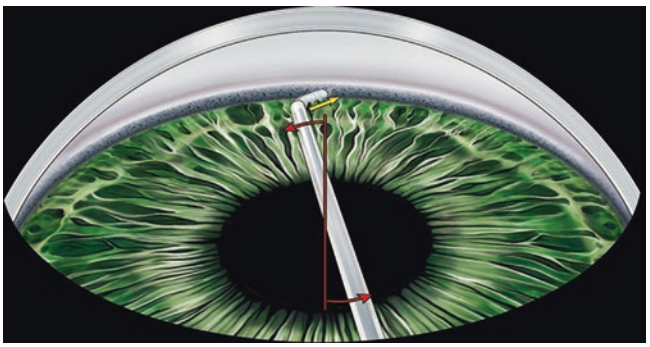

Fig. 8.6 Manoeuvre for the correct positioning of the iStent in the Schlemm Canal (step 5). Holding the goniolens in the non-dominant hand, the iStent preloaded in the injector is held in the dominant hand; it penetrates beyond the pupil margin as far as the angle, more precisely till the anterior 1/3 of the trabeculate, at a 15° angle

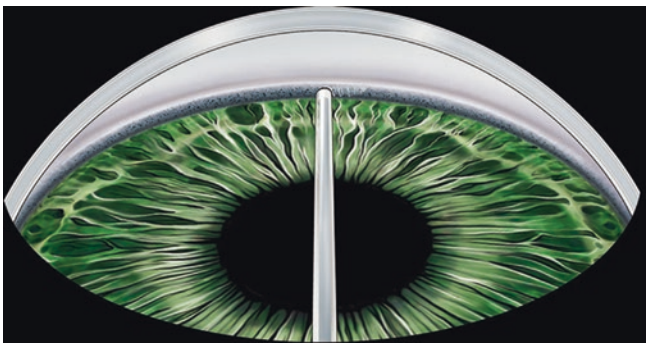

Fig. 8.7 To ensure that the iStent approaches the Schwalbe Line correctly, the surgeon must perform a slight rotation to allow it to lie perpendicular to the angle: in this maneuver, the surgeon will perceive a sensation similar to wet tissue paper. During the correct insertion, considering that the IOP drops, a small amount of blood reflux will be observed in the Schlemm Canal. If the surgeon perceives considerable resistance, the posterior portion of the Schlemm Canal may have been engaged: in this event, the iStent should be withdrawn and re-implanted 1–2 h later

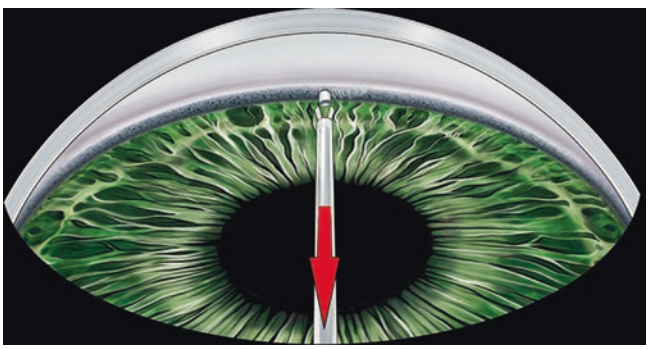

Fig. 8.8 Release of the iStent in the Schlemm Canal (step 6). The injector is fitted with a botton used to release the device (Fig.8.8). Then the injector is delicately withdrawn. Once the iStent has been released in the desired position, the surgeon should gently touch the end of the insert with the injector tip to check whether the position of the device is stable

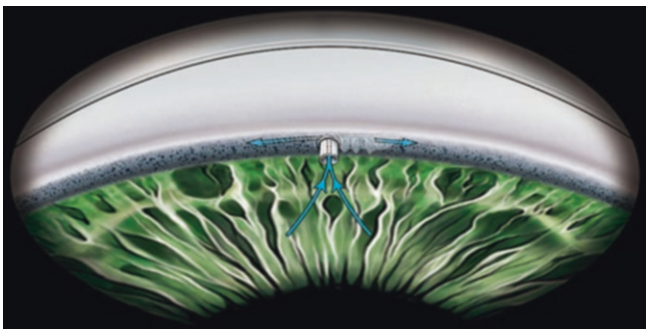

Fig. 8.9 Visualization and control of the correct position of the iStent in the Schlemm Canal (step 7). When inserted, the iStent must lie parallel to the trabeculate, with its internal foot plate covered by the trabeculate and the opening of the device extending into the AC (Fig. 8.9). The scleral spur is a surgical landmark that can be used to verify the correct position of the device and ensure that it is parallel to the trabeculate (and not at an angle). The retention arches of the device should be slightly opaque, as they are covered by the trabeculate. On the other hand, if the arches are visible, it may be because there has been a rupture of the trabeculate or the iStent is not perfectly positioned. As was mentioned before, when the iStent has been positioned correctly, the surgeon may observe a small amount of blood reflux in the Schlemm Canal; VES may be used to displace the blood and control the position of the stent. The drawing illustrates how the aqueous humor passes through the iStent (*blue arrows*), from the AC to the Schlemm Canal, by-passing the trabeculate.

– Step 8: removal of the VES. The VES must be removed completely to avoid it obstructing the iStent;
– Step 9: hydrosuture and tsuture of the corneal incision. Following the hydrosuture, the surgeon must check for any leakage; if leakage is observed a 10.0 nylon thread suture should be added

When this procedure is combined with phacoemulsification, iStent surgery is performed first and the phacoemulsification follows: this sequence allows a smaller corneal incision to be created (with better closure of the AC) and to work in clear cornea. However, some surgeons prefer to perform the phacoemulsification procedure first and then proceed with the implantation of the iStent

Results

As mentioned earlier, the FDA approved the iStent for the treatment of mild or moderate open-angle glaucoma. The approval was based on clinical studies that also included cases of pigmentary, pseudo-exfoliative, steroid-induced and post-trauma glaucoma. This procedure results in only a modest reduction in the IOP. The scientific literature also shows that the best tonometric results are achieved when the procedure is performed in combination with phacoemulsification (rather than with the glaucoma treatment alone). The literature also reports that the pressure-reducing effect may increase if several inserts (multiple inserts) are positioned during the same procedure, even though these statement still require complete validation. Regards the safety profile, the iStent is a procedure associated with an extremely low incidence of complications (and the same applies to all other MIGS procedures). In fact, it is anastigmatogenic and asso-

ciated with a very low incidence of hypotonia. The incidence of complications associated with the stent is also very low: 3–21% for incorrect positioning and 4–10.5% due to obstruction of the stent in the postoperative period due to formation of anterior peripheral synechias or occlusion of the lumen (for example, due to hypoema): this condition can be resolved with a Nd-Yag or argon laser procedure in the postoperative period. Some cases of transitory corneal edema have also been reported in the early postoperative period (8%). In conclusion, considering the modest reduction in the IOP and the excellent safety profile, the iStent is an ideal alternative in the patients with early-moderate open-angle glaucoma, in which the surgeon wishes to reduce the number of eyedrop therapy required (in pharmacological polytherapy) and delay filtering surgery. If the hypotensive effect will not be sufficient, at a later stage the surgeon can perform a procedure that involves the manipulation of the conjunctiva, without reducing the success rate because the conjunctiva was not manipulated during previous procedures.

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Trabectome (Trabeculectomy Ab Interno)

9

Luigi Caretti and Lucio Buratto

Introduction

The trabectome is one of the most promising of the new mini-invasive procedures developed in glaucoma surgery (Mini-Invasive Glaucoma Surgeries, MIGS, see Chap. 9). The trabectome (NeoMedix Corporation, Tustin, CA, USA) was used for the first time in USA in 2005 for open-angle glaucoma surgery following approval by the FDA; then in 2009 it was presented at the World Glaucoma Congress in Boston and at the time of writing, the use of this technique is increasing slightly. The rationale behind this procedure is that the mail sites of resistance to the aqueous humor outflow is the trabeculate and the internal wall of the Schlemm Canal (see Chap. 1 on surgical anatomy). The feature that makes unique this technique is the selective electrosurgical ablation of the trabeculate and the internal wall of the Schlemm Canal through the use of a special probe that operates inside the anterior chamber (AC). The remaining aqueous humor outflow system (the external wall of the Schlemm Canal, the collector canals and the aqueous veins) are basically left intact. The ablation is selective, without any damage to the surrounding structures; in theory, the fistula will not be occluded by fibrosis. The special probe of the trabectome is used for the permanent ablation of a strip of trabeculate and the internal wall of the Schlemm Canal; it is also used to aspirate the debris from the procedure, improving the aqueous humor outflow through the collector canals (that are more numerous in the nasal sector) and the episcleral veins: this is an *ab interno* trabeculectomy, and it does not involve the manipulation of the conjunctiva or the formation of a bleb. These are important advantages in case of inadequate long-term intraocular pressure (IOP) control, infact incisional glaucoma surgery still remain a valid option. At the time of writing, the trabeculectomy *ab interno* with the trabectome is a valid surgical option for slow-progression glaucoma. The surgical technique includes the use of 1–2% pilocarpine eyedrops in the days immediately prior to surgery, the use of the surgeon's preferred type of anesthesia (peribulbar, topical-intracamerular, retrobulbar), the appropriate position of the patient's head (rotation of 30° on the opposite side from the surgeon) and 40° tilting of the microscope to improve visualization of the trabeculate.

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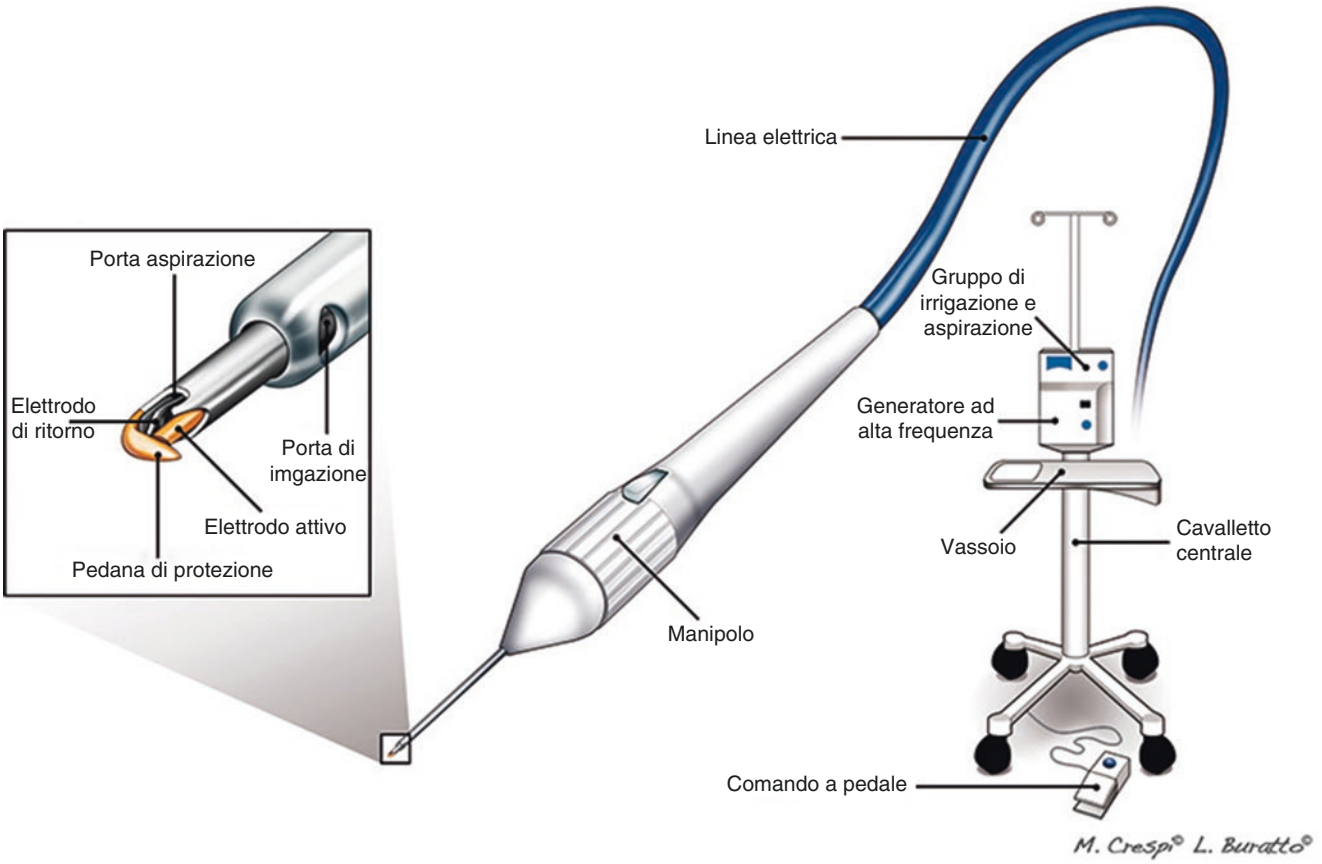

Fig. 9.1 The trabectome probe. The probe is mono-use (disposable) and has a 19.5G tip connected to a console that allows the irrigation, the aspiration and electrocauterization (Fig.9.1). The tip is bent 90° to create a triangular plate: on the one hand, this will consent penetration into the trabeculate and on the other, easy entrance into the Schlemm Canal while protecting the posterior wall. The shape of the probe allows it to position the trabecular and juxtacanalicular tissue between the bipolar electrodes, inducing the ablation during movements inside the Schlemm Canal, while protecting the tissues from any inflammatory and scarring stimuli. In addition to generating the bipolar electrosurgical impulse, the handle of the trabectome also includes an irrigation system (to stabilize the depth of the AC and dissipate the heat produced) and an aspiration system (to remove the ablated tissue). Unquestionably, the most important action of the handle is high frequency electrocauterization (550 kHz)

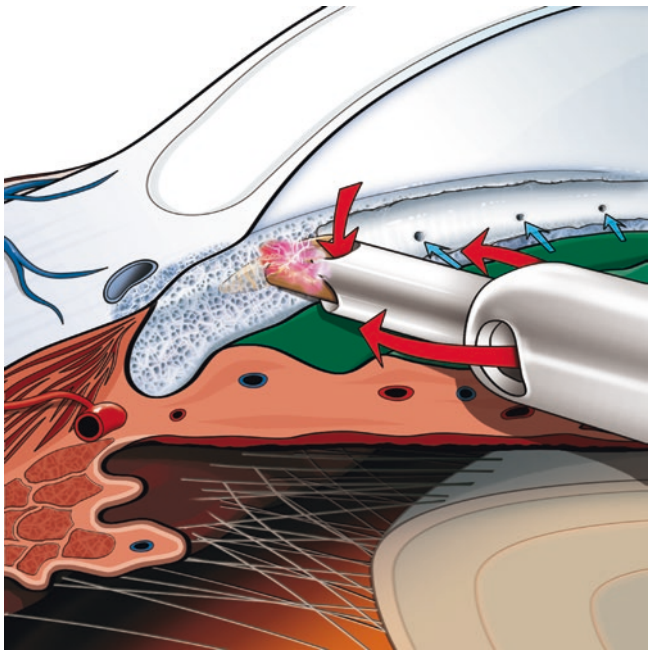

Fig. 9.2 Surgical technique. The procedure can be split into the following steps:

1. Create a 1.6–1.7 mm clear cornea temporal incision parallel to the iris.
2. Introduce low resting molecular weight cohesive VES into the AC to facilitate the entrance of the handle: with this maneuver, the surgeon must avoid the creation of air bubbles in the AC that may obstruct the visualization of the camerular angle.
3. Position the goniolens on the cornea and control the vision of the angle. Normally, a modified Swan-Jacobs lens is applied.
4. Remove the goniolens and insert the tip of the handle in the AC.
5. Progression of the tip in a nasal direction inside the AC, reposition the goniolens and activate the continuous irrigation (*red arrows* exiting the probe) (Fig. 9.2).
6. Insert the tip in the Schlemm Canal anterior to the scleral spur through the trabeculate in the nasal sector and successive ablation, first in a clockwise and then in an anticlockwise direction with the assistance of a fulcrum point.
7. Ablate a strip of trabeculate and the internal wall of the Schlemm Canal for 60°–140°, depending on the patient's IOP, under direct gonioscopy control. As mentioned earlier, one part of the tip easily enters the trabeculate and the other slides easily into the Schlemm Canal. The trabecular and juxtacanalicular tissues are ablated during the movements inside the Schlemm Canal. The ablated tissue is aspirated immediately (*red arrow* entering the probe). If the surgeon has decided to perform a 30° ablation, starting from a specific point, he performs the ablation for 30° in one direction to remove the trabeculate, and then performs the same maneuver for 30° in the opposite direction. The entire maneuver is performed extremely slowly and carefully. Intraoperative reflux of blood may be observed during this phase through the solution of continuity created; many authors believe that this is a positive sign as it confirms the *ab interno* unroofing of the Schlemm Canal. The probe is set at 0.7–0.9 W (range 0.5–1.5 W) and successively regulated with variations of 0.1, depending on the results achieved. The target tissue is destroyed by applying a series of energy bursts of high peak power and low duty-cycle. This destroys the tissue without generating a considerable amount of heat, as happens with normal cauterization of blood vessels. If the surgeon observes tissue being burned, the power should be set at a lower level; on the other hand, the power level must be increased if the surgeon wishes to remove a greater amount of the trabeculate.
8. Control the appearance of the angle following ablation.
9. Irrigation and aspiration of the viscoelastic: this procedure must be performed extremely carefully and accurately.
10. The corneal incision is closed with a 10.0 nylon suture.

If this procedure is combined with phacoemulsification, the trabectome surgery is performed first and followed by the phaco procedure: this will consent the procedure to be performed with a smaller incision (with better closure of the AC) and allow the surgeon to work in clear cornea

Results

The micro-invasiveness, the *ab interno* approach, the reproducibility and the relative simplicity of this procedure allow the technique with the trabectome to be an interesting surgical alternative to the traditional techniques used. Postoperative therapy includes the continued use of the glaucoma eye-drops used previously. Therapy is integrated with 1–2% pilocarpine for a few days, in addition to corticosteroid anti-inflammatory and topical antibiotic treatment. The relative lack of available literature to date does not allow us to give a definitive opinion on the efficacy of the method. Indications can be provided by the initial work by Minckler that demonstrates how, 24 months from treatment, 37 patients were seen to have a reduction in the IOP of 40% with a reduction (from 2.93 to 1.2) in the mean number of drugs used. These clearly promising results have been partly confirmed by other studies; however, the findings will need to be validated in the future by larger clinical and long-term trials. This surgical technique can be successfully associated with phacoemulsification as demonstrated by Minckler and Francis: in this latest trial, the authors believe that with this technique, it is possible to reduce the IOP and decrease the use of IOP-reducing eye-drops in the majority of cases. Very few complications have been reported with the incidence comparable to those reported for the initial studies using the trabectome alone. The only frequent complication, reported in almost 80% of cases, is blood reflux; this will usually resolve spontaneously in a matter of days. A number of authors believe that this procedure is more efficacious when combined with the cataract procedure (compared to the procedure with the trabectome alone). On the basis of the results from recent studies, the trabeculectomy *ab interno* procedure would appear to be less effective than the classical trabeculectomy. Moreover, according to some authors, this technique functions better in the exfoliation procedures, with better results in combination with phacoemulsification and could be indicated in cases for which the target pressure is lower. In any case, the long-term success of this device is still unknown and further clinical studies are necessary to clearly define its role as an option in glaucoma surgery. Regarding the complications, intraoperative blood reflux from the Schlemm Canal (hypoema) is a frequent though transitory occurrence; less frequent are the complications determine a reduction in the visual acuity, such as hypotonia (reported in 0–1% of cases) or cataract. The safety profile of this technique would appear to be better than the trabeculectomy and the drainage implants.

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Schlemm Canal Device

10

Luigi Caretti and Lucio Buratto

Introduction

These glaucoma devices are included in the MIGS group, namely the new mini-invasive glaucoma surgical procedures. As with all of the MIGS, these devices are more efficacious when performed in combination with cataract surgery. The Hydrus Microstent (Ivantis Inc., Irvine, CA) is a device designed for implantation in the Schlemm Canal (SC), using an *ab interno* approach. This extremely promising device will soon be available on the market.

Description of the Hydrus Microstent

The Hydrus Microstent increases and maintains the conventional outflow of aqueous humor through an opening created in the trabeculate (that will by-pass the resistance produced by the trabeculate) and through the dilation of a significant portion of the Schlemm Canal that exploits the circumferential drainage to the multiple collector canals (Fig. 10.1).

Fig. 10.1 The Hydrus Microstent. The material used in the production of this microstent is nitinol, an extremely elastic and biocompatible metal used for cardiovascular and orthopaedic implants. Nitinol also has memory form properties and consequently is an ideal support structure in the Schlemm Canal. Once it has been positioned, the microstent allows the formation of scaffolding for the Schlemm Canal that permits access to the multiple collector canals that drain the aqueous humor from the trabeculate. The Hydrus Microstent has a proximal opening that allows the trabeculate to remain patent, minimizing the possibility of obstructions: in this way, a communication pathway is guaranteed between the AC and the SC, without damage to the trabeculate. The microstent has an 'open frame' configuration with windows that allow an obstruction-free outflow of the aqueous humor to the collector canals. The most promising version is 8 mm long, with an almost circular shape; it dilates the SC up to 166 μm for the entire length and for 241 μm at the opening

Surgical Technique

As for the other MIGS techniques, even though this procedure is easier than other glaucoma surgeries, we would recommend local anesthesia (retrobulbar or peribulbar) when the learning surgeon is performing his first implant procedures. Preoperative instillation of miotic eyedrops (1–2% pilocarpine) is recommended to open the angle. For this type of surgery, the surgeon assumes the sitting position described in Chap. 7 for goniotomy, in Chap. 8 for the iStent and in Chap. 9 for the trabectome: he will position himself on the side opposite to the portion of the angle he intends operating on; the patient's head is slightly rotated to the opposite side from the surgeon. The operating microscope is tilted 30–45 degrees to permit optimal visualization of the angle.

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Fig. 10.2 Dedicated device for the insertion of the Hydrus Microstent. A dedicated device is used for the insertion the microstent in the SC

The first surgical steps are the same as those described in Chaps. 7–9. They are as follows:

- Step 1: creation of a 1.5 mm incision in clear cornea, in a temporal position and parallel to the iris;
- Step 2: introduction of VES in the AC;
- Step 3: placement of gel on the cornea, on the goniolens and control of the vision of the angle; Normally a modified Swan-Jacobs lens: high magnification is recommended (10–12×). Having identified surgical landmarks (the trabeculate localized between the scleral spur and the Schwalbe line), the surgeon enters the AC with the device.

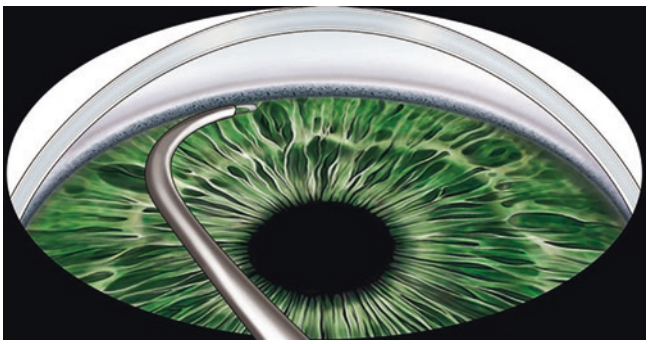

Fig. 10.3 The device approaches the camerular angle (step 4)

Fig. 10.5 Withdrawal of the insertion device from the AC (step 6). The insertion device is gently removed.

- Step 7: visualization and control of the correct position of the insert. Following insertion, the microstent must lie parallel to the trabeculate.
- Step 8: the viscoelastic is removed.
- Step 9: hydrosuture and possible additional sutures of the corneal incision. After the hydrosuture, the surgeon must check that there is no leakage; if leakage is observed, a suture in 10.0 nylon is positioned

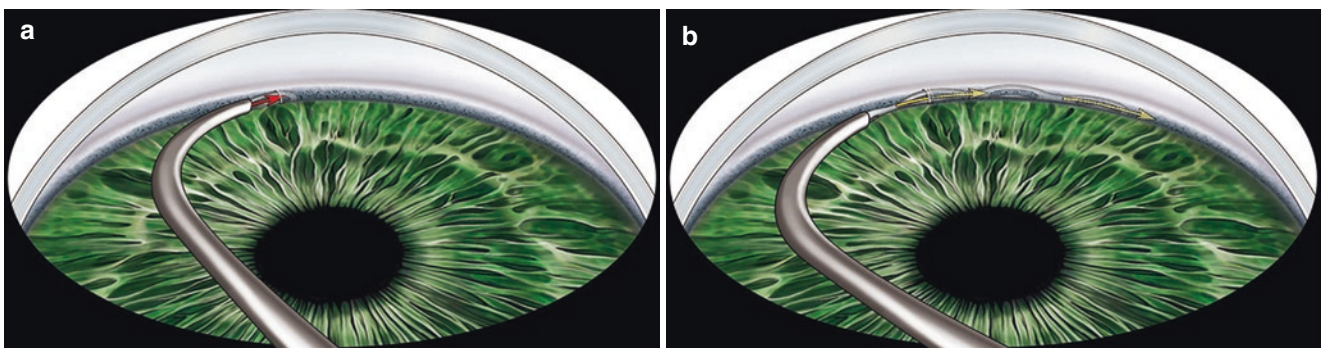

Fig. 10.4 (**a**, **b**) The microstent is positioned in the Schlemm Canal (step 5). The microstent is positioned in the Schlemm Canal by exerting soft pressure on the dedicated plunger of the device (**a** and **b**)

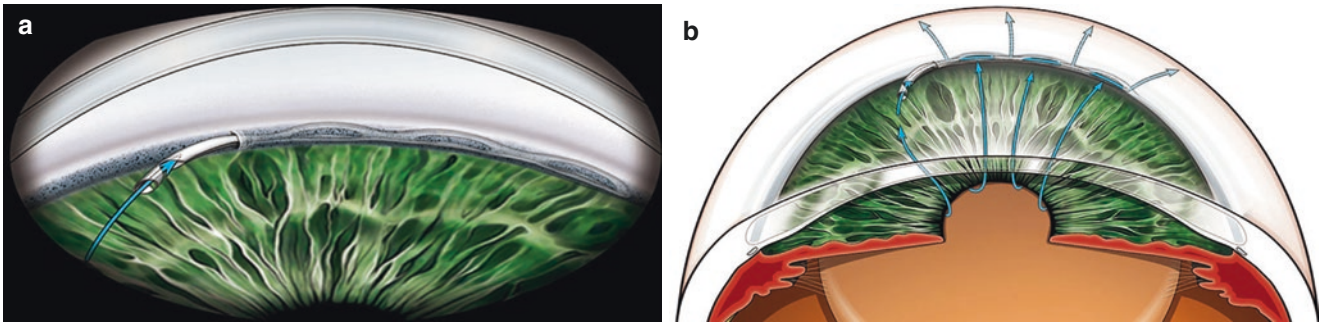

Fig. 10.6 (**a**, **b**) Outflow of the aqueous humor following implantation of the Hydrus Microstent. As mentioned previously, the microstent increases and maintains the conventional outflow of the aqueous humor through the creation of an opening in the trabeculate and by dilating a significant portion of the SC that exploits the circumferential outflow to the multiple collector canals (**a** and **b**). Given that the Hydrus Microstent can be positioned through a small incision in clear cornea (1.5 mm), it can be associated with micro-incisional surgery of the cataract (MICS)

Results

According to several clinical studies, this device is efficacious in eyes affected by primary mild-moderate open-angle glaucoma and pseudo-exfoliative glaucoma. As mentioned previously, the pressure-lowering effects are greater when associated with cataract surgery. The efficacy and the initial safety profile have been confirmed by clinical studies; it has been reported that complications are observed in just 1% of cases and are mainly transitory post-operative inflammation.

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Supra-Choroidal Devices

11

Luigi Caretti and Lucio Buratto

Introduction

These devices are part of the MIGS techniques. The MIGS procedures (see Chap. 8) reduce the intraocular pressure (IOP) and improve the drainage or outflow of the aqueous humor (and to a lesser degree, reduce its production by the ciliary bodies). The MIGS that increase the drainage of the aqueous humor can influence several physiological pathways: some procedures improve the aqueous humor discharge into the Schlemm Canal (SC) by removing the resistance from the trabeculate (conventional discharge pathway), or by by-passing it. Other procedures improve the uveo-scleral drainage (non-conventional drainage pathway), creating a connection between the anterior chamber (AC) and the supra-choroidal space. The uveo-choroidal drainage system consists of the ciliary body, the suprachoroidal space, the choroid and the sclera. As mentioned previously, this pathway drains the aqueous humor from the AC into the supra-choroidal space. This occurs because of the natural pressure gradient between these two compartments and the high absorption capacity of the supra-choroidal space. The aqueous humor then drains from the supra-choroidal space through the blood vessels (scleral and choroido-capillary vessels), through the scleral pores, to then drain into the episcleral tissue. It is believed that in physiological terms, the therapeutic potential of the uveo-scleral drainage system is important: the uveo-scleral drainage is lower than the trabecular drainage, draining approximately between 5 and 44% of the total quantity of aqueous humor. Access to the supra-choroidal space through the creation of a cleft in the ciliary bodies, meaning a separation of the scleral spur from the ciliary bodies, is a pressure-lowering surgical procedure and is not a recent development. This type of surgery was not popular in the past because of the frequent and serious side-effects (severe hypotonia or acute hypertonia linked to the sudden closure of the cleft). To maintain long-term patency of the uveo-scleral pathway and to reduce the incidence of complications, over time, several different materials and substances have been suggested, but none has resulted in any significant clinical success. Recently, however, devices such as micro-stents and micro-shunts in new biocompatible materials have been presented:

- Gold Micro-Shunt (GMS, SOLX Corp, Waltham, MA)
- Cy-Pass Micro-Stent (Transcend medical, Menlo Park, CA)
- Aquashunt (Opko Health, Inc. Miami, FL

The Gold Micro-Shunt and the Aquashunt necessitates an *ab esterno* approach, while the CyPass Micro-Stent necessitates an *ab interno* approach, The Aquashunt is still in the experimental phases. All these devices facilitate the drainage of the aqueous humor from the AC into the supra-choroidal space. The literature reports some findings that suggest they may reduce the IOP; however, there are no publications that demonstrate the long-term efficacy. In this chapter we describe the Gold Micro-Shunt and the CyPass Micro-Stent. Even though both of these operations are more simple compared to other glaucoma surgery, we would recommend application of local anesthesia (retrobulbar or peribulbar) for the first implants. Preoperative instillation of miotic eye-drops (1–2% pilocarpine) is recommended to open the angle.

The Gold Micro-Shunt

The Gold Micro-Shunt (GMS) is a mini-device in 24 carat gold. It is flat, not valved and biocompatible. It is inserted trans-scleral and connects the AC to the suprachoroidal space.

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Surgical Technique

The series of drawings that follow illustrate the various surgical steps.

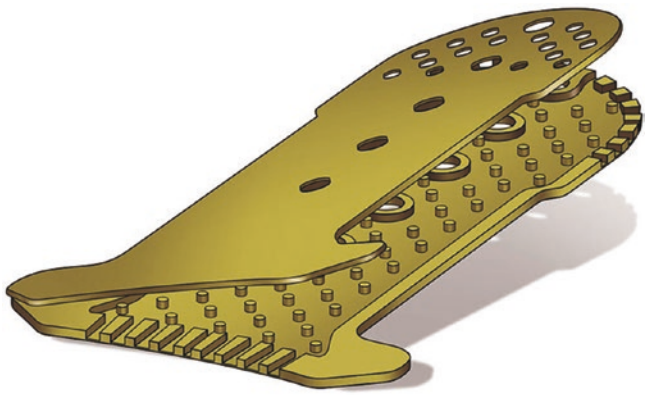

Fig. 11.1 Gold Micro-Shunt. The GMS is a device consisting of two wings that are fused together; it is rectangular and is equipped with a rounded proximal edge that enters the AC. The distal edge is designed with small fin-shaped wings that helps to anchoring the device in the suprachoroidal space. The drawing illustrates the internal section of the GMS; there are canals and tubules that facilitate the flow of aqueous humor from the AC to the suprachoroidal space. The shunt is 5.2 mm long, 3.2 mm wide and 44 μm thick. It has 19 canals or tubules: 9 of these are open with a lumen 24 μm wide and height 50 μm. On the proximal edge, there are 60 small holes (of diameter 100 μm) and a hole of 300 μm that allows the aqueous humor to drain into the shunt. The distal part has a grid consisting of 117 holes (of diameter 110 μm) that allow the liquid to drain from the shunt. Finally, there are other canals (12 anterior and 10 posterior) on the sides that also allow the outflow of aqueous humor

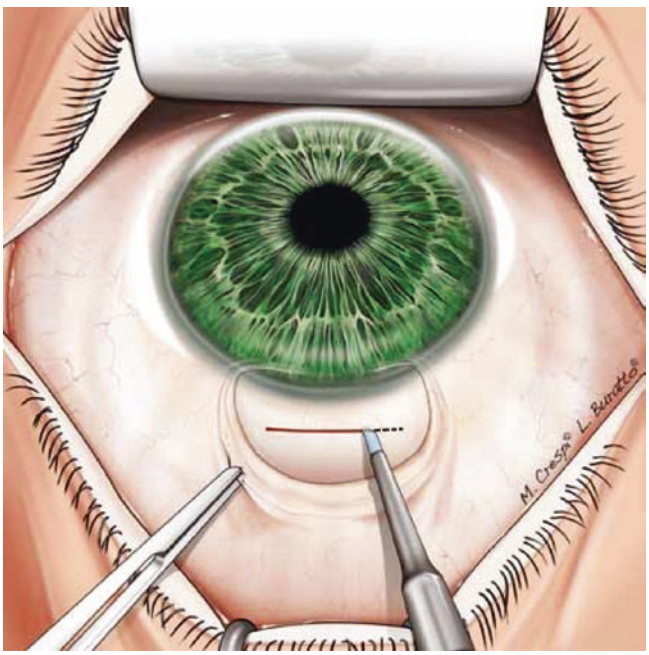

Fig. 11.2 Conjunctival Flap and Scleral Incision. After having created the conjunctival fornix based flap, the surgeon creates a scleral incision that is 4 mm long; it extends for approximately 90% of the scleral depth and is positioned 2–3 mm from the limbus

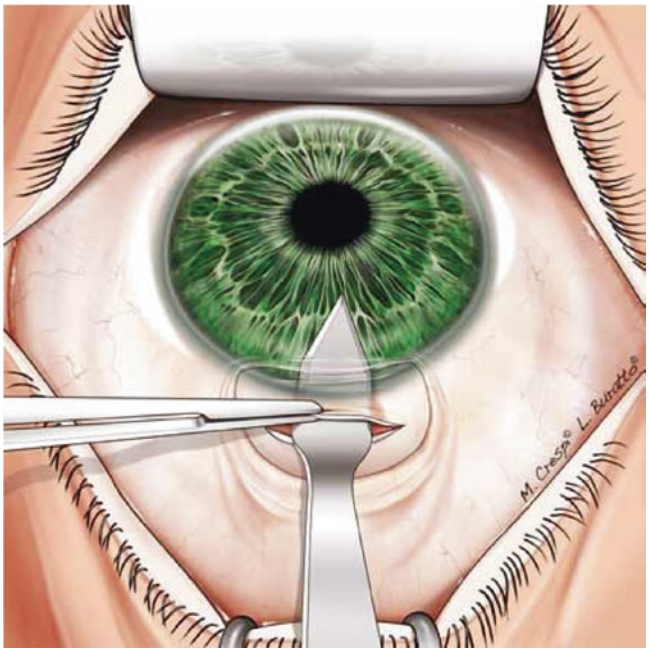

Fig. 11.3 Scleral Tunnel. A scleral tunnel is created, using trapezoidal or crescent knives. The surgeon creates a scleral tunnel that is directed anteriorly towards the cornea. The AC depth can be maintained with VES or with an AC maintainer

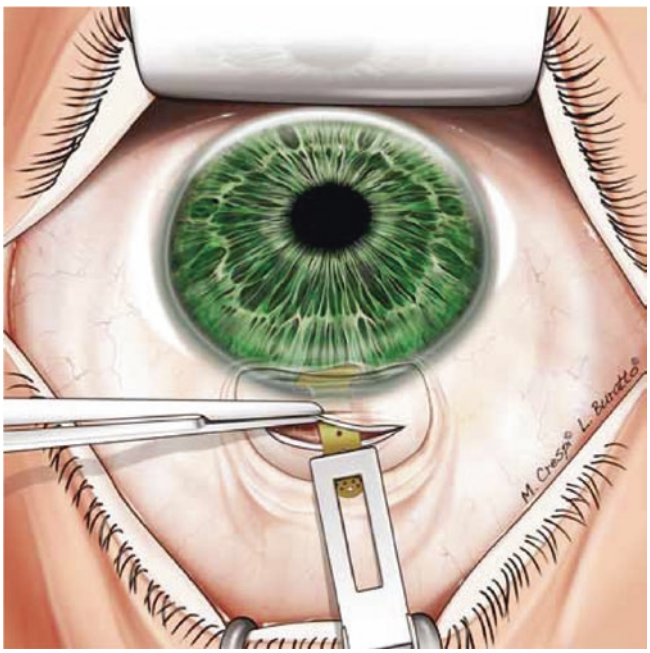

Fig. 11.4 An implant with a dedicated injector. A dedicated re-usable, sterilizable injector is available for inserting and positioning the implant. The injector is inserted in the scleral tunnel; the surgeon proceeds in an anterior direction to allow the distal portion enters the AC

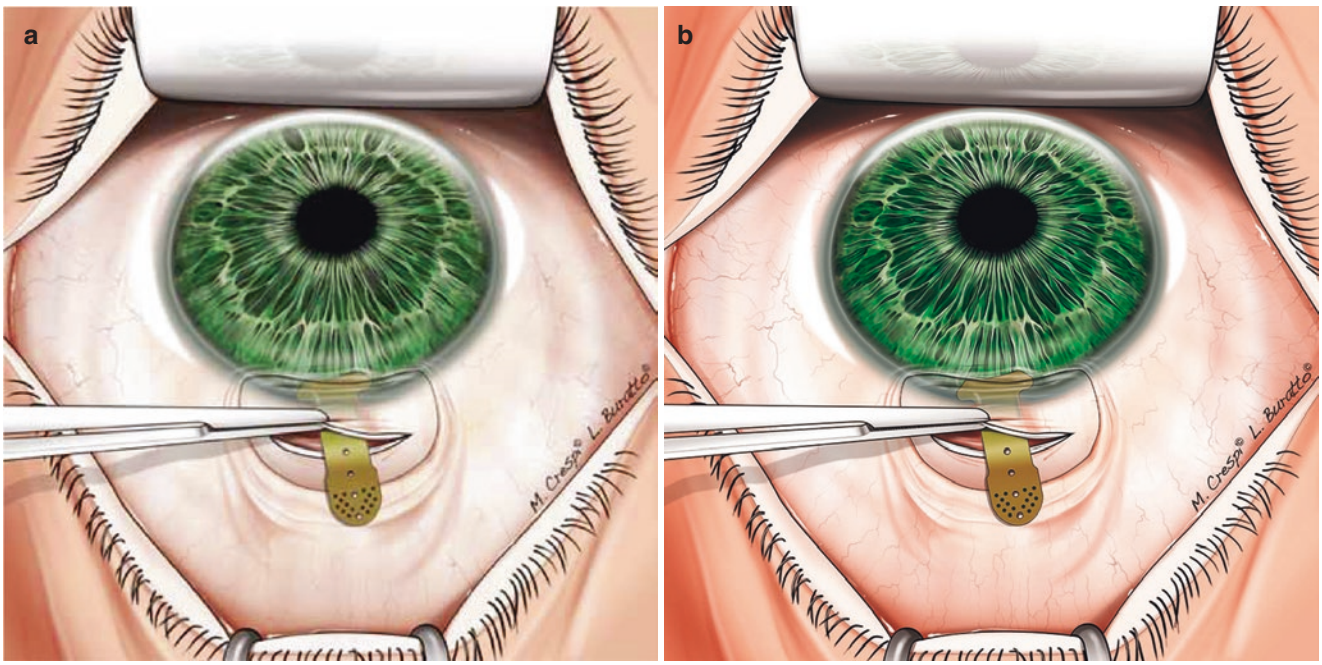

Fig. 11.5 (**a**, **b**) Removal of the injector. At this point, the injector is withdrawn (**a**); part of the device remains inside the AC and part inside the scleral tunnel (**b**)

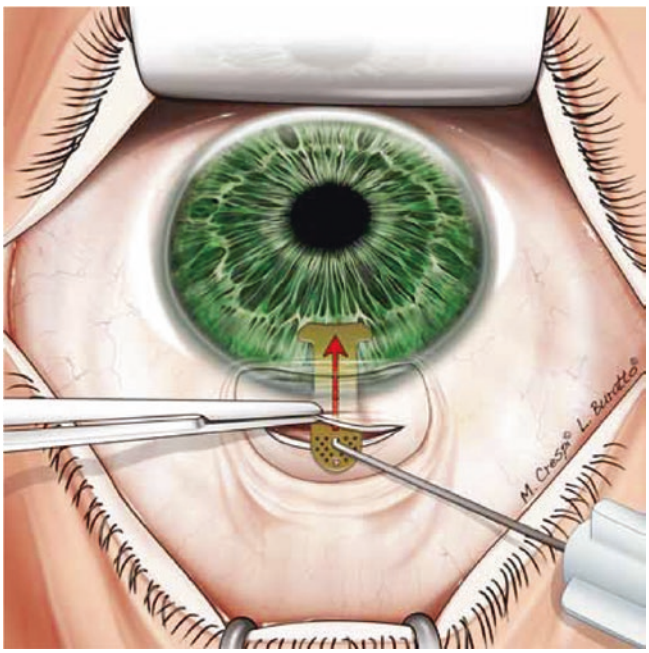

Fig. 11.6 Positioning the distal portion of the device. The device is now mobilized anteriorly towards the AC (see the *red arrow*), using a standard hook inserted through one of the numerous holes. The distal portion of the device is introduced into the AC: it has a concave shape designed to minimize any possible contact with the iris or with the corneal endothelium. Only 1–1.5 mm of the device should be visible in the AC

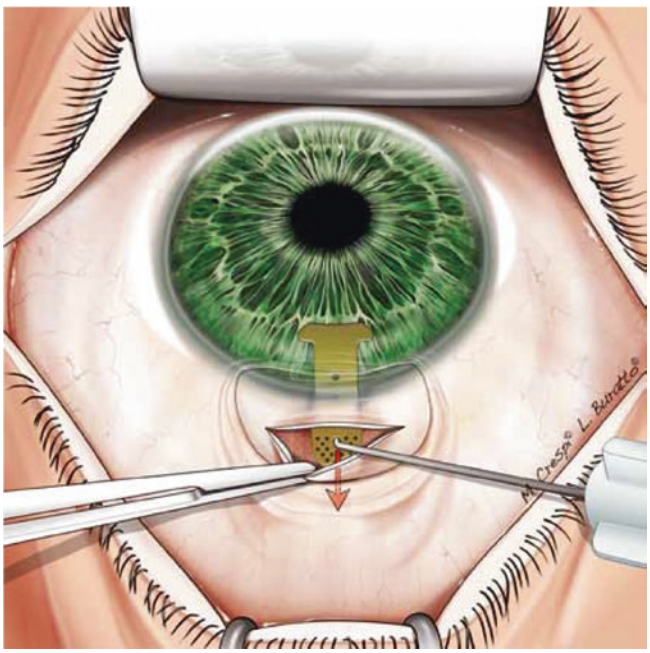

Fig. 11.7 Positioning the proximal portion of the device. The proximal portion of the device is positioned in the suprachoroidal space, again using a hook (see the *red arrow*), so that all the posterior drainage openings are covered by the posterior scleral slit. The correct position of the implant can be controlled by intraoperative gonioscopy

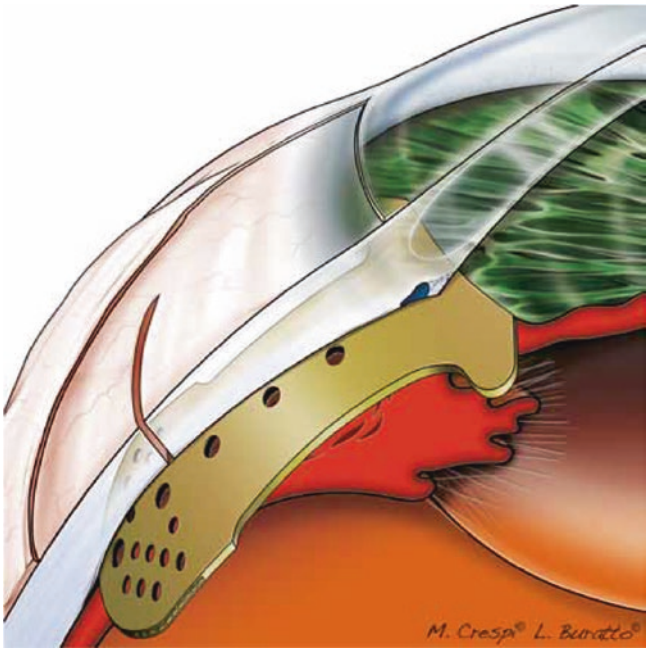

Fig. 11.8 Correct final position of the Gold Shunt (side view). The distal portion of the device enters the AC for 1–1.5 mm, while the posterior portion is positioned in the supra-choroidal space

Results

This procedure is indicated for primary or secondary open-angle glaucoma. Only a few clinical studies have been published in the literature and they report that the IOP reduction is comparable to those provided by other MIGS. Similarly, the rate of complications, such as transitory hypoema, is low and mild. Sometimes, thin membranes may form on the surface of the implant. They may occlude the anterior or posterior holes and lead to a rise in IOP.

The CyPass Micro-Stent

Introduction

The CyPass Micro-Stent is a minimally invasive supra-choroidal device implanted using an *ab-interno* approach

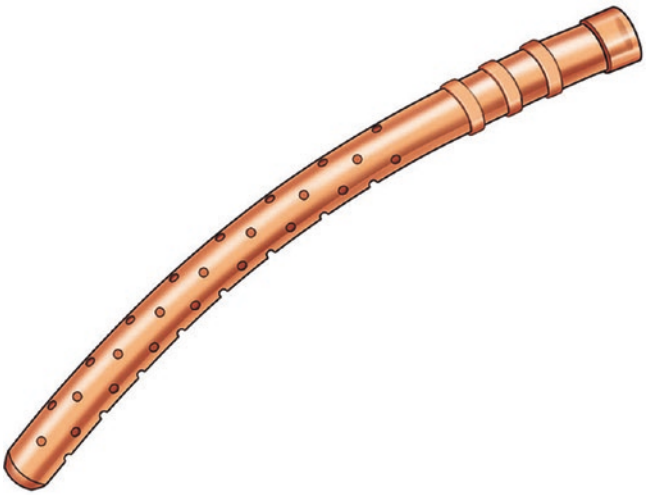

Fig. 11.9 The CyPass Micro-Stent. The device consists of a tube, 6.35 mm long, with an external diameter of approximately 0.5 mm and a lumen of 300 μm. There are fenestrations along the length of the device for the drainage of the aqueous humor

(that will avoid manipulation of the conjunctiva and the sclera). It has been produced in a biocompatible and not biodegradable material, similar to the polyamide used to create the loops of the IOL.

Surgical Technique

The implantation technique is relatively simple, and associated with a fairly short learning curve, even for young and less experienced surgeons. The device can be inserted through an incision in clear cornea; this can be an isolated procedure or it can be performed in combination with phacoemulsification. For this type of procedure, the surgeon sits in a specific position, as described in Chap. 7 for goniotomy: he sits on the side opposite the portion of the angle he wishes to operate on. The patient's head is rotated slightly on the opposite side with respect to the surgeon. The operating microscope is tilted 30°–45° to consent excellent visualization of the angle.

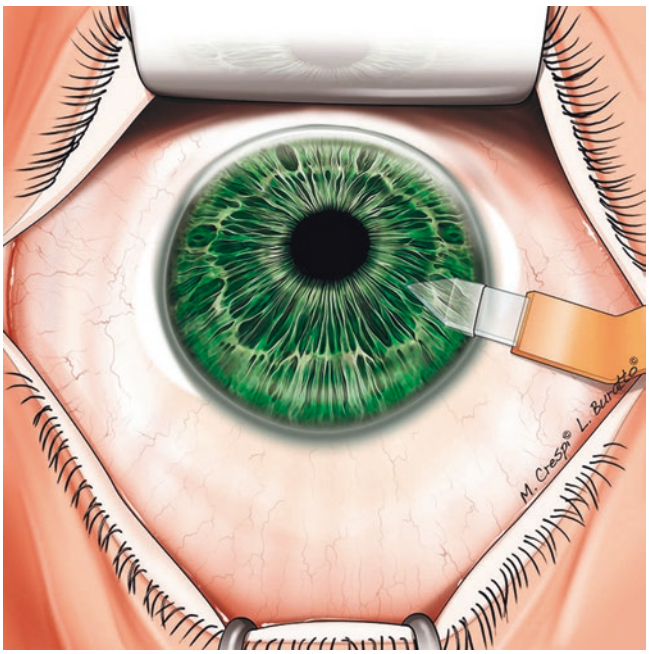

Fig. 11.10 The corneal incision. The drawings that follow illustrate the various surgical steps. An incision measuring 1.2–1.5 mm is created in clear cornea, parallel to the iris. The incision should be created in a position opposite the site identified for the implant and should be close to the limbus

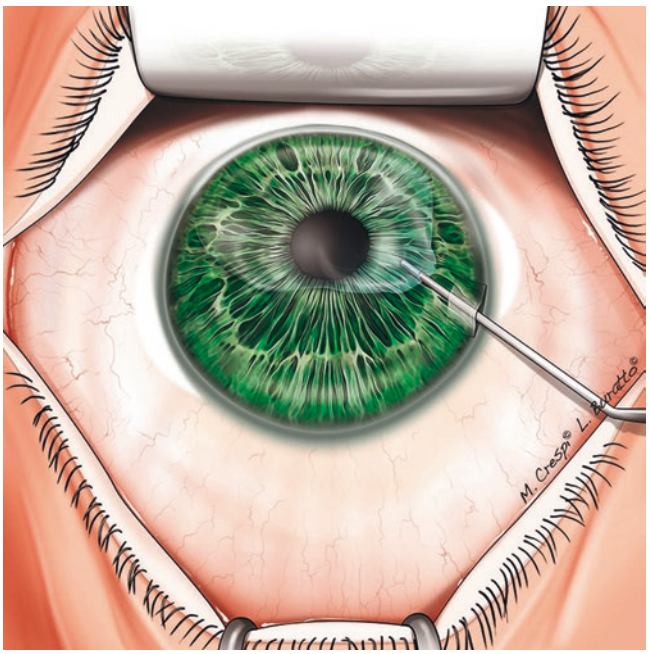

Fig. 11.11 Introduction of VES in the AC. Introduction of VES in the AC maintains the AC volume, extension of the camerular angle and the successive entrance of the device: in this maneuver, the surgeon must avoid the creation of air bubbles in the AC that can reduce visualization of the camerular angle

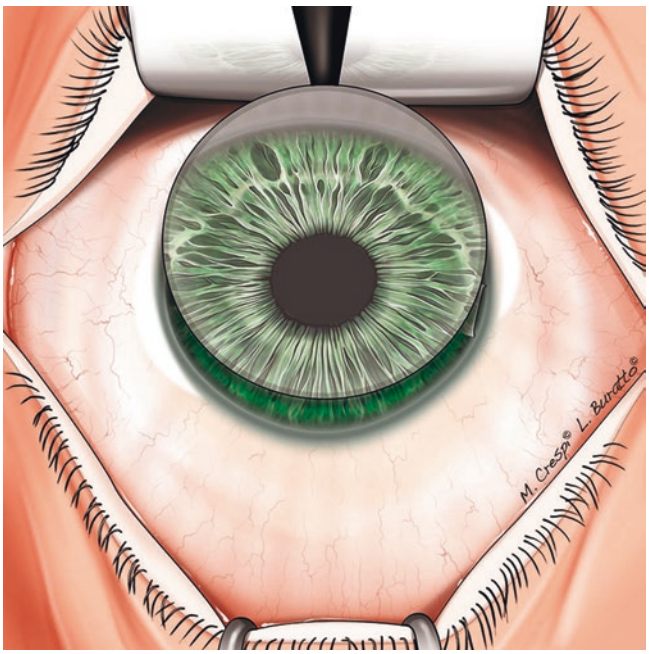

Fig. 11.12 Gel and goniolens placement on the cornea and angle vision check. Now the surgeon places gel on the cornea and the goniolens and controls his vision of the angle. Nevertheless, some authors suggest implanting the device without using a goniolens. He will normally use a modified Swan-Jacobs lens: high magnification (10–12×) is recommended. Generally-speaking, the gonioprism is held in the non-dominant hand; the surgeon exerts mild pressure to maintain a uniform meniscus of gel on the cornea. Excessive pressure exerted in this phase can create corneal folds that can obstruct vision of the angle. When the reference points have been identified (the scleral spur, the trabeculate and the root of the iris), the surgeon concentrates on implanting the device

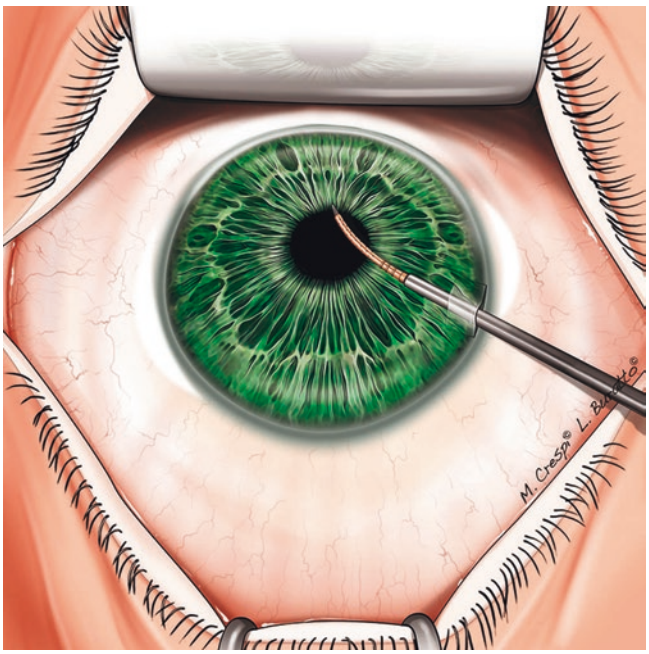

Fig. 11.13 Removal of the goniolens and insertion of the implant in the AC. The device is positioned in a small curved injector. The surgeon inserts the injector in the AC, proceeds as far as the angle and beyond the pupil margin

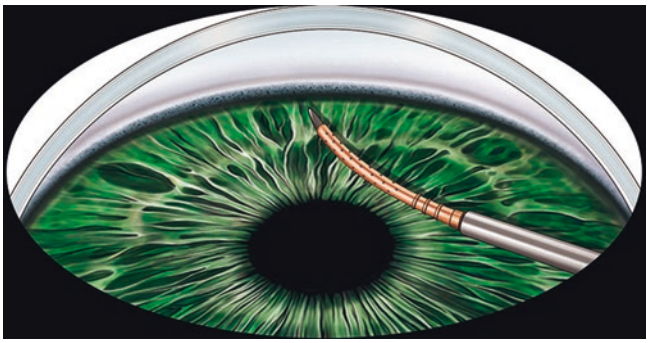

Fig. 11.14 Repositioning the goniolens and positioning the implant. Holding the goniolens in the non-dominant hand, the surgeon proceeds with the implantation procedure using the dominant hand. In this drawing, the device is positioned close to the angle

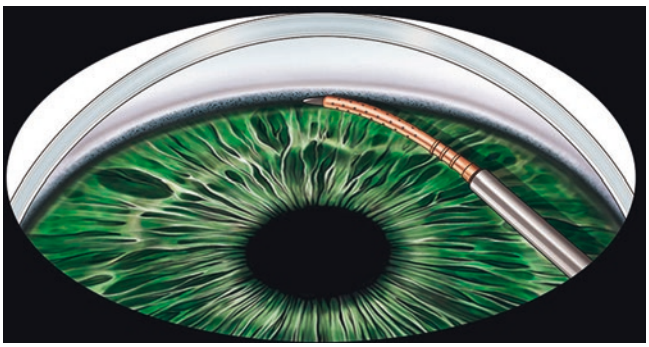

Fig. 11.15 Insertion of the device. Again, holding the goniolens in one hand, the surgeon proceeds with the insertion of the implant held in the other hand. The guide of this device has a blunt distal portion that allows the non-traumatic dissection of the ciliary body from the sclera, creating micro-cyclodialysis. The trabeculate is not cut. The device must be positioned with the distal portion underneath the scleral spur in the ciliary body and supra-choroidal space with the proximal collar in the AC. The device is injected very slowly: the curved shape of the injector allows the procedure to follow the natural curvature of the eyebulb. In Fig. 11.15, the surgeon is positioning the distal portion of the device, while Fig. 11.16 shows the positioning of the proximal collar. Once the device is positioned correctly, the injector is withdrawn. Some authors connect Healon 5 to the injector: some surgeons prefer to inject 60 µl of VES in the supra-choroidal space to encourage patency

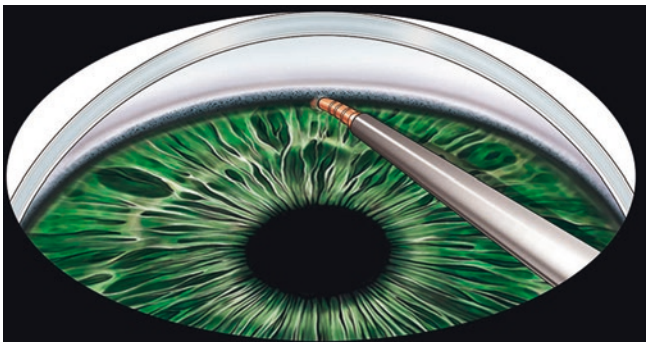

Fig. 11.16 Insertion of the device. Again, holding the goniolens in one hand, the surgeon proceeds with the insertion of the implant held in the other hand. The guide of this device has a blunt distal portion that allows the non-traumatic dissection of the ciliary body from the sclera, creating micro-cyclodialysis. The trabeculate is not cut. The device must be positioned with the distal portion underneath the scleral spur in the ciliary body and supra-choroidal space with the proximal collar in the AC. The device is injected very slowly: the curved shape of the injector allows the procedure to follow the natural curvature of the eyebulb. In Fig. 11.15, the surgeon is positioning the distal portion of the device, while Fig. 11.16 shows the positioning of the proximal collar. Once the device is positioned correctly, the injector is withdrawn. Some authors connect Healon 5 to the injector: some surgeons prefer to inject 60 µl of VES in the supra-choroidal space to encourage patency

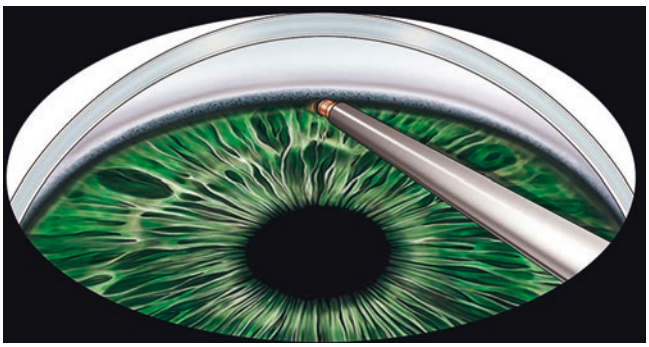

Fig. 11.17 Visualization and control of the correct position of the insert. Only 1–2 rings of the distal portion of the device must be observed. If the surgeon observes more than two rings, it is probable that the device touches the cornea

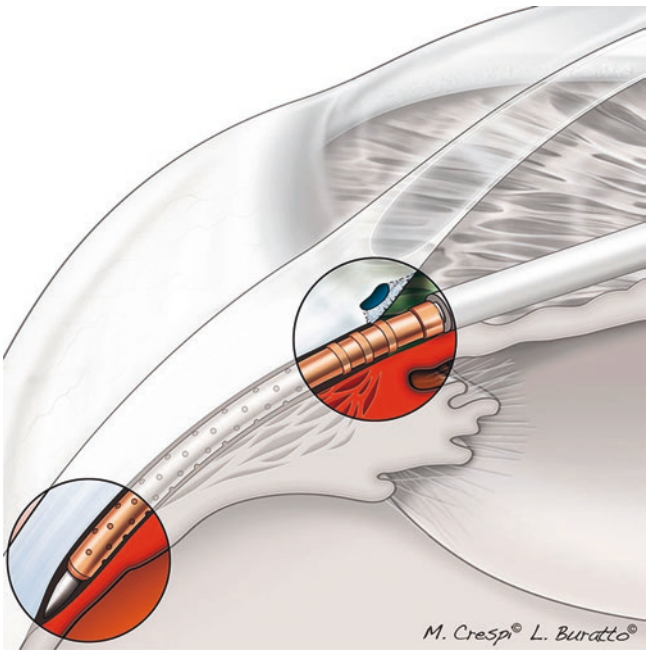

Fig. 11.18 Sagittal view of the correctly-positioned device. As mentioned previously, the device must be positioned with the distal portion underneath the scleral spur in the ciliary and supra-choroidal space (see the *circle* on the left of the drawing) and the proximal collar in the AC (see the *circle* on the right of the drawing)

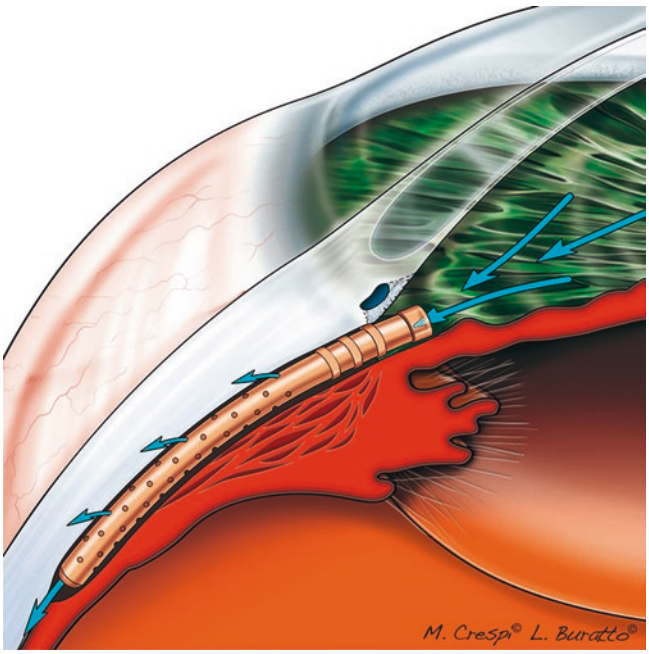

Fig. 11.19 Mechanism of action of the CyPass Micro-Stent. The aqueous humor drains from the AC into the supra-choroidal space (see the *blue arrow*)

Final Phases of the Procedure

At the end of procedure, the surgeon proceeds with the removal of the VES from the AC; this is followed by hydrosuture and thread suture closure of the corneal incision. Following the hydrosuture, the surgeon should check for leakage; if leakage is observed, he should add a 10.0 nylon suture.

Results

This device has been developed for the treatment of open-angle glaucoma. The procedure will to a reduction in the IOP in the majority of cases. The scientific literature also reports that the best tonometric results appear to be achieved when the procedure is combined with phacoemulsification (compared to the isolated procedure). In terms of the safety profile, insertion of the CyPass Micro-Stent is a procedure with a low incidence of complications (the same as the other MIGS procedures). Hypoema may be observed; however, this usually resolves spontaneously. Obstruction of the stent may occur in the postoperative period. This may be caused by endocapsulation of the device. There is a very low incidence of athalamia (shallow chamber) with hypotonia.

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Ab Internal Stent

12

Luigi Caretti and Lucio Buratto

Introduction

These devices also belong to the group of MIGS techniques. As mentioned in previous chapters, the MIGS procedures reduce the intraocular pressure (IOP) and improves the outflow of aqueous humor (and to a lesser degree, reduces the production of aqueous by the ciliary bodies). The devices that increase the aqueous humor outflow can influence various physiological pathways: some procedures improve the drainage of the aqueous humor into the Schlemm Canal by removing the resistance by the trabeculate (the conventional drainage pathway) or by by-passing it. Other procedures improve uveo-scleral drainage (non-conventional drainage pathway) creating a connection between anterior chamber (AC) and the supra-choroidal space. The micro-incisional approach of MIGS is for the most part *ab interno;* this would appear to be less invasive and avoids incisions and the scars of the conjunctiva and sclera, preserving the natural drainage pathways for the aqueous humor (even though some authors believe that the *ab externo* approach can be equally successful). One new *ab interno* device with a sub-conjunctival approach is the Xen Glaucoma Implant.

The XEN Glaucoma Implant

Recently Aquesys Inc. (Aliso Viejo, CA) proposed a new *ab interno* sub-conjunctival procedure to obtain a reduction of the IOP in patients affected by open-angle glaucoma. The device is called the XEN Glaucoma Implant; it consists of a gelatine network. It is implanted using a minimally-invasive *ab interno* approach; it facilitates the outflow of the aqueous humor from the AC into the sub-conjunctival space created. Specifically, this device is cylindrical and consists of a biocompatible, hydrophilic gel (a collagen-derived glutaraldehyde of pig origin); it is 6 mm long and has a variable internal diameter for the three models available. During the implantation procedure, the device is hydrated by the aqueous humor; it swells in situ to become a drainage canal consisting of gelatine that is stable, permanent and flexible. The fact that this material is soft and adapts well to the tissues minimizes potential problems associated with the presence of synthetic materials, such as migration, erosion and damage to the corneal endothelium. The Xen Glaucoma Implant reduces the IOP through the creation of a permanent outflow pathway for the aqueous humor, from the AC to the sub-conjunctival, by-passing the resistance to the outflow (from the trabeculate, the juxta-canalicular tissue, the Schlemm Canal and the collector canals). Outflow through the device is slow and diffused in the sub-conjunctival space (a healthy, intact tissue that has not been cut). A bleb is formed here, guaranteeing maximum efficacy regarding the reduction of the IOP. The resulting drainage is different from the outflow below the bleb following the traditional *ab externo* trabeculectomy. After this procedure, the sub-conjunctival bleb is diffused

Fig. 12.1 The injector for the XEN implant. The XEN injector is pre-loaded and disposable (mono-use)

Fig. 12.2 Close-up of the distal portion of the injector. The implant is contained in the needle in the distal portion of the injector

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and slightly elevated, different to the bleb created following the trabeculectomy procedure; moreover, the wall of this bleb is thicker than the bleb created with the trabeculectomy. One of major advantages of this procedure is that this mechanism of action consents better control of the outflow over time compared to the trabeculectomy. It also eliminates the risk of reducing the efficacy of the implant due to any obstruction to the outflow; finally, it reduces the risk of complications associated with the traditional bleb. There are several potential outflow pathways for the aqueous humor from the sub-conjunctival space: diffusion through the conjunctiva, diffusion into the venous system of the sclera and the conjunctiva, and finally diffusion through the lymphatic system. As mentioned earlier, there are three models available (with different internal diameters) and each can provide a different degree of control of the IOP and are consequently suitable for different pressure targets. This implant can be repeated in time (multiple implants), if necessary at any stage.

Surgical Technique

As mentioned previously, the implant requires an *ab interno* approach and is implanted using an injector.

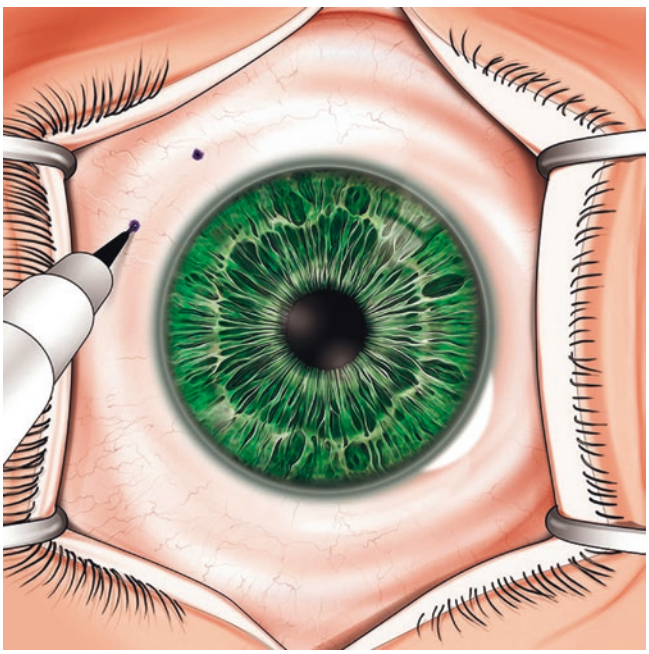

Fig. 12.3 Conjunctival marking 3 mm from the limbus. For greater precision, the surgeon should use a dermographic pen to mark two points of the conjunctiva, 3 mm from the limbus, in the nasal-superior quadrant for example

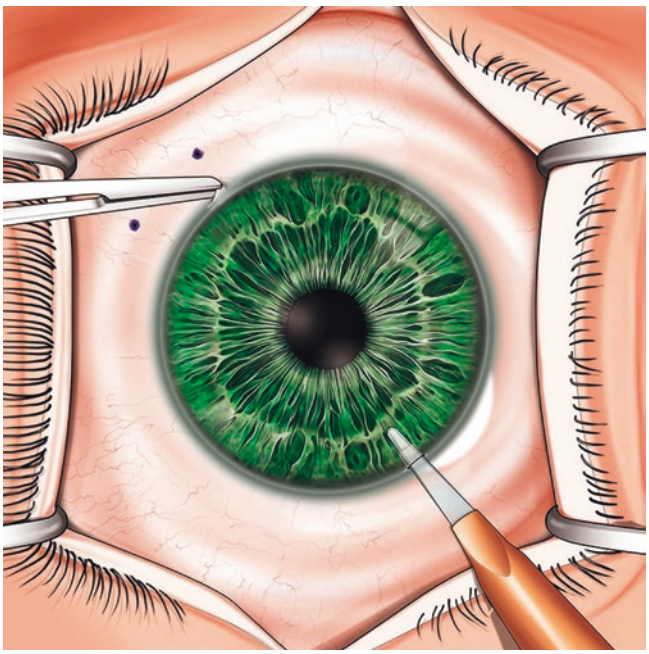

Fig. 12.4 Peripheral corneal incision. The surgeon must create a peripheral corneal incision, 1–1.2 mm long, in the sector that is diametrically opposite to the implantation site, for example, in the temporal-inferior quadrant. When a learning surgeon is performing his first procedures, we would recommend filling the AC with a cohesive VES to expand the spaces

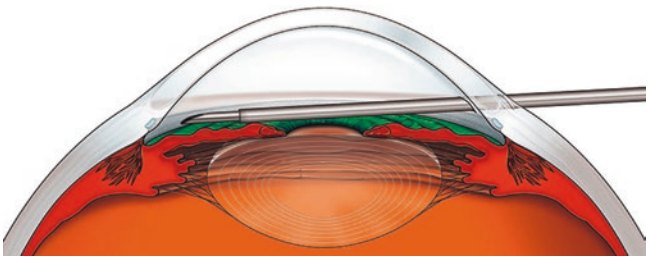

Fig. 12.5 Insertion of the injector into the AC towards the camerular angle. Through the AC, the tip of the injector is directed towards the camerular angle, preferably in a bevel-down position. The figures show a sagittal view (Fig. 12.5) of the procedure and a view from above (Fig. 12.6)

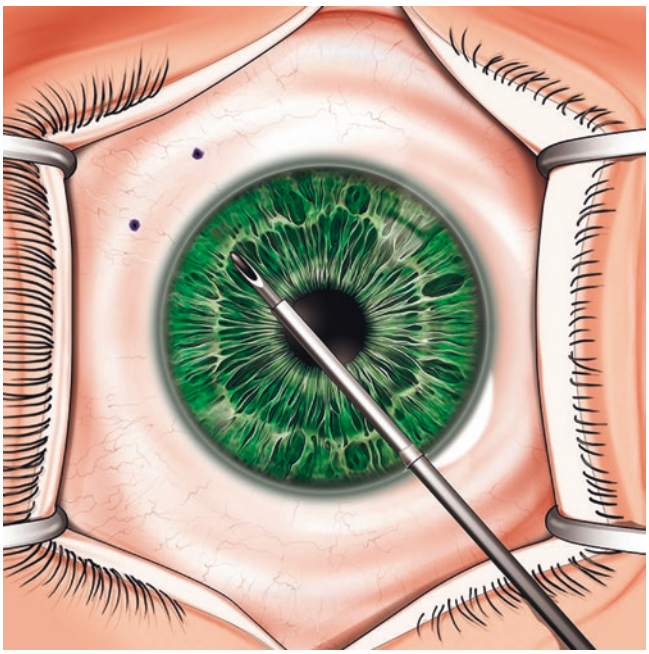

Fig. 12.6 Insertion of the injector into the AC towards the camerular angle. Through the AC, the tip of the injector is directed towards the camerular angle, preferably in a bevel-down position. The figures show a sagittal view (Fig. 12.5) of the procedure and a view from above (Fig. 12.6)

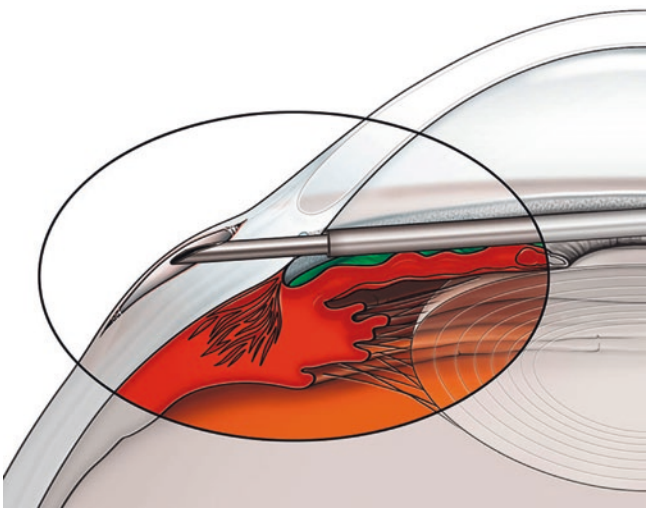

Fig. 12.7 Penetration of the sclera and the sub-conjunctival space. Compared to the other MIGS procedures, in this case the entrance zone to the angle is not well-defined: as maximum precision is not essential, the procedure can be performed without a gonioscopy lens. The needle can penetrate the camerular angle at any point, from the Schwalbe line to the scleral spur. The tip is guided through the sclera into the sub-conjunctival space, creating a slit. The tip's bevel exits the sclera (the intrascleral tunnel measures 3 mm) and extends for approximately 3 mm posterior to the limbus: in this phase, the tip should emerge inside the sub-conjunctival space between the two marks (see the *blue arrows* in Fig. 12.8). Given that the bevel lies almost parallel to the conjunctiva in the sub-conjunctival space, conjunctiva perforation with the tip bevel exiting the sclera can be easily avoided. The surgeon can directly observe the entire bevel of the tip in the sub-conjunctival space. The figures show a sagittal view (Fig. 12.7) of the procedure and a view from above (Fig. 12.8)

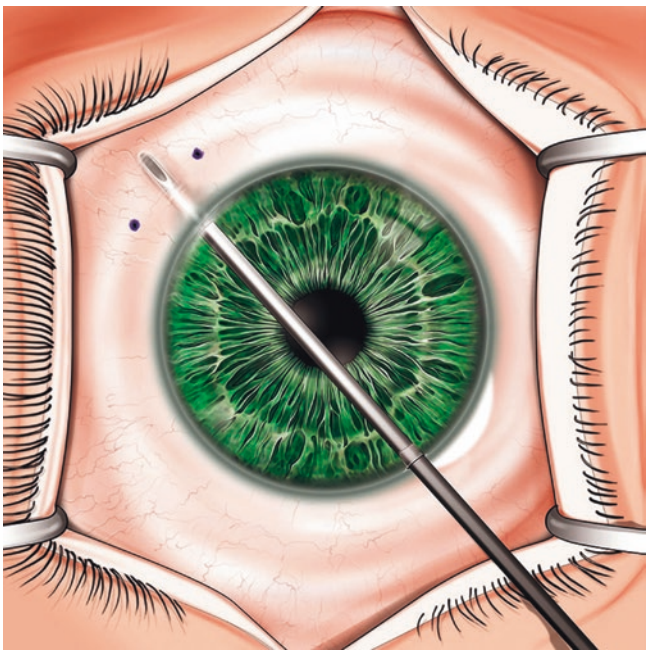

Fig. 12.8 Penetration of the sclera and the sub-conjunctival space. Compared to the other MIGS procedures, in this case the entrance zone to the angle is not well-defined: as maximum precision is not essential, the procedure can be performed without a gonioscopy lens. The needle can penetrate the camerular angle at any point, from the Schwalbe line to the scleral spur. The tip is guided through the sclera into the sub-conjunctival space, creating a slit. The tip's bevel exits the sclera (the intrascleral tunnel measures 3 mm) and extends for approximately 3 mm posterior to the limbus: in this phase, the tip should emerge inside the sub-conjunctival space between the two marks (see the *blue arrows* in Fig. 12.8). Given that the bevel lies almost parallel to the conjunctiva in the sub-conjunctival space, conjunctiva perforation with the tip bevel exiting the sclera can be easily avoided. The surgeon can directly observe the entire bevel of the tip in the sub-conjunctival space. The figures show a sagittal view (Fig. 12.7) of the procedure and a view from above (Fig. 12.8)

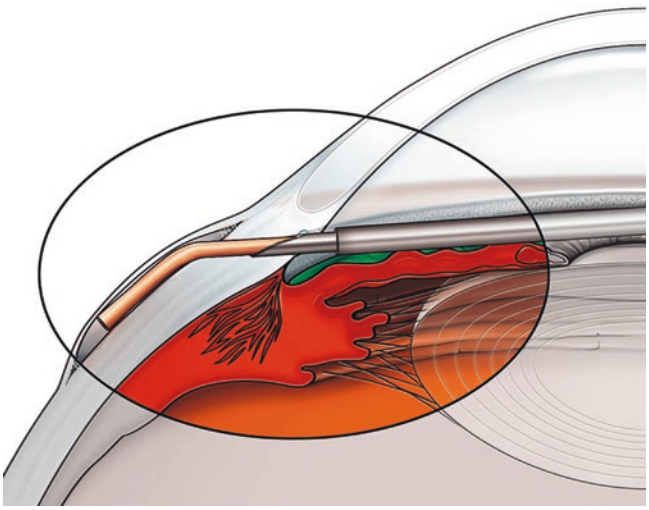

Fig. 12.9 Injection of the XEN implant. The surgeon now releases the XEN Glaucoma Implant in a similar way to a standard IOL. The implant is slowly inserted into the subconjunctival space using the injector's plunger. The figures show a sagittal view (Fig. 12.9) and a view of the procedure from above (Fig. 12.10): in Fig. 12.10, the *blue arrow* indicates the position of the insertion

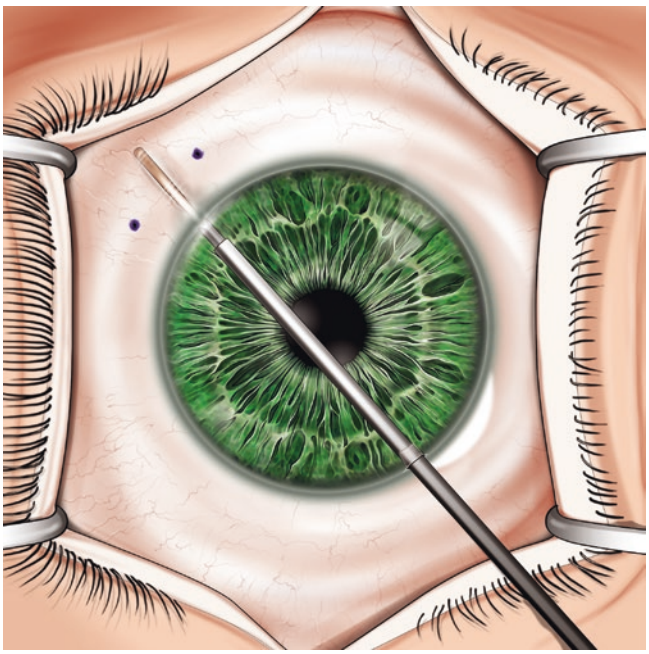

Fig. 12.10 Injection of the XEN implant. The surgeon now releases the XEN Glaucoma Implant in a similar way to a standard IOL. The implant is slowly inserted into the subconjunctival space using the injector's plunger. The figures show a sagittal view (Fig. 12.9) and a view of the procedure from above (Fig. 12.10): in Fig. 12.10, the *blue arrow* indicates the position of the insertion

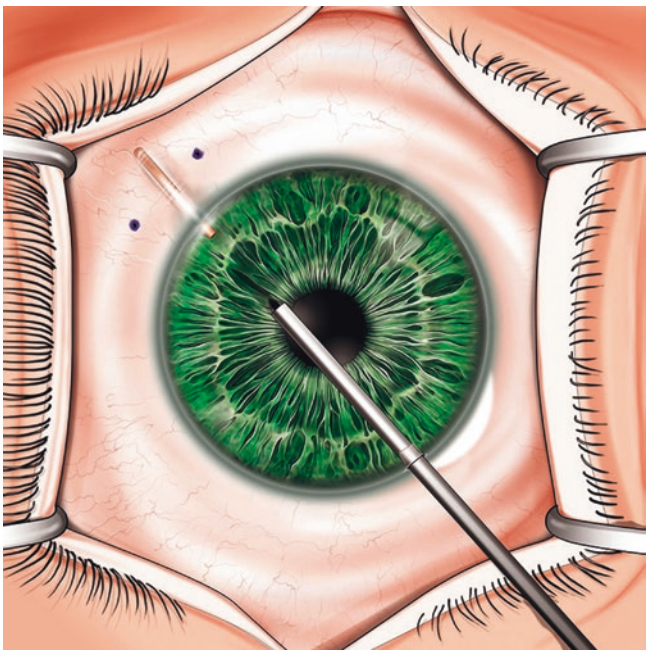

Fig. 12.12 Withdrawal of the tip and removal of the injector. The tip is completely withdrawn into the blunt sleeve of the injector, that is then withdrawn from the eye-bulb. The figures show a sagittal view (Fig. 12.11) and a view of the procedure from above (Fig. 12.12). The surgeon must control that device enters the AC for 1 mm and that it lies in a position parallel to the iris. And finally, any VES injected is removed

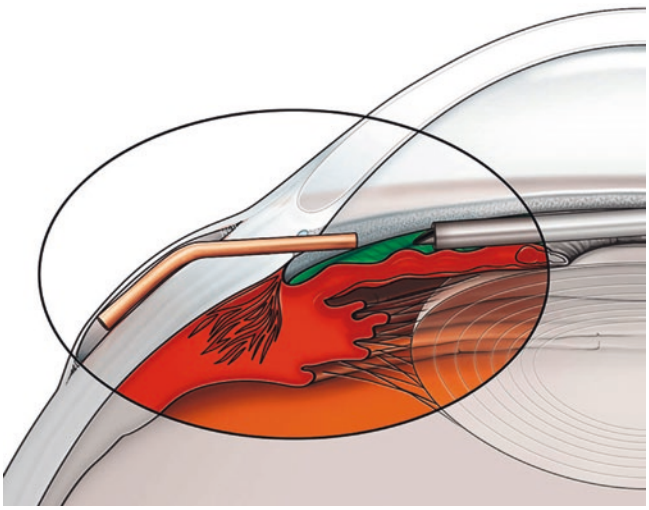

Fig. 12.11 Withdrawal of the tip and removal of the injector. The tip is completely withdrawn into the blunt sleeve of the injector, that is then withdrawn from the eye-bulb. The figures show a sagittal view (Fig. 12.11) and a view of the procedure from above (Fig. 12.12). The surgeon must control that device enters the AC for 1 mm and that it lies in a position parallel to the iris. And finally, any VES injected is removed

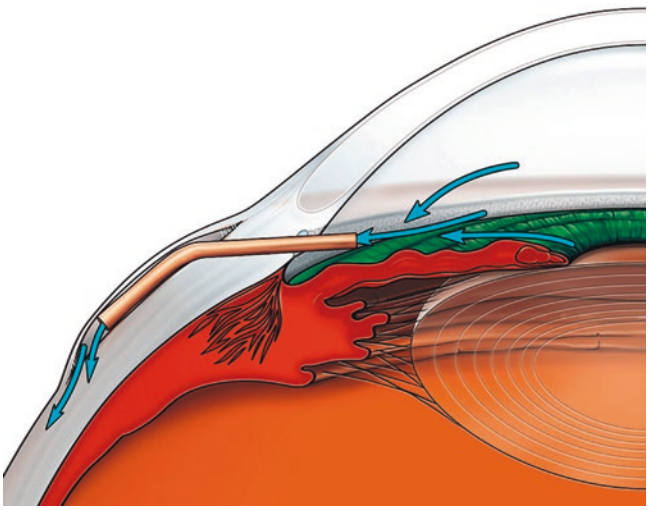

Fig. 12.13 Final position of the implant. This sagittal view shows how the implant is positioned in its final anatomical site: the device must extend partially into the AC (1 mm), through the angle and the sclera (3 mm of intrascleral penetration), extending 2.5–3.5 mm in the subconjunctival space, posterior to the limbus. When the implant has been correctly positioned, the aqueous humor drains from the AC into the subconjunctival space, by-passing the trabeculate, the Schlemm canal and the obstructed collector canals (*blue arrows*)

Results

This implant is indicated for patients affected by open-angle glaucoma. The results of the clinical trials reported in the literature demonstrate the efficacy and the safety of this device. Specifically, some studies have documented the efficacy in cases of mild, moderate, severe and refractory glaucoma, with a follow-up of up to 3 years. As for the other MIGS, this procedure can be combined with phacoemulsification: the implant can be positioned before or after the phacoemulsification procedure.

Medical Antiglaucomatous Therapy

13

Silvia Babighian

Introduction

According to the European Society for Glaucoma Guidelines, the medical therapy to treat glaucoma consists of a first therapeutic approach to reduce the ocular pressure, essential to preserve the patient's visual function. The management of glaucoma becomes more expensive as the severity of the disease increases and numerous clinical studied have clearly demonstrated that by lowering the IOP, the condition may deteriorate more slowly.

A drug for the treatment of glaucoma must have the following characteristics:

- A high pressure-reducing action to achieve the target pressure value
- Constant efficacy over time, throughout the day and in the long-term
- High local and systemic tolerability
- Efficacy with a minimum dose to guarantee good compliance.

There are five classes of drug used in the treatment of glaucoma. Depending on the active principle it contains, the drug has a different mechanism of action (Table 13.1).

The two classes of drugs with the best IOP-reducing capacity are the beta adrenergic receptor antagonists and the prostaglandins. There is no universally 'normal' IOP. It is advisable to lower the IOP by 20/30% with respect to the basal value and, if possible, achieve an IOP that will always be lower than 18 mmHg.

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When determining the target pressure, the surgeon must consider a number of different factors:

- Degree of damage: the greater the pre-existing damage from the glaucoma, the lower the target pressure should be
- The level of IOP that presumably caused the damage: target pressure must always be lower than this value
- The patient's life expectancy: the longer the life expectancy, the lower the target pressure should be
- Speed of progression of the damage: the more rapid the progression, the lower the target pressure
- Concomitant risk factors (family history of glaucoma, myopia …): their presence would dictate a lower target pressure.

Drug therapy should initially be monotherapy to test efficacy, to reduce costs and complications and improve compliance. If the first therapeutic attempt does not produce the desired target pressure, a second drug can be added, with a different active principle. This is because it rarely happens that drugs belonging to the same pharmacological class will mutually enhance the effects. Alternately, to make the medical therapy as simple as possible and to improve patient compliance, a pre-constituted combination of two drugs, with different active ingredients, in a single formulation can be used. The fixed associations play an important role in glaucoma therapy as they will optimize the pressure control in some patients, preventing deterioration of the visual field and preserving visual function (Table 13.2).

The advantages offered by the fixed combinations are:

- They are often mono-administrations
- They have fewer side effects
- There is better patient compliance
- Treatment costs are reduced

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Table 13.1 Antiglaucoma Drugs

Class	Active principle	Brand name	Mechanism of action
Beta blockers	Betaxolol Carteolol Levobunolol Timolol	Betoptic Carteol Vistagan Timoptol, Timogel	Decrease of aqueous production
Carbonic anhydrase inhibitor	Brinzolamide Dozolamide Acetazolamide	Azopt Trusopt Diamox	Decrease of aqueous production
Prostaglandin analogues	Bimatoprost Latanoprost Travoprost Tafluprost	Lumigan Xalatan Travatan Saflutan	Increase of uveoscleral and trabecular outflow
Alpha2 agonist	Brimonidine Apraclonidine Clonidine	Alphagan Iopidine Isoglaucon	Decrease of aqueous production and Increase of uveoscleral outflow
Miotics	Dapiprazolo Pilocarpine	Glamidolo Pilocarpina	Increase of outflow

Table 13.2 Fixed Combination Drugs

Active principle	Brand name
Combination with prostaglandin analogues	
Timolol + Latanoprost Timolol + Travoprost Timolol + Bimatoprost	Xalacom Duotrav Ganfort
Combination with carbonic anhydrase inhibitor	
Timolol + Dorzolamide Timolol + Brinzolamide	Cosopt Azarga
Combination with Alpha2 agonist	
Timolol + Brimonidine	Combigan
Combination with miotics	
Timolol + Pilocarpine	Equiton

Valid medical therapy involves the use of efficacious drugs that successively control the IOP throughout the day (24 h). These must be well-tolerated by the patient as it is well known that many patients will not take their medication as prescribed or will not take the drugs prescribed. They will often ignore the therapies and miss their control visits. Compliance must always be taken into consideration and the surgeon should allocate the necessary time to explain to his patients the nature of the condition, the objectives of therapy and also illustrate any side effects, prior to initiating any medical therapy to treat glaucoma.

Laser Antiglaucomatous Treatments

14

Silvia Babighian

Introduction

In recent years, we have seen large development of laser technology in ophthalmology.

There are various types of laser treatments, suitable for every form of glaucoma (Fig. 14.1). They include the *iridotomy* for closed-angle glaucoma with pupil block, *iridoplasty* for *en plateau* irises, *trabeculoplasty* for open-angle glaucoma, *cyclo-photocoagulation* of the ciliary body for neovascular or refractory glaucoma. Moreover, the laser may also be used after glaucoma surgery to modulate the postoperative IOP through lysis of the sutures following the trabeculectomy or perforation of the Descemet membrane following canaloplasty (goniopuncture).

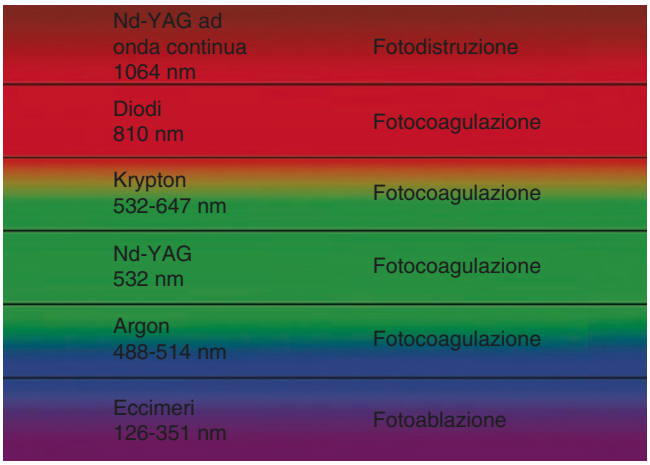

Fig. 14.1 Each type of laser emits a specific wavelength of energy and this determines its mechanism of action

Iridotomy (Fig. 14.2)

The iridotomy procedure is traditionally *contraindicated* in the following cases:

- Corneal edema
- Iris-corneal contact
- Iris rubeosis
- Anticoagulant therapy

This method generally involves the use of a Neodimium-yag: Q-switched laser and includes the following steps:

- Instillation of 1–2 drops of pilocarpine 30–60 min prior to treatment to thin the iris tissue and provide better vision of the crypts;
- Treatment inside an iris crypt (if possible), preferably in the superior sector between 10 and 2 o'clock to avoid diplopia, and in the peripheral section, between the internal 2/3 and the external 1/3 of the distance between the pupil edge and the limbus, to avoid the block of the iridotomy by the crystalline or by the ciliary body (Fig. 14.3).

The laser parameters for the iridotomy procedure are described in Table 14.1.

Generally-speaking, this is an extremely low risk procedure. The most frequent complications observed are pressure spikes 2–3 h from treatment, iritis, small areas of sub-capsular opacity of the crystalline, rare episodes of retinal detachment, cystoid macular edema or late closure of the iridotomy.

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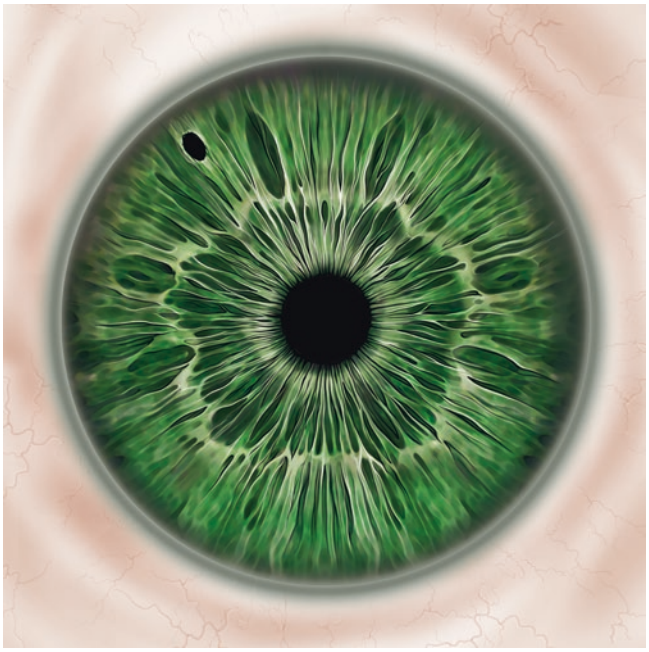

Fig. 14.2 Iridotomy. The objective of the iridotomy is to create small, full-depth holes in the peripheral iris tissue to reduce the pupil block in closed-angle glaucoma (either chronic or following an acute attack). The iridotomy is also indicated in pigmentary glaucoma with the inverted pupil block

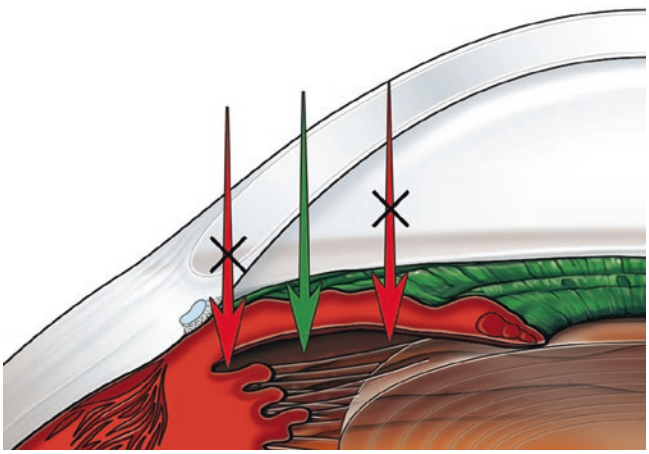

Fig. 14.3 Corrected localization od laser beam during iridotomy

Table 14.1 Laser iridotomy parameters.

Iridotomy: laser settings	
Power	3–10 mJ
Exposition time	30 ns–20 ps
Spot number	1–2
Spot target	Between the inner 2/3 and the outer 1/3 of pupillary border and limbus distance

Fig. 14.4 The most popular lenses used for the iridotomy are the Abraham lens with an optic disk of +66D and the Wise lens with an optic disk of +103D

Iridoplasty (or Gonioplasty)

The indications for iridoplasty are:

- *En plateau* iris (that can be associated with an iridotomy procedure to eliminate the effect of the pupil block)
- Nanophthalmos
- Sectorial angle stricture

Contraindications to iridoplasty are:

- Marked corneal opacity
- Excessively low AC

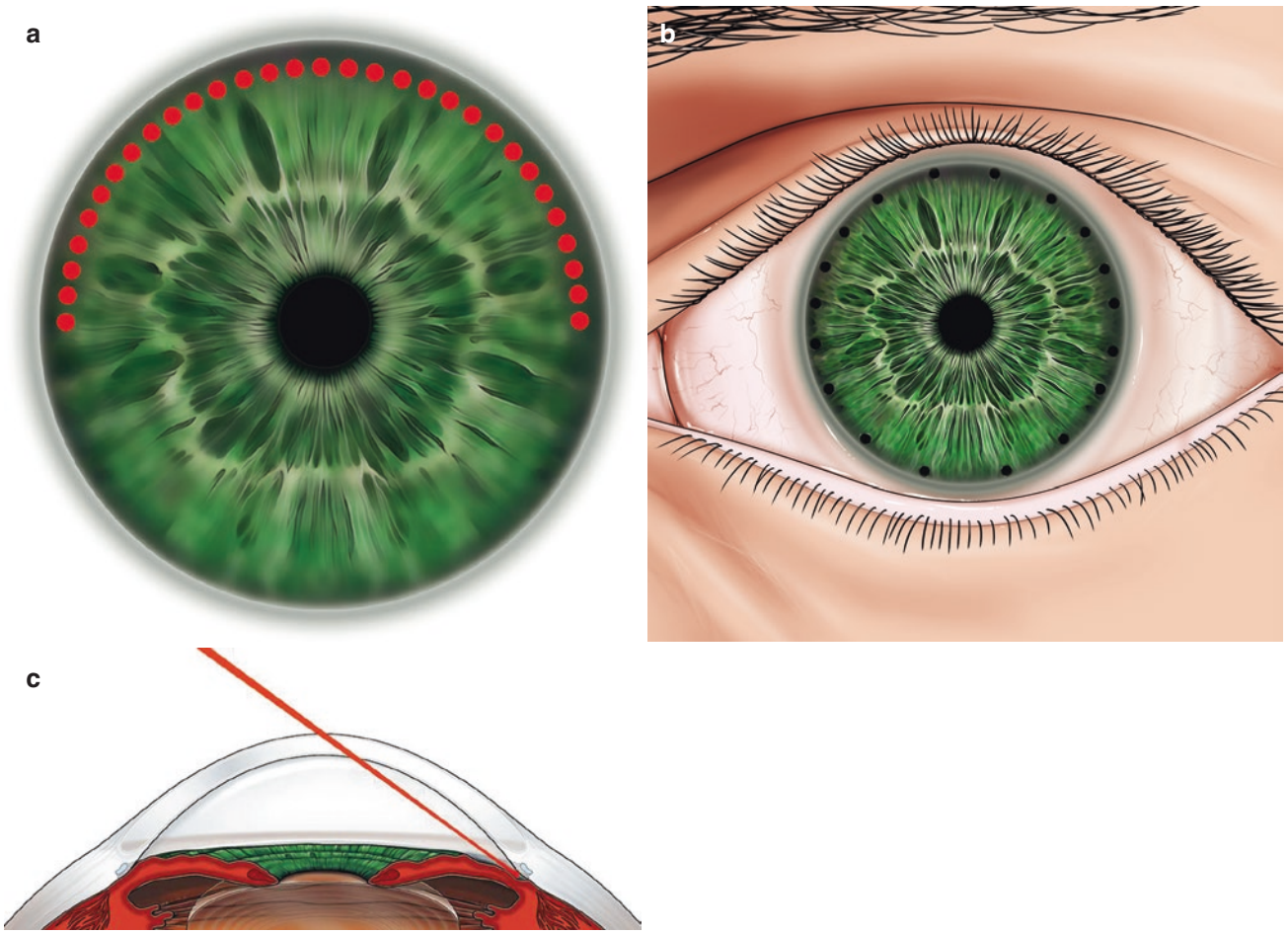

Fig. 14.5 (**a–c**) This is photocoagulative treatment of the extreme peripheral iris that induces retraction and atrophy with consequent widening of the camerular angle

Fig. 14.6 The technique involves the use of a laser: argon or krypton and the use of the Ritch gonioscopy lens

Table 14.2 Laser iridoplasty parameters.

Iridoplasty: laser settings	
Spot diameter	150–200 μm
Power	150–300 mW
Exposition time	0.5 s
Spot number	24–36 (360 grades surface)
Laser target	Iris root

The laser parameters are described in Table 14.2.
The possible complications from iridoplasty include:

- Localized Goniosynechiae (with high energy)
- Transitory ocular hypertonia
- Mild uveitis
- Endothelial burns
- Ease of regression

Trabeculoplasty

Argon Laser Trabeculoplasty (ALT)

The Argon Laser Trabeculoplasty (ALT) is a technique that was proposed by Wise and Witter in 1979. It has always been considered to be the Gold Standard of para-surgical treatments for primary open-angle glaucoma that cannot be controlled with drug therapy (Fig. 14.7).

ALT usually involves the use of an Argon laser. The parameters are indicated in Table 14.3.

The indications for ALT are as follows:

- primary open-angle glaucoma not compensated by maximum doses of drug therapy
- drug intolerance
- poor patient compliance

The contraindications for ALT are the following:

- malformation glaucoma
- narrow or closed angle
- advanced damage from glaucoma
- glaucoma with low pressure, steroid glaucoma

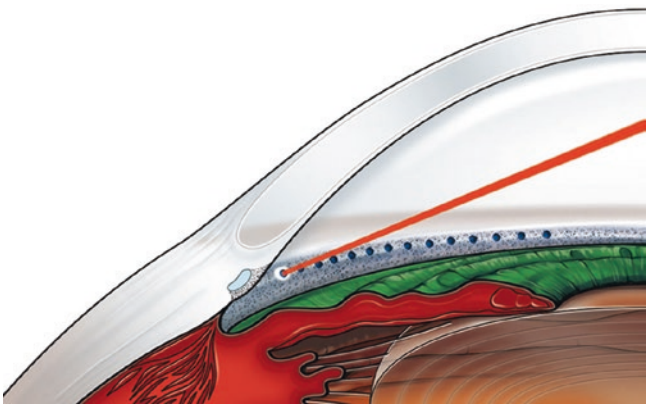

Fig. 14.7 The objective of treatment is to widen the intertrabecular spaces through direct action on the trabeculate

The possible complications include:

- pressure spikes in the initial 2–3 h from treatment
- haemorrhage (a rare occurrence)
- mild iritis
- corneal burns
- late-onset anterior peripheral synechias (Fig. 14.8).

Table 14.3 Laser Trabeculoplasty parameters

Laser settings	ALT	SLT
Wavelength	514 nm	532 nm
Spot diameter	50 µm	400 µm
Power	500–700 mW	0.4–1–4 mJ
Exposition time	0.1 s	3 ns
Spot number	80–100 (360 grades surface)	50 (180 grades surface)/100 (360 grades surface
Target	Anterior trabeculate	trabeculate
Spot features	Separated	Confluent

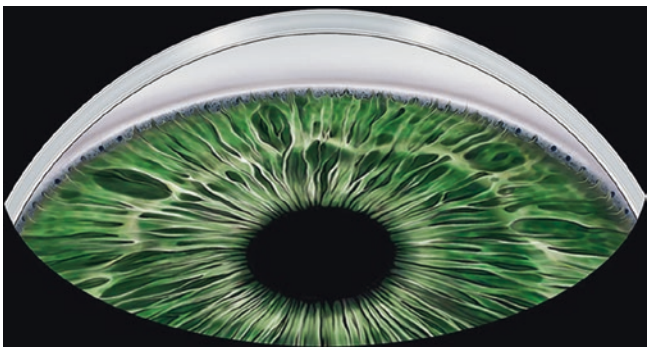

Fig. 14.8 Peripheric anterior synechiae (PAS)

Selective Laser Trabeculoplasty (SLT)

Due to coagulation damage induced by ALT that also affects the healthy trabeculate and demonstrated by numerous studies reviewed under the electron microscope, other lasers have been developed over the years to improve the outflow of aqueous humor. A new, more conservative laser procedure for the treatment of primary open-angle glaucoma is the Selective Laser Trabeculoplasty (SLT), proposed by Mark Latina in 1995 and approved by the FDA in March 2001.

The mechanism of action of the SLT procedure is based on selective photo-thermolysis. The wavelength (532 nm) associated with the pulse speed (3 ns) ensures that the radiant energy emitted by the laser is confined inside the target pigment particles. Only a minimal part is transformed into heat, with no heat dissipation and coagulation damage to the surrounding non-pigmented cells. The architecture of the trabeculate is preserved as demonstrated by studies under the electron microscope.

This method involves the use of a Nd: YAG Q-switched laser with frequency duplication that emits 532 nm, with a short pulse duration and low fluence.

The parameters are indicated in Table 14.3.

Only minimal complications are observed following SLT and these are reduced by the presence of transitory spikes in IOP in the immediate post-operative. The pressure spike appears more easily in the treatment of highly pigmented angles (for example, pigmentary glaucoma, pseudoexfoliative glaucoma). Consequently, it is advisable to use low power levels and treat limited areas of trabecular meshwork. The SLT technique is indicated as the first-line treatment and as an adjunct treatment for the treatment of open-angle glaucoma, particularly in the following cases: persistent hypertonia despite the use of drug therapy, intolerance to the local medical therapy administered, poor patient compliance, previous unsuccessful ALT. SLT is contraindicated in cases of closed-angle glaucoma, neovascular glaucoma, glaucoma caused by cortisone, previous uveitis.

Fig. 14.9 The Latina gonioscopy lens with mirror is normally used as it will provide a clear vision of the trabeculate

Cyclophotocoagulation Using a Diode Laser

Cyclophotocoagulation of the ciliary body using a diode laser is mainly used to treat:

- refractory glaucomas (that do not respond to medical, laser or surgical treatment)
- eyes that are blind or painful due to ocular hypertension
  - aphakic or pseudophakic glaucoma
  - neovascular glaucoma
  - post-keratoplasty glaucoma
- terminal glaucoma
- patients in physical conditions that preclude more aggressive surgical procedures

Among the various types of cyclophotocoagulation (transpupillary, trans-scleral, endoscopic), trans-scleral is the most frequently used, particularly, the contact trans-scleral cyclophotocoagulation. The surgeon uses a diode laser at a wavelength of 810 nm, connected to a G Probe with a shape that adapts well to the sclera-corneal junction (Fig. 14.10)

The laser parameters are described in Table 14.4.

During the treatment, the starting power is increased until the characteristic 'pop sound' is heard; this indicates destruction of the tissue. The surgeon should always avoid intervening at 3 and 9 o'clock to avoid the long ciliary arteries. He will also save the superior sector for any further filter surgery. Some surgeons prefer to use lower energy levels and a greater number of applications. Retreatments are often necessary.

The possible complications associated with cyclophotocoagulation of the ciliary body using the diode laser are:

- persistent inflammation
- hypoema
- corneal decompensation
- reduction of the visual acuity
- hypotonia and phytsis

Post-operative management includes administration of topical corticosteroids + atropine for 2–3 weeks.

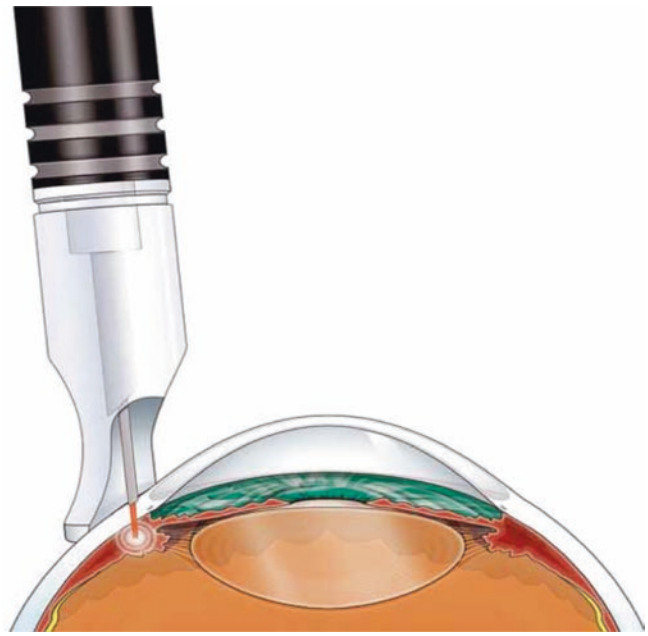

Fig. 14.10 The G-probe is positioned on the limbus to allow direct treatment of the ciliary body

Table 14.4 Diode laser cyclophotocoagulation parameters.

Cyclophotocoagulation laser settings	
Initial power	1500 mW (dark iris) 2000 (soft coloured iris)
Exposition time	1.5–2.5 s
Spot number	10–24 (180–270 grades surface)
Spot target	1.5–2 mm from limbus

Postoperative Laser Procedure

Photolysis of the Suture Closing the Scleral Flap

This step is performed using an argon laser to cut the suture closing the scleral flap created during the trabeculectomy procedure. A Hoskins lens is used (Fig. 14.11) at different postoperative times:

- without anti-metabolites within 7–10 days
- with 5-FU within 14 days
- with MMC within 1 month

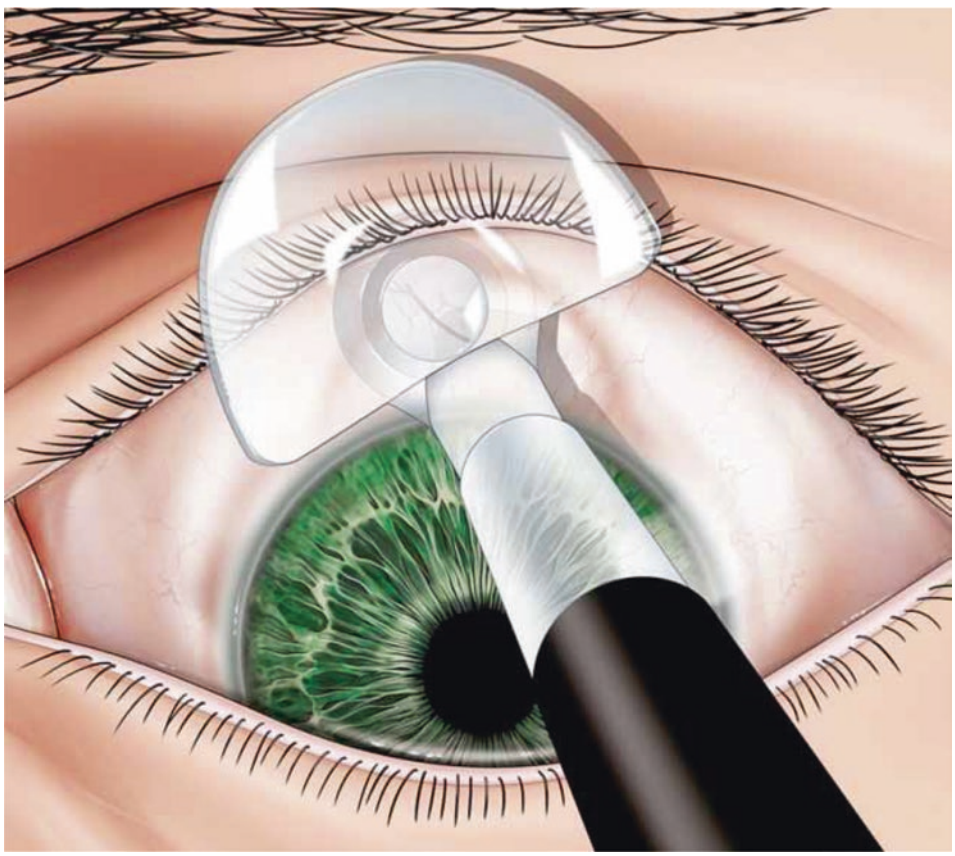

Fig. 14.11 The Hoskins suture lysis lens is positioned over the bleb, compresses conjunctival blood vessels and provides a clear view of the sutures. The flange holds the eye lid out of the way

The laser parameters are as follows:

- spot diameter: 50 μm
- power: 200–400 mW
- time: 0.2 s

Nd:YAG Laser Goniopuncture

Nd:YAG laser goniopuncture is used in cases of postoperative hypertonia following non-perforating procedures (deep sclerectomy, canaloplasty). It can restore the control of the pressure and increase the outflow of aqueous humor from the anterior chamber to the decompression chamber, transforming the non-perforating procedure into a perforating one.

Prior to treatment, two drops of 2% pilocarpine are instilled to avoid any iris involvement; after application of the gonioscopy lens (Goldmann, Ritch, Latina or Laseg), the laser beam is directed onto the Descemet window created by the removal of the deep sclera-corneal flap, in front of the anterior trabeculate. In the case of goniopuncture following canaloplasty, the surgeon should avoid hitting the prolene thread inserted during surgery.

Between 2 and 10 spots are pulsed with an energy level of between 1 and 8 mJ (Fig. 14.12).

Following treatment, the surgeon initiates topical steroid therapy that will continue for a week.

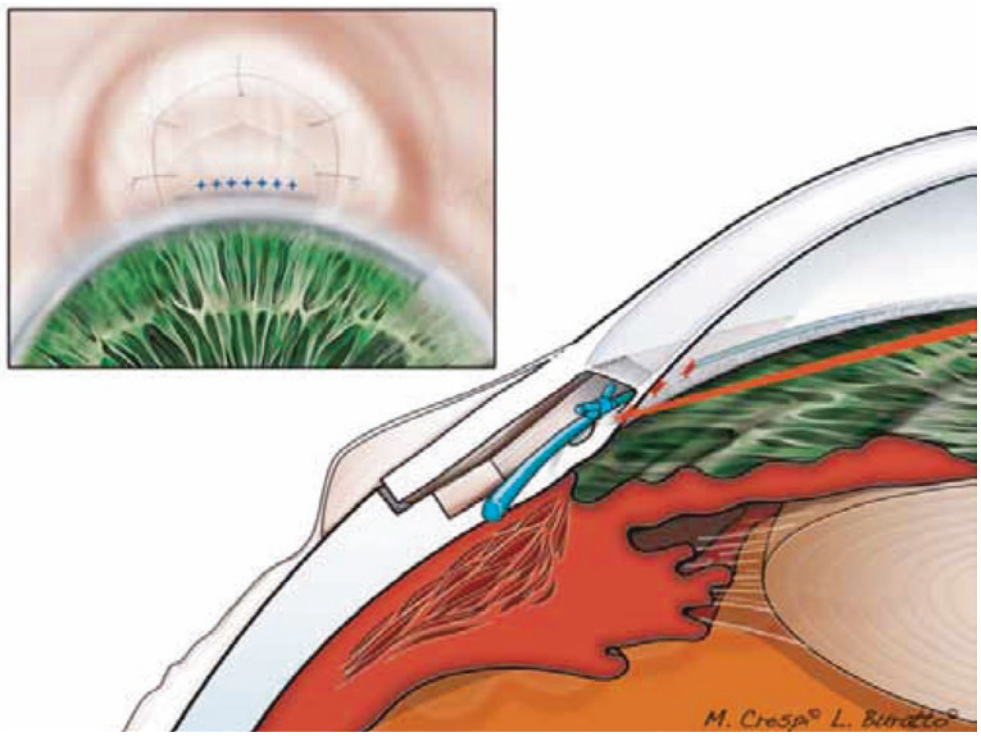

Fig. 14.12 Gonioscopic view subsequent to canaloplasty. When performing goniopuncture, the beam should be targeted approximately 150 to 200 mm anterior to Schwalbe line. The blue stars represent where the targeting beam should be aimed

The Choice of Glaucoma Treatment

15

Silvia Babighian

Introduction

Following detailed and correct diagnosis, the best procedure for the treatment of glaucoma is chosen on the basis of:

- The patient (his/her age, the degree of compliance, his/her life style)
- Glaucoma (the type, the stage of the condition and whether it is associated with other pathologies of the eye).

The therapeutic choice depends on the stage of the condition in cases of **open-angle glaucoma**. In the initial phases, when the optic nerve and the visual field have still been preserved, the surgeon should prescribe drug therapy. If the patient is not adequately compensated, not compliant or is allergic or intolerant to the drugs, a selective trabeculoplasty is recommended; this option is more conservative and associated with fewer side effects compared to the older argon laser trabeculoplasty technique. In the advanced phases, when there has been damage to the optic disc and the visual field that may be progressing, surgery is the best option. One of the techniques available is canaloplasty, a technique that was introduced fairly recently. It is associated with low levels of trauma and the absence of a sub-conjunctival bleb means that the success is not conditioned by conjunctiva fibrosis. Moreover, this technique is an excellent therapeutic option due to the low percentage of complications and the good results reported in the literature in the medium-term. Nevertheless, the long learning curve, the need for dedicated instruments and the fact that it is not always possible to incannulate the Schlemm Canal, induce many surgeons to opt for Cairns trabeculectomy; this is still considered to be the most efficacious surgical approach to achieve the target pressure to arrest the damage induced by the glaucoma. Both these glaucoma procedures can be combined with cataract extraction if present. In the terminal phases or in the event of failure of the standard surgical technique, if there is residual visus, the surgeon can opt to insert a drainage implant. In the event of very poor or absent visual acuity, particularly if associated with eye-bulb pain caused by ocular hypertension, the surgeon may use a diode laser to perform cyclophotocoagulation of the ciliary body, a procedure that has recently been replaced by cycloablation of the ciliary body using ultrasound. In the case of **closed-angle glaucoma** in a young patient or in the initial phases of the disease, the situation can be resolved using local drug therapy (miotics, in particular) and YAG laser iridotomy to resolve the pupil block and avoid any acute episodes. In the full-blown condition of the disease, the surgeon must consider a filtering surgical technique if goniosynecchias are present; alternately, he may opt for the surgical extract of the cataract using phacoemulsification, or the extracapsular extraction if there has been appositional angle closure. In the case of **congenital glaucoma**, the surgical approach is the only valid therapeutic option. If the cornea is transparent, the surgeon can perform a goniotomy (or trabeculotomy) procedure; on the contrary, if the cornea is cloudy, trabeculectomy can be performed, or he can opt for the trabeculectomy. In secondary glaucoma, surgery is the option associated with greatest success. Frequently, it will be associated with laser techniques that may contribute to increasing the success of achieving the target intraocular pressure. In conclusion, each glaucoma treatment must be adapted to the type of patient and to the type of glaucoma. The surgeon must carefully explain to the patient the reasons behind the therapeutic decisions, explaining the risks, the possible complications and the impact these choices will have on the quality of life; he must also explain that if no adequate treatment is available, there may be irreversible damage to the visual function that might even result in blindness.

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Glaucoma Devices

16

Amrit Rai and Iqbal Ike K. Ahmed

Introduction

Glaucoma is a progressive optic neuropathy of unknown origin. It is characterized by an accentuated excavation of the optic nerve head, peripheral loss of the visual field and thinning of the nerve fiber layer. Several risk factors associated with the progression of the disease have been identified; however, high IOP is the only modifiable risk factor. Consequently, the various treatments (topical and systemic drugs, laser procedures and surgery) have the objective of reducing the IOP. In recent years, new minimally-invasive (MIGS) surgical procedures have been developed; these are safe and efficacious therapeutic alternatives beside the traditional surgical procedures, such as trabeculectomy and the glaucoma drainage implants. The modern glaucoma surgeon must be familiar with a wide range of procedures for the treatment of glaucoma. In this chapter, we will examine the surgical approach useful for the implantation of two commonly-used glaucoma drainage devices and three new MIGS procedures that are equally popular.

Glaucoma Drainage Devices

The first glaucoma drainage device was developed by Anthony Molteno in 1966. Since then, new models have been developed with modifications to the basic design (the tube and the plate) that have greater efficacy and ease of implantation. The Ahmed valve (New World Medical, Inc., Rancho Cucamonga, California, USA) and the Baerveldt implant (Advanced Medical Optics, Santa Ana, California, USA) are two drainage devices that are commonly used at the time of writing. These implants are produced in a variety of materials and dimensions and consist of a flexible silicone tube (of length 25.4–32 mm) connected to a plate.

Fig. 16.1 The Ahmed Valve. The valved device developed by Ahmed consists of a silicone drainage tub connected to a plate in silicone, polypropylene or polyethylene, in a range of dimensions (from 85 to 184 mm^2) depending on the model (Fig. 16.1). The aqueous humor drains through the tube to the subconjunctival bleb above the plate. Inside its lumen, the Ahmed valve is fitted with a unidirectional flow limiter based on a Venturi system. This limiter theoretically restricts the aqueous flow when the IOP drops below 8–12 mmHg. The system contributes to a reduction in the risk of ocular hypertension, particularly in the post-operative period when the bleb has still not been encapsulated

Once implanted, these devices drain the aqueous humor from the anterior chamber into a sub-conjunctival blrb above the plate. During the surgical procedure, the plate is fixed at the equatorial region of the eye-bulb. The fibrous capsule above the bleb is the main source of resistance to the aqueous outflow. The presence of thin capsules and the large surfaces of encapsulation are associated to a greater reduction of the IOP.

Implantation, Insertion, Position

The position of the implant must be determined following clinical examination and the results of any previous surgery. Generally-speaking, the drainage devices are implanted in the supero-temporal quadrant, given that the blebs located in the inferior segments are associated with a higher rate of infection.

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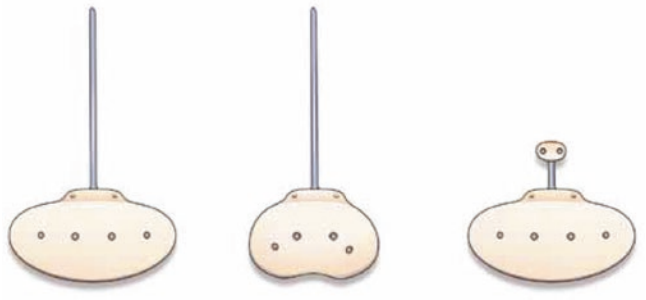

Fig. 16.2 The Baerveldt Implant. The Baerveldt glaucoma draining implant is a non-valved implant. It consists of a silicone tube attached to a round silicone plate impregnated with barium (Fig. 16.2). The terminal plate has a surface area of 250 mm^2 or 350 mm^2, depending on the model. The fenestrations in the plate promote the growth of fibrous bands that will contribute to reducing the profile of the bleb. During the implantation procedure, the Baerveldt Implant requires an external suture around the tube to prevent an excessive outflow of fluid in the early postoperative period. Once the bleb has been encapsulated, the external suture can be removed or it may reabsorb spontaneously. With this temporary suture in place, fluctuations in the IOP may be observed (ocular hypotonia or hypertonia). Nevertheless, this delayed drainage of the aqueous humor may be beneficial, given that the early fluid outflow is often associated with fibrocapsular thickening of the bleb capsule

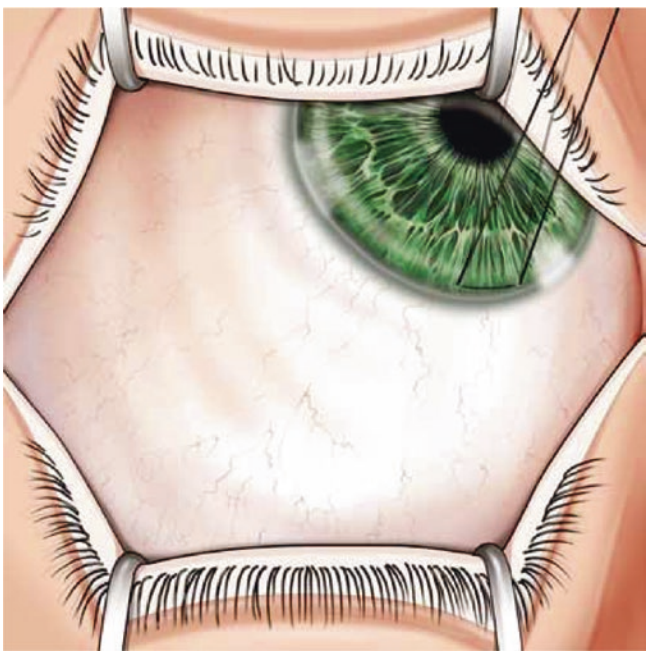

Fig. 16.3 Adjusting the tension of the suture in infero-nasal direction with consequent exposure of the supero-temporal quadrant of the eye. The traction suture serves to position the eye in an infero-nasal direction (Fig. 16.3). This guarantees adequate surgical exposure of the supero-temporal quadrant. A screen to block light must be positioned on the cornea to avoid retinal phototoxicity during surgery

Nevertheless, previous surgery or scar tissue may preclude positioning the device in the superior quadrant. A description of the supero-temporal approach follows: the surgical approaches used to implant the Ahmed Valve and the Baerveldt

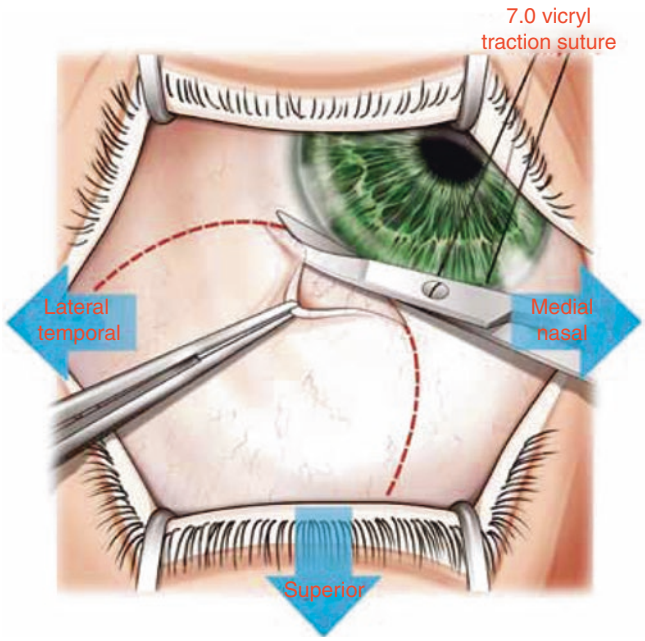

Fig. 16.4 Conjunctival peritomy with fornix based flap. The surgeon must create a conjunctival peritomy with a hinge at the fornix; it must be created at the limbus (and extend for 3 h), using ring forceps and Westcott scissors. The radial incisions of this peritomy must be created posteriorly on the temporal and superior meridians. The anterior edge of the peritomy must lie at the limbus

have many steps in common. The surgical steps for the implantation procedure for both devices is described below, and the differences between the two devices are highlighted. A traction suture in 7.0 vicryl may be passed through the cornea in the superior or supero-nasal sectors, at approximately 1 mm from the limbus. Alternatively, the suture may be passed through the sclera close to the limbus, following the peritomy.

The Baerveldt Implant

The Baerveldt implant must be extracted from its container without being contaminated in any way.

The rectus muscles adjacent to the quadrant chosen for the implant are identified and isolated using muscle hooks. In general, the muscle isolated are the superior rectus and the lateral rectus.

Using forceps, the plate is positioned 9–10 mm posterior to the limbus. Two suture threads in 7.0 Vicryl or 6.0 Prolene are used to anchor the implant to the sclera.

The suture knots must be fixed firmly to avoid micromovements of the device following implantation as this may lead to excessive endocapsulation or trauma to the surrounding tissues. Once the implant has been fixed to the sclera, the free ends of the suture must be shortened. While the surgeon is stabilizing the plate with toothed forceps, the guides for the needle can be used to rotate the suture knots into the implant's

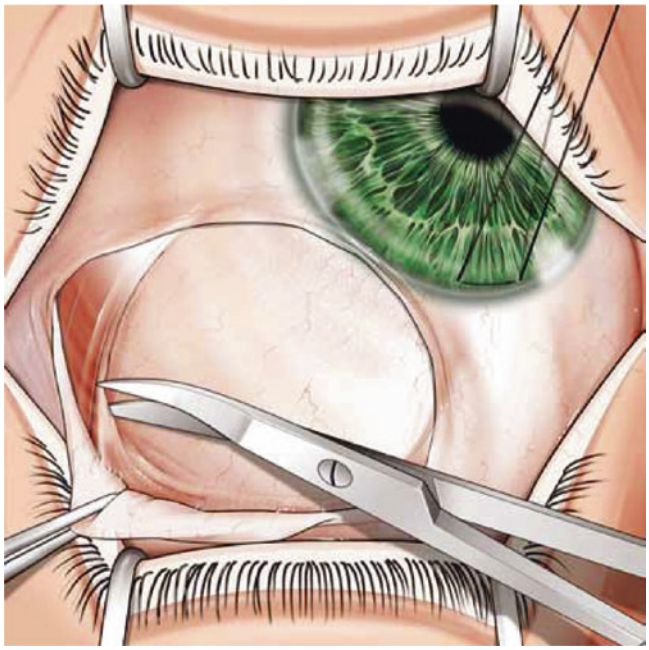

Fig. 16.5 Intermuscular membranes cut under the conjunctival flap. The creation of the conjunctival peritomy with a limbus-based flap is more difficult and is associated with an increased risk of post-operative infections of the bleb. Additional anesthetic agent must be injected into the subconjunctival space below the peritomy to boost the local anesthesia. The conjunctival flap must be extended posteriorly from each edge of the peritomy. Blunt Westcott scissors can be used to mobilize the conjunctiva and cut the intramuscular membrane, if necessary. This step provides adequate access to the posterior scleral surface for the successive positioning of the implant's plate. When a Baerveldt implant is used, the conjunctiva located in the infero-temporal sector must be cut delicately to create an internal pouch that will house the suture at the end of the procedure. Bipolar cauterization can be used to achieve hemostasis of the episcleral vessels beneath the conjunctival flap. The following steps vary depending on the device implanted

fixing holes to prevent the exposure of the knots or erosion of the conjunctiva in the post-operative period. Before proceeding, the surgeon should mobilize the conjunctival flap to ensure that it has not been trapped behind the implant. At this point, the surgeon can release the traction suture and allow the eye to return to its original position.

This thread can now be cut and safely positioned in the conjunctival pouch that was created previously in the adjacent quadrant—normally the infero-temporal quadrant—at an adequate distance from the limbus.

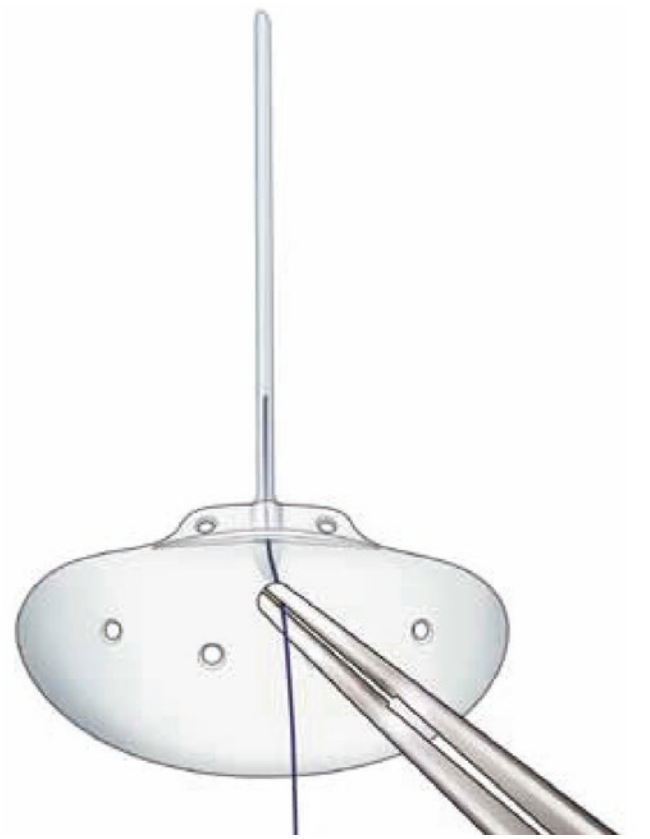

Fig. 16.6 The blue suture is inserted in the device tube at the tube-plate junction. A length of 4.0 nylon thread is positioned inside the tube's lumen (of diameter 0.3 mm) just a few millimetres beyond the tube-plate junction

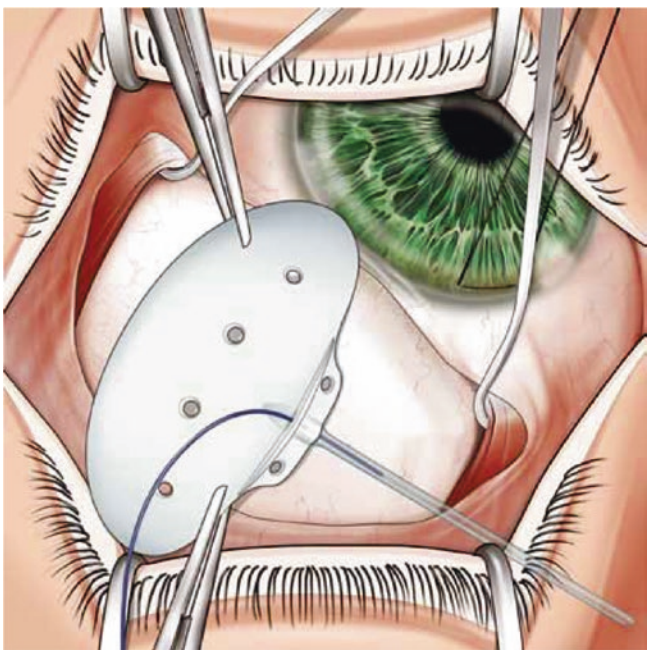

Fig. 16.7 The muscle hooks are used to isolate the superior and lateral rectus and Bearveldt implant is positioned under the muscles. The hooks can be used to position the wings of the implant plate below the rectus muscles

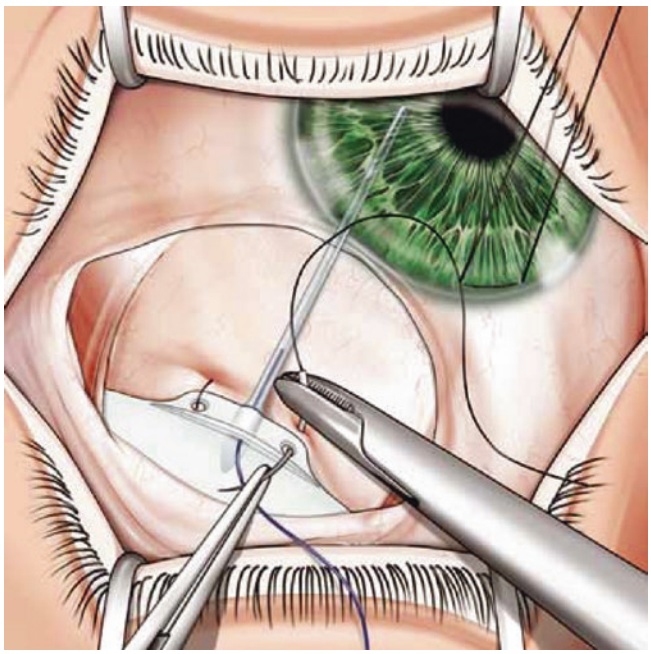

Fig. 16.8 Final position of the device. Fixating sutures are inserted in the two fixating holes on the device (near the tube-plate junction) The proximal portion of the implant's plate has two large holes for fixing to the sclera

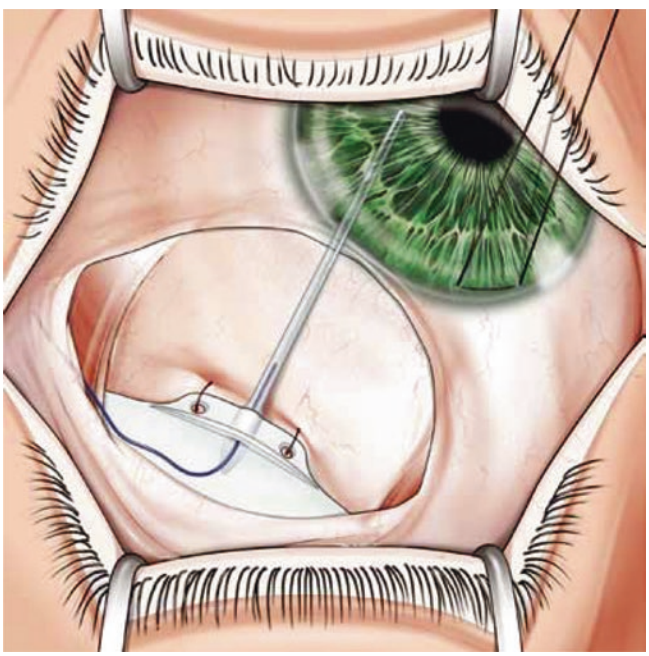

Fig. 16.9 The tube is in the primary position and the surgeon places the free suture end in the conjunctival pouch in the infero-temporal quadrant of the eye bulb. Only 3 mm of the suture should be visible in the tube lumen. A length of nylon 4.0 thread must be pulled so that approximately 3.0 mm are still visible in the distal section of the tube

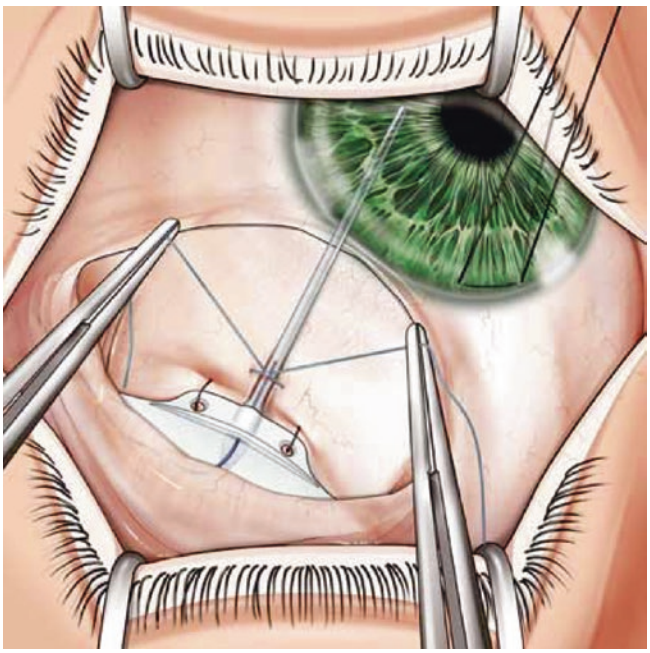

Fig. 16.10 The binding of the suture that forms a knot in the inferior surface of the tube is highlighted. The suture should be tightened enough in order to create an indentation in the tube. A 7.0 Vicryl thread ties the tube above the visible suture zone to guarantee good closure. This biodegradable ligature is used to prevent the unpredictable aqueous flow in the post-operative period and avoid complications associated with hypotonia. The knot must be rotated and positioned underneath the tube. In this way, only the loop of the suture is left on the surface of the tube. This will facilitate the laser lysis of the suture following surgery. High magnification visualization of the ligature can be used to confirm the indentation in the silicone tube created by the suture. The water-tightness can be controlled by injecting BSS into the tube and observing any liquid flow over the plate; liquid flow over the plate indicates that the closure is not watertight

The Ahmed Implant

The Ahmed flexible valved device should be removed from its packing taking care to avoid any contamination. Firstly, the patency of the device must be controlled by injecting BSS using a blunt cannula. The flow through the valve mechanism must be controlled by direct vision. Similar to the Baerveldt implant, the superior and lateral rectus muscles must be identified.

Using forceps, the plate is positioned 10 mm posterior to the limbus. The surgeon must take care to avoid engaging the plate above the valve portion with the forceps, as this could damage the delicate valve structures. Similar to the Baerveldt implant, the Ahmed valved device has two fixation holes in the proximal portion of the plate. Two Vicryl 7.0 sutures are positioned to fix the plate to the sclera. And again, similar to the Baerveldt implant, the fixation sutures must be rotated into the fixation holes.

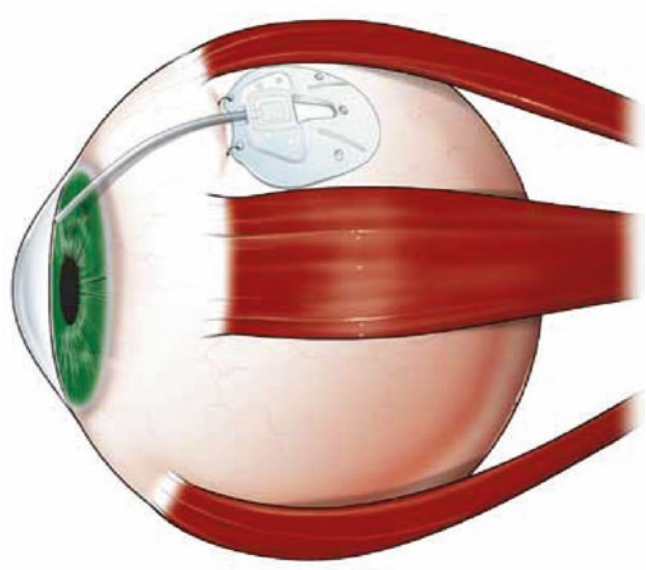

Fig. 16.11 Ahmed implant position. Note that this implant is not positioned under the muscles. The surgeon inserts the relatively small plate of the Ahmed valved device between the two rectus muscles, instead of underneath them

Insertion in the Anterior Chamber

The following steps are similar for both the Baerveldt implant and the Ahmed valved device. With the plate fixed to the sclera, the tube should rest naturally on the cornea.

Using forceps, the tube should be tilted obliquely towards the nasal quadrant and positioned so that it enters the eye at the 12–1 o'clock position, if the left eye is being treated.

This will guarantee an adequate covering of the tube by the eyelid in the postoperative period. This maneuver will allow the surgeon to observe the length of the tube in relation to the ocular structures. If necessary, using forceps and Westcott scissors, the entrance tube can be cut, so that 2–3 mm of tube are visible inside the anterior chamber. The tube cut must be blunt with the bevel facing upwards at an angle of approximately 30° to allow easy insertion and to reduce the risk of occlusion by the iris. At this point, if the surgeon performs the combined cataract and glaucoma procedure, he can begin extracting the cataract using a standard procedure. Following closure of the main corneal incision, the surgeon's attention can turn to the device for the treatment of glaucoma.

A 22 or 23-G needle enters the eye at the scleral spur along a plane parallel to the iris. This orientation will reduce the risk of anterior contact between the tube and the cornea, or posterior contact between the tube and the iris. Similar to the manual positioning of the tube described previously, the needle pass towards the nasal quadrant must be oblique and the tube must enter the eye between 12 and 1 o'clock. This needle pass will be used to guide the entrance of the tube into the anterior chamber. As the surgeon withdraws the needle, the external wound is widened slightly with side-to-side movements of the needle's sharp tip. This dilation will facilitate easier insertion of the tube.

The surgeon holds the tube with forceps and inserts it delicately into the needle pass. When the tube has been inserted, a few millimetres must be visible inside the anterior chamber. The tube must be anterior and parallel to the iris plane.

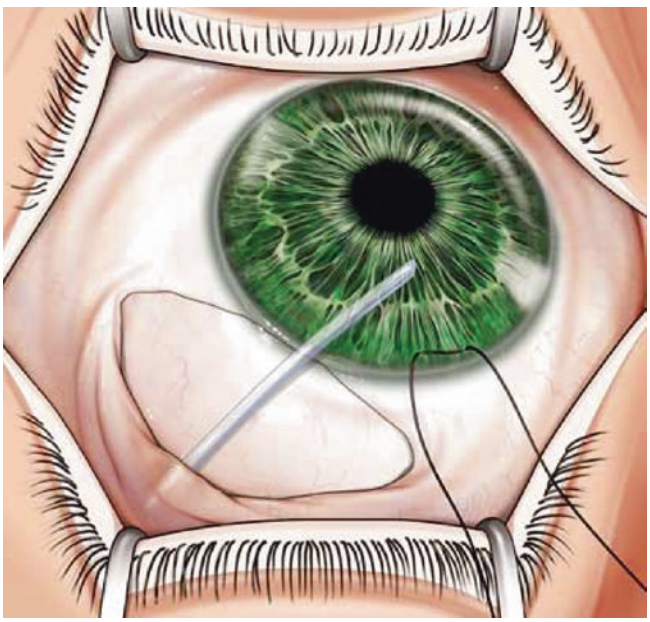

Fig. 16.12 The illustration shows how the tube must be positioned in the eye bulb

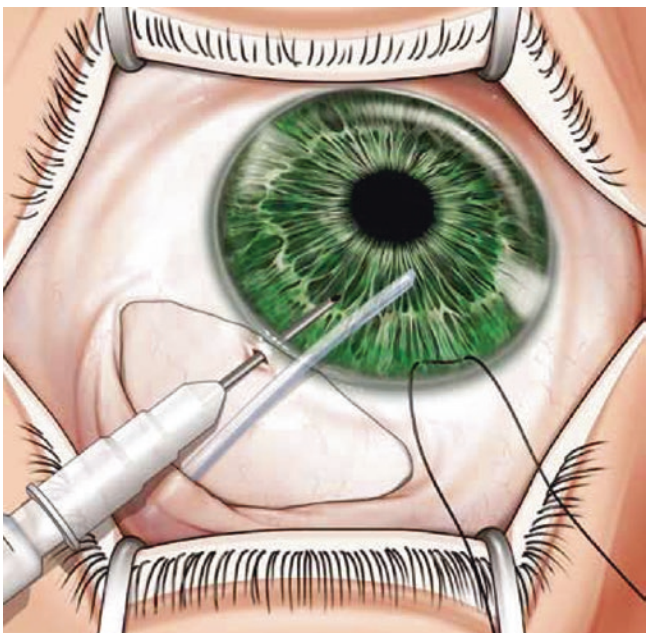

Fig. 16.13 Note that needle tip enters in the anterior chamber with an angle parallel to the iris. The needle enters athwart in the AC. Note that the device tube (on the right) is not inside the AC, but is just placed on the cornea

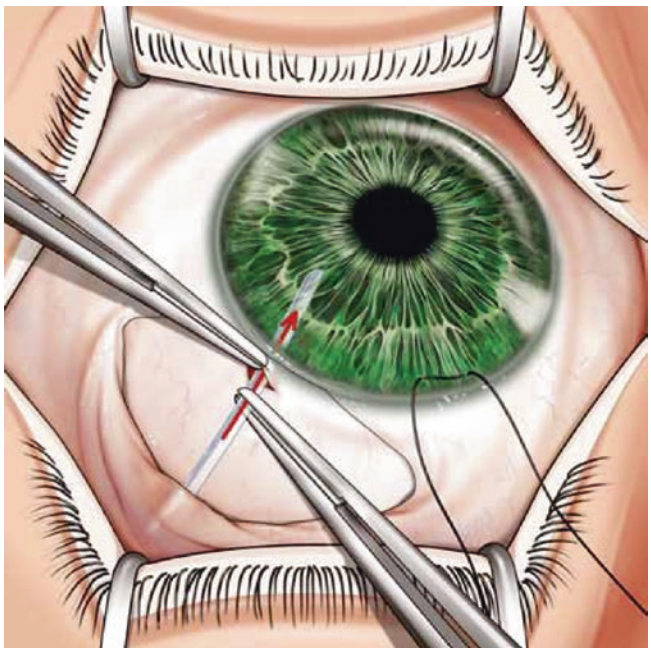

Fig. 16.14 Tube placement in the anterior chamber. The surgeon holds the tube with forceps and inserts it delicately into the needle pass (shown by the direction of the *red arrows*)

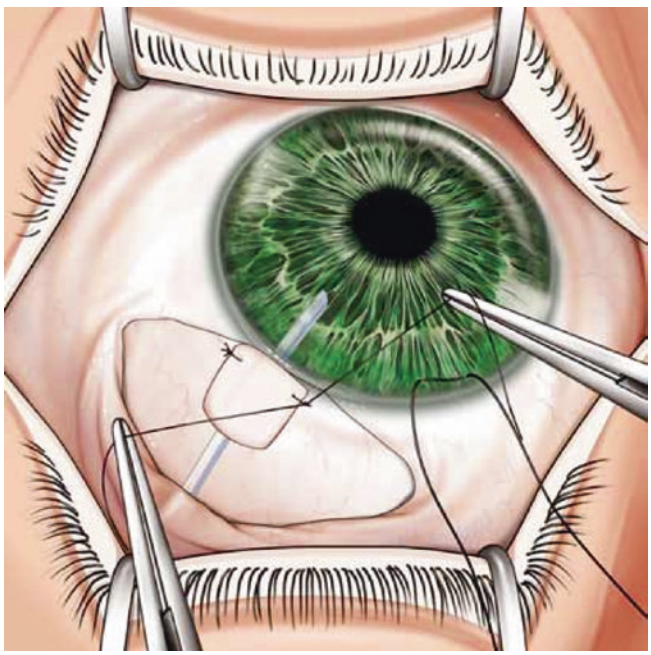

Fig. 16.15 A 3 × 3 mm patch is fixated at the limbus to cover the tube

Covering the Tube

A patch measuring 3 × 3 mm can be positioned above the entrance point of the tube and fixed with two single suture points 7.0 Vicryl to lie adjacent to the limbus. These patches will prevent erosion by the tube through the conjunctiva and they are typically made from scleral tissue. However, patches of pericardium or cornea are valid alternatives. The fixation sutures must not be excessively tight as this may orient the tube upwards.

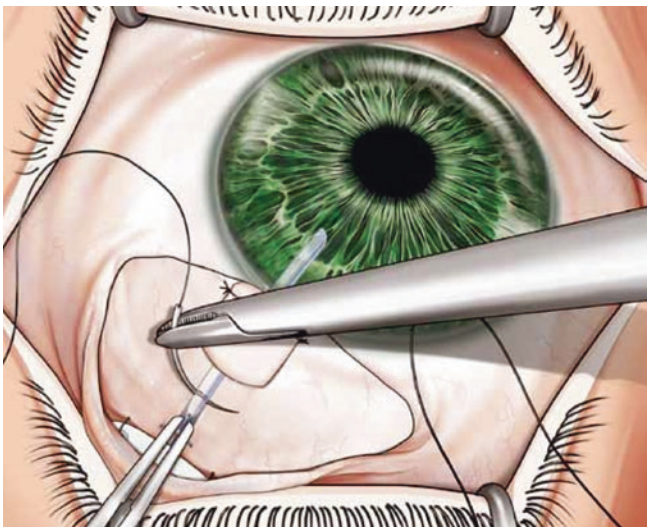

Fig. 16.16 The sharp blade of the needle is used to punch Baerveldt tube lumen. Note that the needle goes through the tube from side to side. Note also that those fenestrations are created between the suture (that can be seen in this illustration as the dark suture inside the tube) and the scleral patch

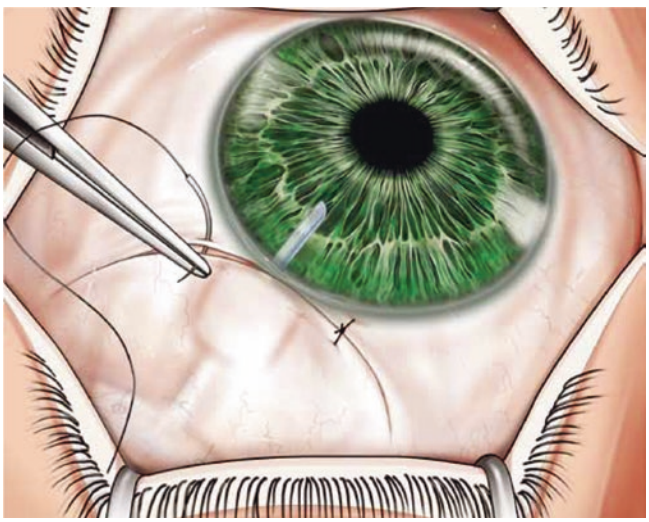

Fig. 16.17 Conjunctiva and Tenon's capsule are sutured to restore the original anatomy. Note that the suture is already placed to close the radial incision in the upright side of the illustration. The surgeon is placing the sutures to close the temporal radial incision

When a Baerveldt implant is inserted, the surgeon may create one-three fenestrations in the lumen of the tube, in the section between the patch and the nylon thread.

The fenestrations must be created in the lateral portion of the tube, given that superior fenestrations may be occluded by the patch above or the conjunctiva. The fenestrations are

created with the sharp tip of the needle. They can be widened by moving the needle tip from side-to-side during insertion of the tube. Liquid flow through the fenestrations can be confirmed by injecting BSS into the anterior chamber. The fenestrations are necessary to provide adequate control of the IOP during the early post-operative period, before the suture thread (ligature) has been absorbed. In the final phase of the surgical procedure, the conjunctiva and the Tenon membrane must be replaced at the limbus using 7.0 Vicryl sutures. It is important that flap covers the anterior portion of the patch. The screen for light positioned on the cornea and the traction suture can now be removed. Maxitrol ointment is used to medicate the eye.

Administration of IOP-lowering drugs can normally be interrupted during the post-operative period; patients can be administered corticosteroids and topical antibiotics for approximately 6 weeks.

MIGS: Mini-Invasive Glaucoma Surgery

The term MIGS refers to a series of procedures that use a micro-incisional *ab interno* approach. These focus on three anatomical landmarks—the Schlemm Canal, the suprachoroidal space and the subconjunctival space. Performing the incisions exclusively in the cornea will protect the conjunctiva from being manipulated and prevent scar formation, permitting future surgical intervention with a conjunctival approach.

The MIGS approach is considered to be less traumatic, and has a better safety profile and more rapid postoperative recovery. The majority of the MIGS procedures reduce the IOP to a lesser degree than the traditional filter procedures.

We will now describe three commonly-used MIGS procedures:

– The Glaukos micro-trabecular Bypass stent (iStent), that targets the Schlemm Canal

Fig. 16.18 Glaukos micro-trabecolar Bypass Stent (iStent). The iStent implant necessitates good visualization of the anterior chamber angle. To facilitate this, the anterior chamber is first filled with a cohesive VES. A dispersive intraocular viscoelastic device (OVD) is then positioned on the cornea

– The Xen stent, that is positioned in the subconjunctival space
– The Cypass suprachoroidal microstent.

Glaukos Micro-Trabecular Bypass Stents (The iStents)

Visualization

For insertion of a stent in the left eye, the lens of the Swann-Jacob gonioscopy is held in the left hand, visualizing the infero-nasal portion of the angle. The point where blood reflux is observed is often noted (if possible) and this is to be the perfect position for the insertion of the stent.

Insertion of the Device

The left iStent device is held in the right hand and is inserted into the anterior chamber. The gonioscopy light and good visualization of the trabecular network are essential for the correct and straightforward insertion of the device.

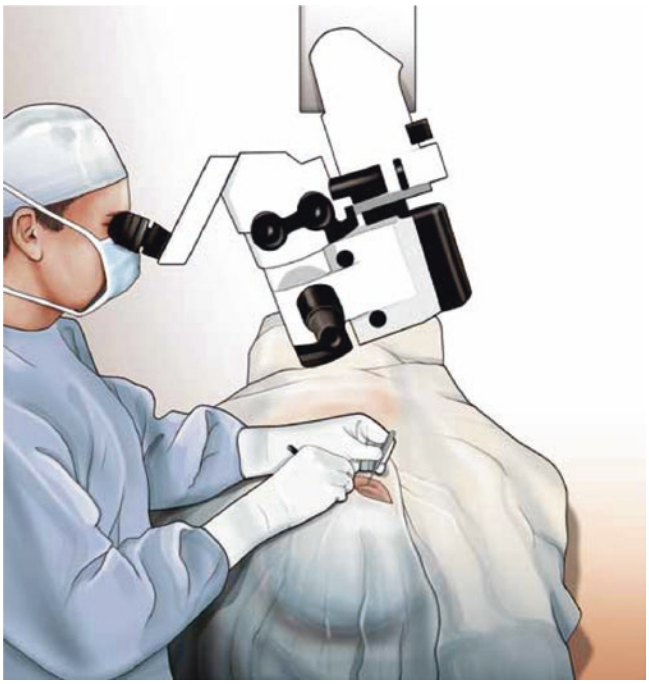

Fig. 16.19 The patient head is moved away from the surgeon and the microscope is tilted of about 30–45 grades. When the device designed for the left eye is being implanted, the patient's head is rotated (away from the surgeon) and he is asked to look downwards. When the device designed for the right eye is being implanted, the patient's head is rotated (away from the surgeon) and he is asked to look up and to the right. The microscope is tilted 30°–45° to align it with the gonioscopic view

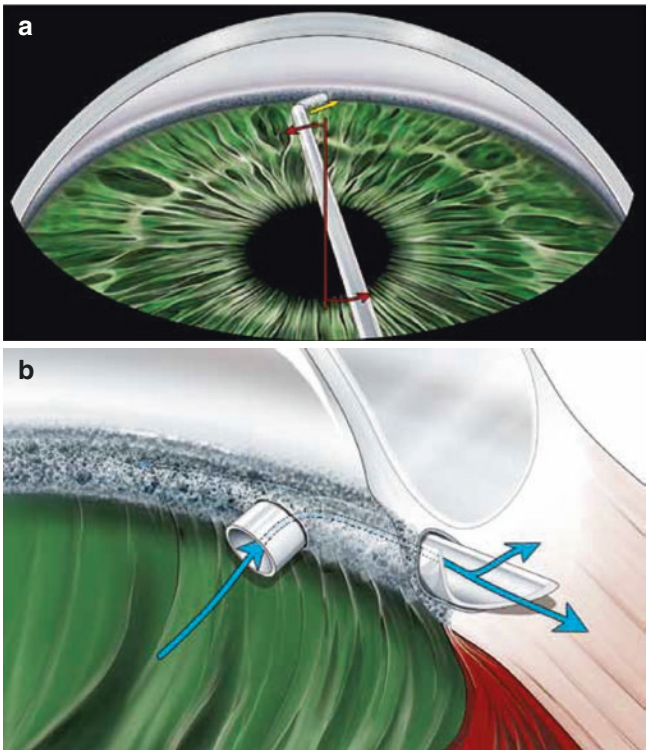

Fig. 16.20 (**a**) Insertion of the left eye dedicated iStent into the trabecular meshwork. The iStent is moved close to the trabeculate at an angle of 45°. Then, when the device has been inserted, the angle narrows to approximately 30° and the remainder of the stent is inserted in the trabecular network. It is important to allow the eye to return to its original position before releasing the stent completely from the injector. The detection of blood reflux through the stent is the intraoperative confirmation of the stent's position in the Schlemm Canal. If there is a substantial reflux of blood that obstructs the intraoperative vision, a greater quantity of OVD can be injected to dislocate the blood and produce better vision of the angle. Touching the stent with the injector may prove useful to confirm the correct position of the device. If the position of the iStent is not correct, iris micro-forceps can be used to reposition it. Following the correct insertion of the device, the VES is aspirated from the anterior chamber and the incisions are hydrated. (**b**) Note the device location into the trabecular meshwork and its operation (the *blue arrows* indicate the aqueous humour outflow)

Subconjunctival Micro-Stent: The Xen Stent

Inspection of the Device

Fig. 16.21 Xen device with injector. This device is preloaded into an injector (Fig. 16.21) to allow its insertion into the angle, under gonioscopy control. Once the injector has been removed from its packaging, it must be carefully inspected underneath the microscope. The metal plug inside the lumen of the needle on the injector is removed with a driver needle. The implant can be pushed just slightly outside the injector by moving the slide forward and then withdrawing it. This maneuver is performed before entering the eye to ensure that the device is mobile in the injector and has not become stuck. The visualization of the device also confirms the position of the Xen implant in the injector and the absence of any irregularities of the device itself

Insertion of the Device

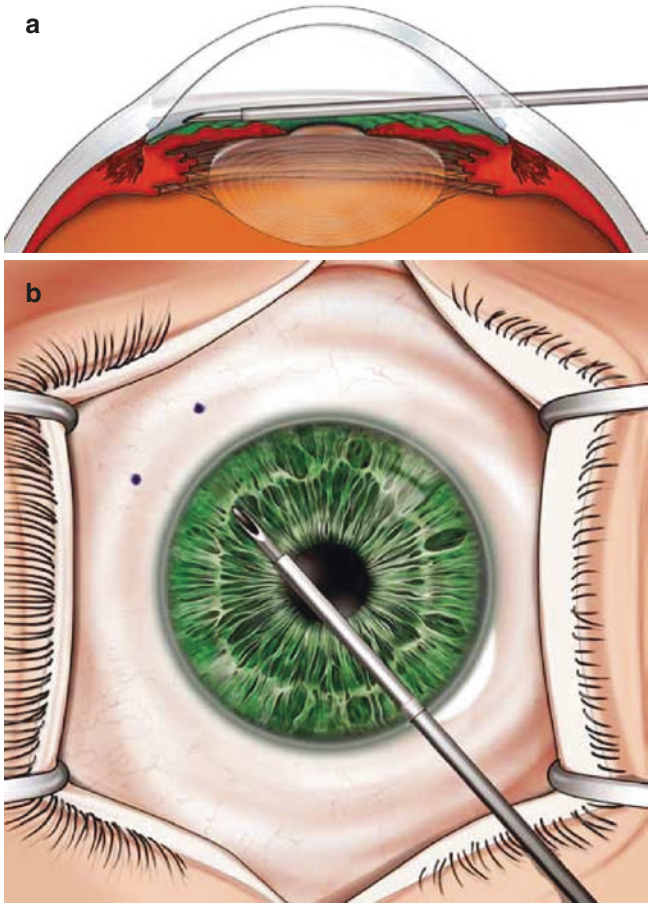

Fig. 16.22 Sagittal vision (**a**) and vision from above (**b**) of Xen device insertion in the anterior chamber filled by viscoelastic. A blade with a cutting side is used to create two lateral corneal incisions (one infero-temporal and the other supero-temporal). Lidocaine and VES are injected into the anterior chamber. The tip of the device is inserted through an incision situated in the infero-temporal quadrant, and progresses in a supero-nasal direction. Under direct gonioscopy observation, the supero-nasal angle and the trabeculate are identified. The tip of the device is positioned in front of the spur-reticular junction of the angle. Maintaining pressure at the angle, through a supero-temporal incision, the eye is held in a primary position with the left hand: for this maneuver, closed forceps or a Vera hook are used. This consents the manipulation of the eye-bulb to facilitate the insertion of the device. Once the eye has been stabilized, the Xen implant is pushed in a supero-nasal direction through the sclera at 1 o'clock. Ideally, the device should exit approximately 3 mm posterior to the limbus, beneath the conjunctiva, in the supero-nasal space

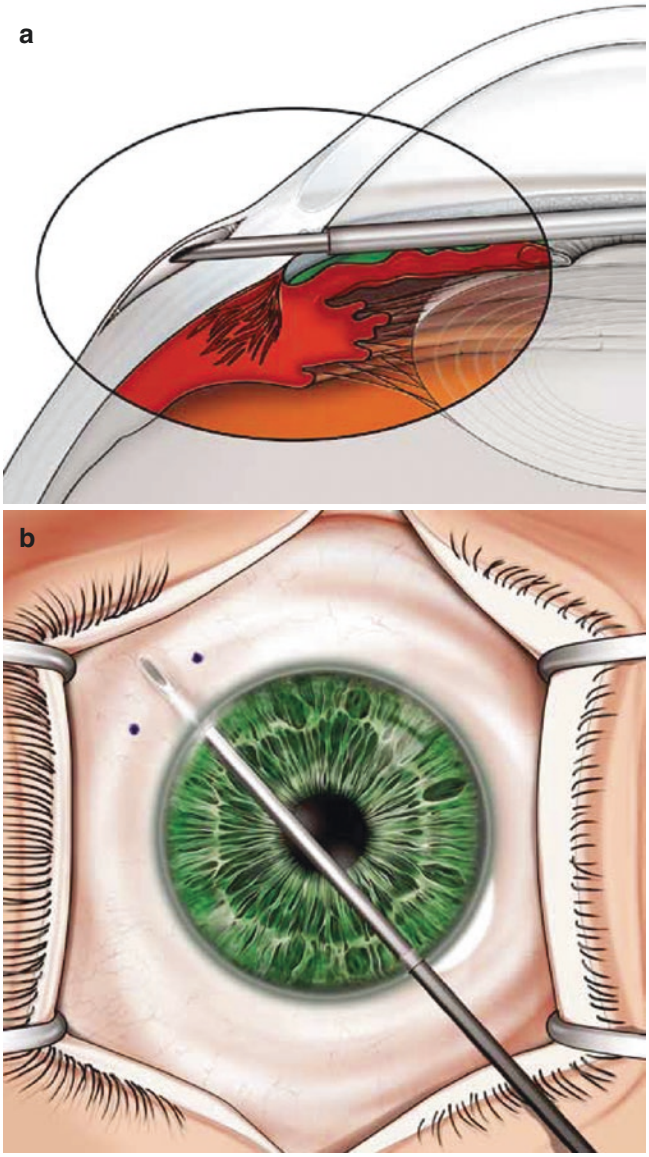

Fig. 16.23 Scleral and sub-conjunctival space penetration (**a**: sagittal vision) (**b** vision from above). Once the tip of the Xen device is visible inside the sub-conjunctival space, the injector's slide is pushed forward and the tip of the cannula is withdrawn. In this way, the device is positioned in the subconjunctival—anterior intrascleral space (**a** and **b**). The injector is then removed from the eye. Now the VES is manually (and passively) removed by injecting BSS into the eye with a 27G cannula. At this point, a bleb should form around the Xen implant. The position of this implant can be controlled using the gonioscopy lens. If the implant has not been positioned correctly, it can be removed from the angle using iris micro-forceps and reloaded into the injector. The insertion procedure can now be repeated. Once the surgeon is satisfied with the position of the stent, the edges of the incisions are hydrated to facilitate good closure of the wounds and a 10.0 nylon suture can be added to close the infero-temporal incision

The Cypass Suprachoroidal Microstent

Preparation of the Device

The device is removed from its packaging and the injector is connected to a syringe containing Healon 5. The Healon 5 is injected into the device when it is still outside of the eye to ensure that the VES has filled the lumen. Two notches on the device's piston corresponds to approximately 60 μL of VES. This same quantity is injected into the suprachoroidal space.

Visualization and Cauterization of the Iris

The surgeon creates an incision in clear cornea in the temporal sector, followed by an injection of lidocaine and VES in the anterior chamber. A gonioprism is used to visualize the anterior chamber angle and identify the trabeculate and the scleral spur.

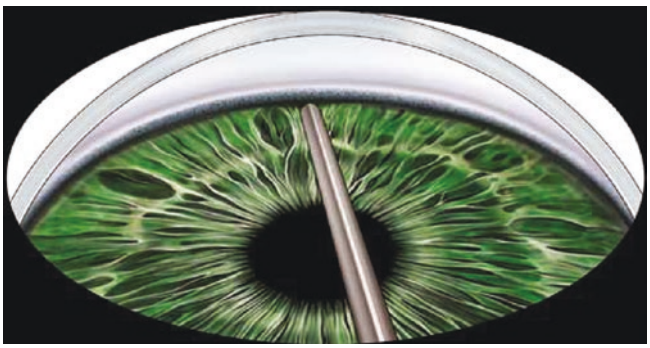

Fig. 16.24 Iris cauterization before Cypass insertion. This procedure determine an iris a coarctation the push away the angle and provide hemostasis. Using the coagulation tip of the phacoemulsifier, the area of the iris close to the scleral spur where the Cypass device will be implanted is cauterized. This maneuver is performed to reduce the possibility of the device being obstructed by the iris

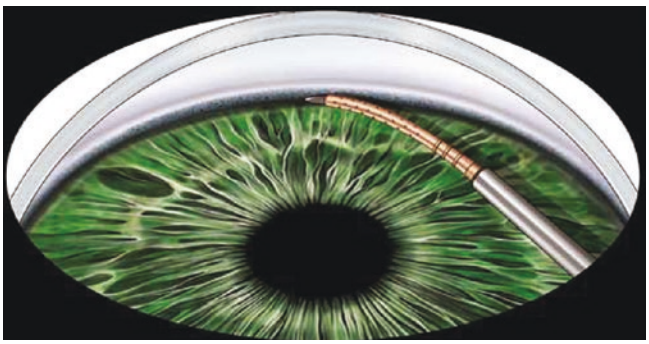

Fig. 16.25 Entrance of the Cypass injection device in the suprachoroidal space. Under gonioscopy control, the insertion of the iris and the guide thread are used to dis-insert the iris at the scleral spur, with an oblique entrance direction

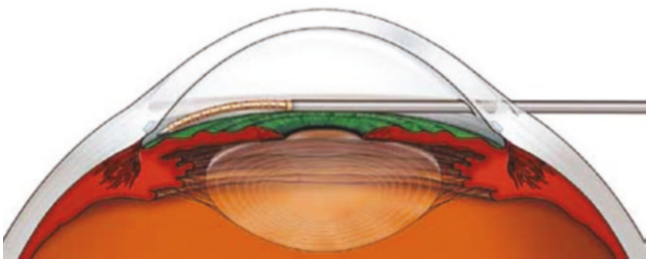

Fig. 16.26 Cypass mounted in the injection device in the anterior chamber

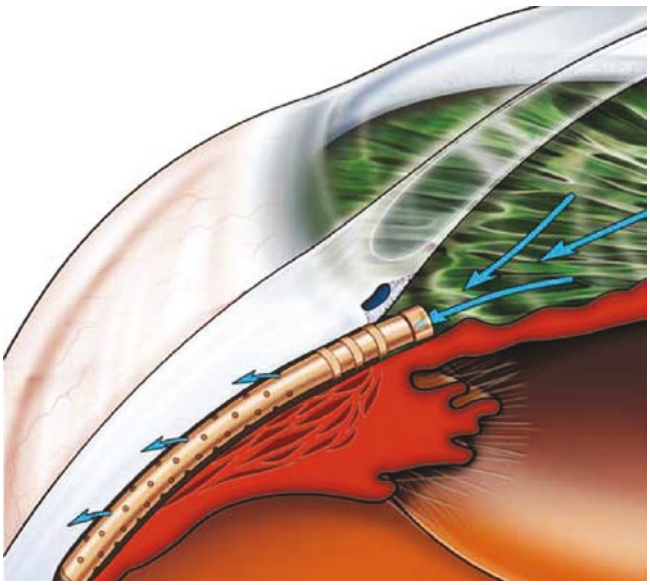

Fig. 16.27 Cypass implant in the suprachoroidal space. The suprachoroidal stent advances until only 1–2 of the rings on the distal tip of the device are visible. If more than two rings are visible, there is the risk that the device may come into contact with the cornea. Approximately 60 μL of Healon 5 are injected through the device and into the suprachoroidal space. This VES will position itself around the device. The VES in the anterior chamber is then removed manually and the edges of the incisions are hydrated to guarantee perfect closure; a single 10.0 nylon suture is also added

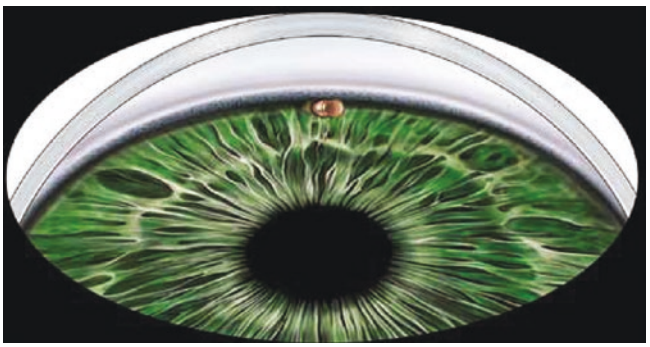

Fig. 16.28 Cypass implant terminal portion view in the anterior chamber, final position

Following surgery, the patients will continue the topical pressure-reducing therapy to maintain a low IOP and prevent the collapse of the suprachoroidal space around the implant.

Deep Sclerectomy

17

Norbert Koerber

Hans Goldmann stated: 'the successful creation of drainage for the aqueous humor without an avascular filtering bleb formation is an important step forward in glaucoma surgery". When he announced this, trabeculectomy had just been developed and there were enormous expectations associated with it. It was hoped that the technique would stabilize the aqueous humor outflow into Schlemm `s Canal without the formation of a bleb. The results demonstrated that a long-term reduction in the IOP could only be achieved using a filtering bleb. At the beginning of the twenty-first century, non-penetrating surgery—as a form of surgery of Schlemm`s Canal—began enjoying renewed interest. Two variations of the technique were developed. One was the deep sclerectomy with a filtering bleb, and in many cases involved an implant of collagen, reticulate hyaluronic acid or hydrophilic acrylate; the other variant was deep sclerectomy with viscocanalostomy without the formation of a bleb The penetrating procedures, such as the trabeculectomy, enter the anterior chamber in correspondence to the sub-scleral incision. Filtering towards the outside leads to the formation of a bleb.

The most recently-developed non-penetrating procedures do not open the Descemet membrane or the trabecular meshwork, but they allow the natural resistance of the tissues to oppose the fluid outflow. The deep sclerectomy involves the creation of two scleral flaps, the removal of the deep flap (deep sclerectomy) leaving the intact descemet membrane and trabecular meshwork and descemet membrane the trabeculate and an aqueous intrascleral pool (often described as a scleral lake) exposed. The deep sclerectomy involves the preparation of two scleral flaps—one superficial and one deep. The superficial flap is usually 300 μm thick and it must be cut at least 1.0 mm in clear cornea. Preparation of the deep flap reveals the scleral spur lying parallel to the limbus, and the anterior blue zone within the limits of the Schwalbe line (rarely visible in Caucasian patients) The Schlemm Canal is found directly in front of the scleral spur. The trabeculate lies anterior to the scleral spur. The Trabecubecular Descemetic Membrane (TDM) extends anteriorly from the Schwalbe line for approximately 1 mm in clear cornea.

The deep flap is removed to create the scleral lake for the potential outflow of the aqueous. In deep sclerectomy, filtrationis mainly external in the subconjunctival space. The structures that protect against the risk of excessive filtration are the superficial flap that controls from the outside, and the TDM that controls from the inside. Once the surgeon has positioned an implant or high viscosity VES under the flap, the flap is anchored with a couple of sutures to allow the filtering bubble to develop. The function of the filtering bleb depends healing process and successively on the scar formation in the structure of the filtering bleb. 5-FU or mitomycin can make an important contribution to preventing scar formation. The maincomplication of fistularizing surgery—hypotonia and a flattened anterior chamber—can be avoided by using the deep sclerectomy technique. The results show good reduction in the IOP and a high safety profile. The reduction in the absolute pressure is lower than with the trabeculectomy technique with mitomycin; however, the better safety profile associated with the procedure has consolidated the important role of deep sclerectomy in the surgical treatment of glaucoma.

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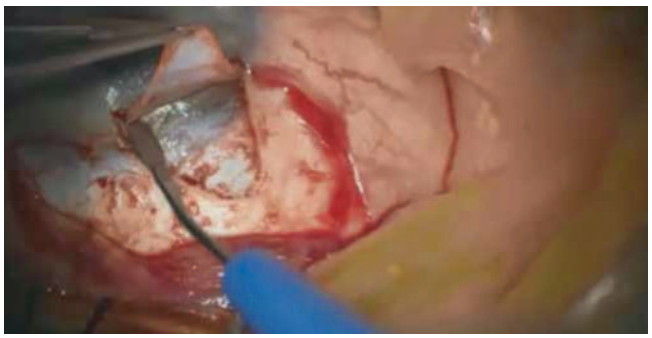

Fig. 17.1 First 300 mcr of thickness scleral flap sculpture, advancing the incision in clear cornea

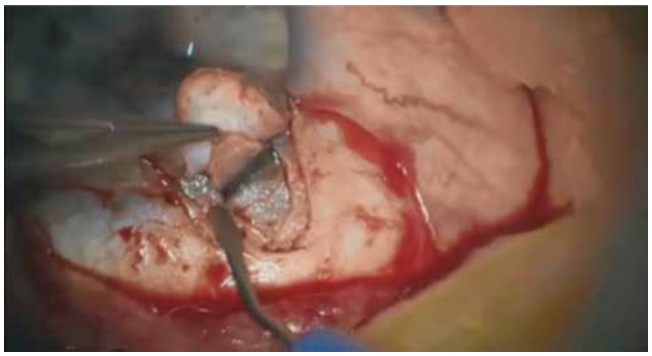

Fig. 17.2 Second scleral flap sculpture and inner Schlemm's canal wall exposition; Descemet membrane is not exposed yet

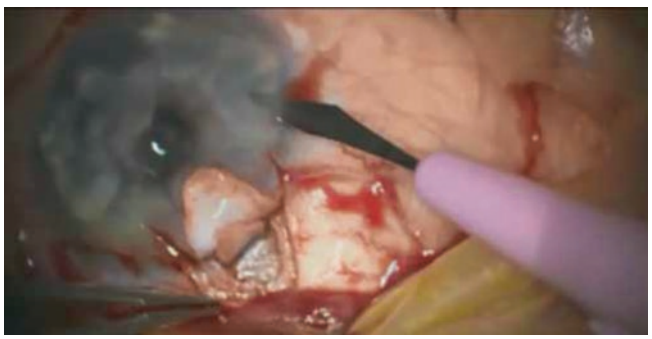

Fig. 17.3 Paracentesis after Schlemm's canal/trabecular meshwork exposition before Descemet window creation made to reduce pressure on a very thin and fragile tissue. In this way we reduce the risk of undesired rupture

Fig. 17.4 Descemet membrane is exposed for 1 mm in clear cornea

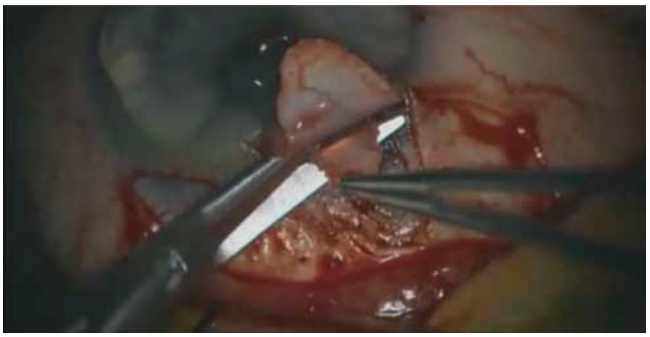

Fig. 17.5 Deep scleral flap excision = deep sclerotomy. Now a scrap of collagen can be sutured or a hyaluronic acid net can be placed in the scleral. Another possible implant, no more available at the time of speaking, is the T-flux implant

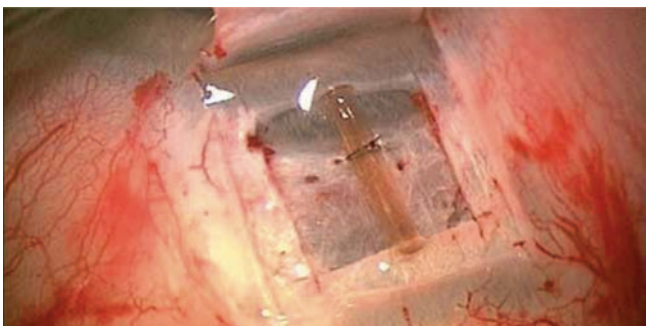

Fig. 17.6 Collagen implant is positioned

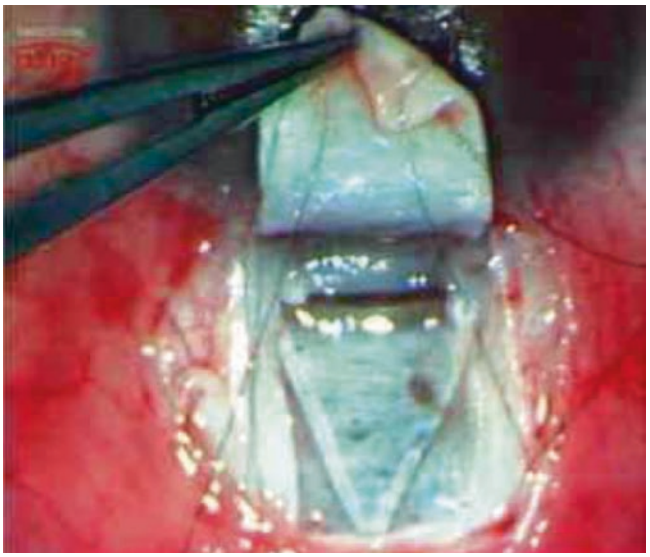

Fig. 17.7 Hyaluronic acid net is positioned

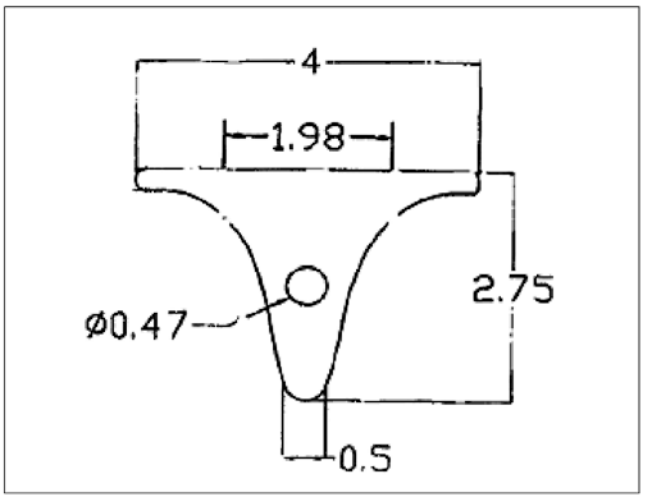

Fig. 17.8 T-flux implant. Size is reported. This implant is created to adapt itself to the Schlemm's canal through its arms. The longer arm act as a scrap from the space under the scleral flap to the sub-conjunctival space. A central opening is present to facilitate the fixation suture

Canaloplasty Surgical Technique

18

Gabor Scharioth

The conjunctiva can be opened at either the fornix or the limbus. A rectangular, square or parabolic-shaped scleral flap measuring 5 × 5 mm is then created and includes 1/3 of the scleral thickness (approximately 300 μm, depending on the scleral thickness of the specific eye). In order to reach the Descemet membrane during the dissection of the deeper scleral flap, the superficial scleral flap must be created 1–1.5 mm anteriorly in clear perilimbal cornea. The initial incision is created with a No.11 stainless steel blade (for example, a 15° Slit Knife for paracentesis) or a diamond blade. The flap is created with a ruby blade or a bevel-up crescent knife (for example, a 1 mm Minidisc Ultrasharp knife, Grieshaber Alcon, USA). Then the surgeon performs the sclera-keratectomy, initially creating a small second flap, then the superficial flap, leaving a step of sclera at the edge to allow the tighter closure for the viscocanalostomy/canaloplasty. The scleral flap is then cut towards the cornea, using a ruby blade or a stainless steel crescent knife. The depth of this dissection must extend almost as far as the choroid/ciliary body and is accurately extended anteriorly, keeping the dissection plane as uniform as possible. In the event the suprachoroidal space is opened, the dissection must be continued a few scleral fibers above. The scleral spur is observed when scleral fibers change direction towards a band parallel to the limbus.

Right behind this, the Schlemm Canal is opened and exposed. The surgeon must take care to cut the Schlemm Canal ostias because it is believed that this will reduce the IOP to very low levels. This maneuver reduces the risk of perforating the trabeculo-Descemet membrane. The dissection must expose a small segment of the Descemet membrane, creating a trabeculo-Descemet window measuring approximately 1–1.5 mm. The corneal stroma can be separated from the Descemet membrane using a sponge, while the edges of the deep scleral flap are cut towards the cornea with a knife. In some cases there is tighter adhesion of the Descemet to the stroma and in these cases the surgeon can use a blunt spatula or a half-moon crescent knife with a brushing movement parallel to the limbus, to release these adhesions. This is a difficult phase of the procedure because there is a high risk of perforating the anterior chamber. The deep sclero-corneal flap is then removed by cutting it in clear cornea with small, delicate, extremely sharp scissors (for example, Vannas or Galand scissors). Then, the surgeon performs the so-called canaloplasty with the help of a microcatheter. This procedure should overcome some of the prob-

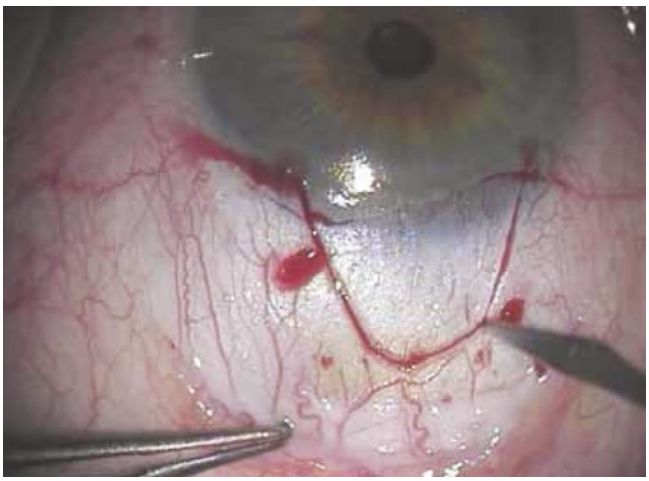

Fig. 18.1 Superficial scleral flap, note that no diathermy is performed on episcleral vessels

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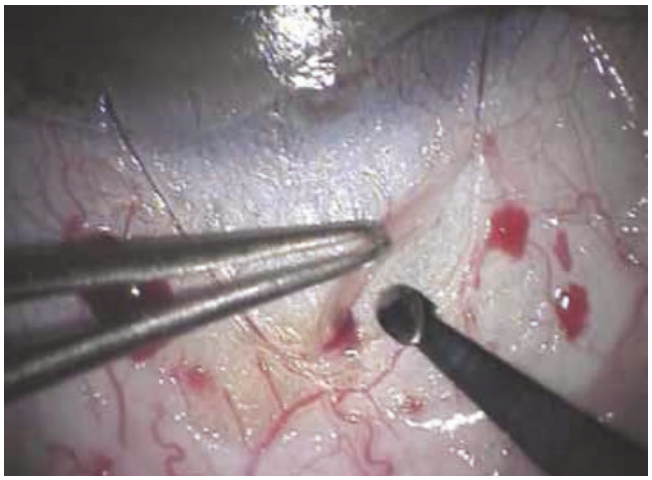

Fig. 18.2 Superficial scleral flap sculpture with mini-Crescent knife

lems associated with the previous procedures that exploited a deep sclerectomy. The idea is to position a thin tension suture in the Schlemm Canal:

- to expand internal space of the canal for the full 360°;
- to expand the intertrabecular spaces;
- to prevent the collapse of the canal, the surgical opening and the Descemet window, and the collapse of the internal wall into the holes of the collector canals;
- to keep the Schlemm canal open;
- to keep the collector canals used for drainage distant from the surgical site.

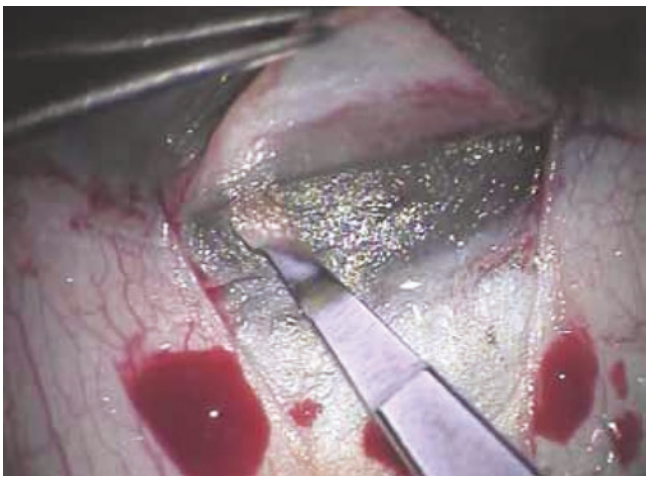

Fig. 18.3 Superficial scleral flap dissection in clear cornea

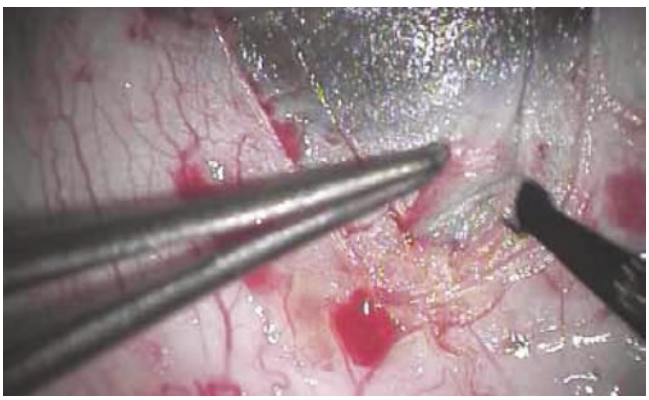

Fig. 18.4 Deep scleral flap sculpture with mini-Crescent knife; note the smaller size of the deeper flap

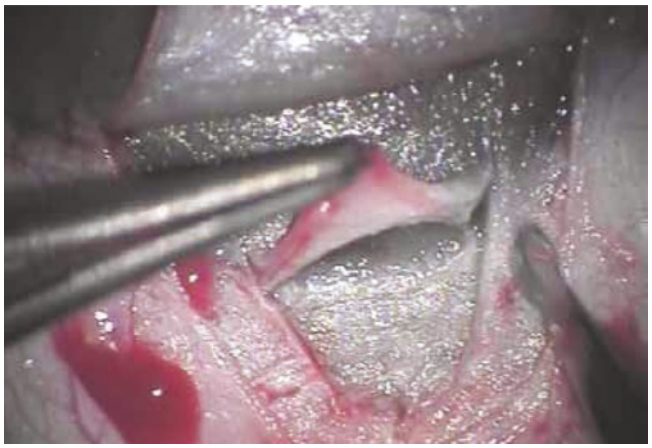

Fig. 18.5 Schlemm's canal opening; note the different colour of the scleral bed, which indicates the adequate depth

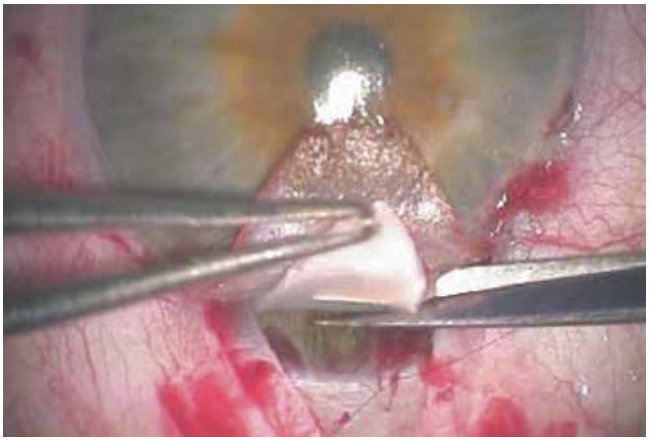

Fig. 18.7 Deep sclerotomy—deep scleral flap dissection with Vannas scissors

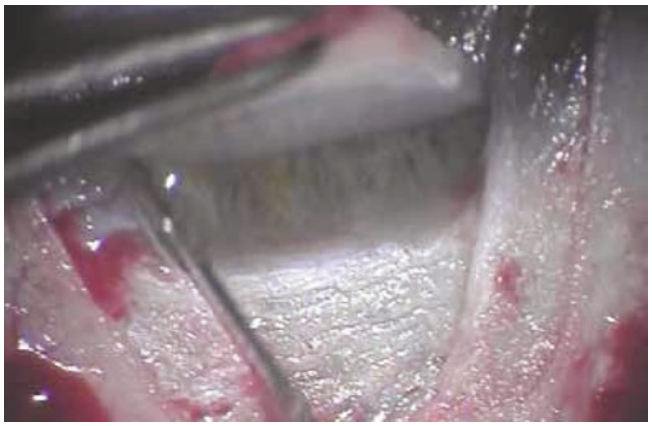

Fig. 18.6 Descemet window enlargement to obtain the best exposition of the trabeculo-descemetic membrane; note the humour aqueous percolation, without membrane perforation; iris is visible thought the intact membrane

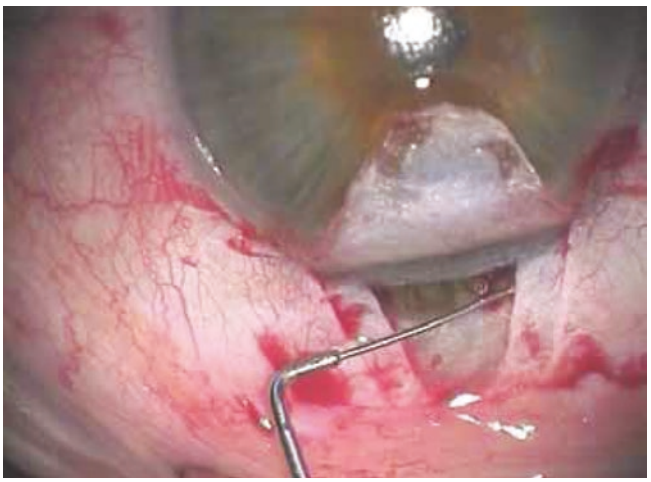

Fig. 18.8 Viscocanalostomy by OVD injection in the Schlemm's canal with a special cannula

A microcatheter for canaloplasty (iTrack, iScience, USA) has been commercially-available since March 2008. This device has a diameter of 200 μm with a non-traumatic distal tip of diameter approximately 250 μm. The device incorporates an optic fiber that provides light to assist the surgical procedures. The illuminated tip is observed through the sclera when the Schlemm canal is catheterized to identify the position of the microcatheter's distal tip. The lumen diameter of the microcatheter is approximately 70 μm and the device is fitted with a Luer lock proximal connector through which OVD (Healon GV) or dye (trypan blue, indocyanine green, fluorescein) can be injected. Other devices used for canaloplasty are Glaucolight (DORC, Holland) and Onalene for canaloplasty (Onatec, Germany). Special forceps are used to manipulate the microcatheter and position the tip inside the surgically-created hole in the Schlemm Canal. The microcatheter progresses for 12 h inside the canal while the surgeon observes the position of the illuminated tip through the sclera. After catheterization with the microcatheter along the entire length of the canal and when the distal tip is exposed at the surgical site, the surgeon ties a 10.0 polypropylene suture thread to the distal tip and the microcatheter is withdrawn, pulling the suture thread into the canal. The thread is cut from the microcatheter and is tied in a loop around the internal wall of the canal with a slip knot or a 4-turn knot. The IOP will have been lowered through the creation of a paracentesis; this will also reduce

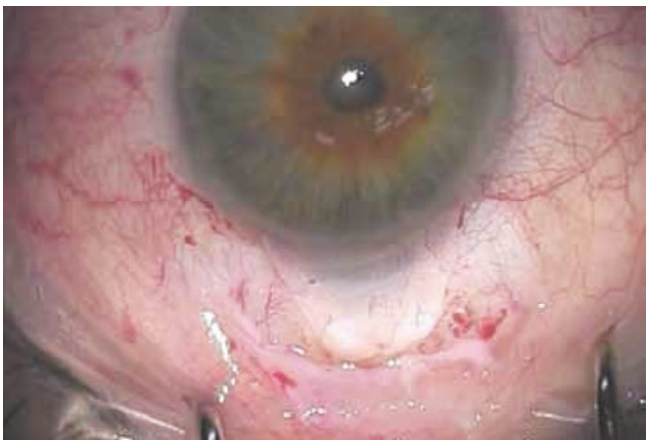

Fig. 18.9 Watertight closure of the superficial scleral flap with 5–6 single interrupted sutures (10.0 absorbable suture)

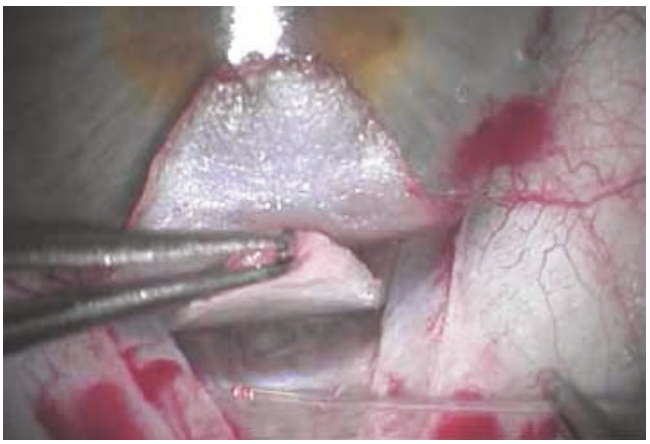

Fig. 18.10 Micro-catheter before Schlemm's canal incannulation

the risk of rupturing the Descemet membrane and facilitate a more efficacious control of the tension with the 10.0 polypropylene suture.

In this phase of the procedure, the surgeon should observe percolation of the aqueous humor towards the remaining visible portions of the membrane. He can also control this visually by adding fluorescein to the surgical area (the Rentsch-Seidel test). The amount of percolation is controlled when the surgeon dries the surgical area with a sponge. To facilitate the outflow, the internal wall of the Schlemm Canal is partially stripped, including the endothelium and the juxta-canalicular trabeculate. Specially-designed forceps may be used or alternately, standard capsulorhexis forceps. Occasionally, the internal wall of the Schlemm Canal, may be fibrotic and a radial incision will be required to initiate the peeling procedure. The next step of the surgical procedure is the injection of VES (OVD-Healon GV) through the surgical hole in the Schlemm Canal.

The superficial scleral flap is repositioned and the wound is sealed with between five and seven single absorbing sutures (in 10.0 Vicryl, Ethicon). The sutures seal the superficial scleral flap and force the liquid outflow into the Schlemm Canal and then into the collector canals. OVD is then delicately injected underneath the scleral flap to reduce the risk of bleeding into the site of the sclerectomy and to prevent scarring in this area; this will maintain the scleral lake. The anterior chamber is filled with BSS (Balanced Saline Solution) to reach a normal or slightly raised IOP; the conjunctiva is repositioned and fixed with two/four single absorbing sutures. It is not clear whether an additional injection of OVD inside the canal is required; however, it is possible to demonstrate that the procedure has been successful without the need for an iTrack catheter and a circumferential injection of OVD.

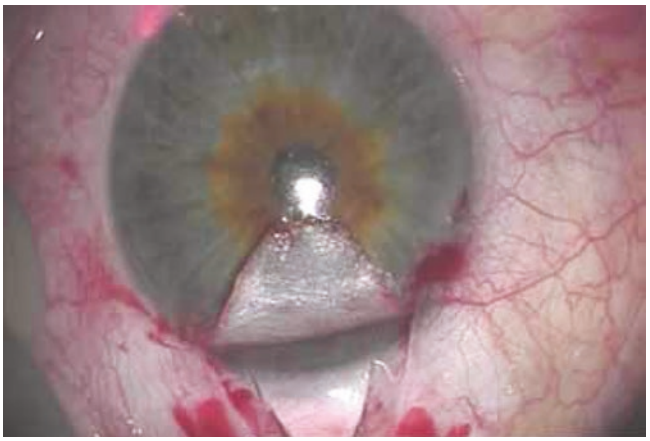

Fig. 18.11 The *red* point indicates the micro-catheter position at five o'clock in the Schlemm's canal

Fig. 18.12 Intraoperative gonioscopy of the micro-catheter illuminated distal tip (red point) inside the Schlemm's canal; note the high-pigmented trabecular meshwork

Conclusions

A new procedure called canaloplasty has recently been presented. This procedure is destined to overcome some of the problems associated with the deep sclerectomy.

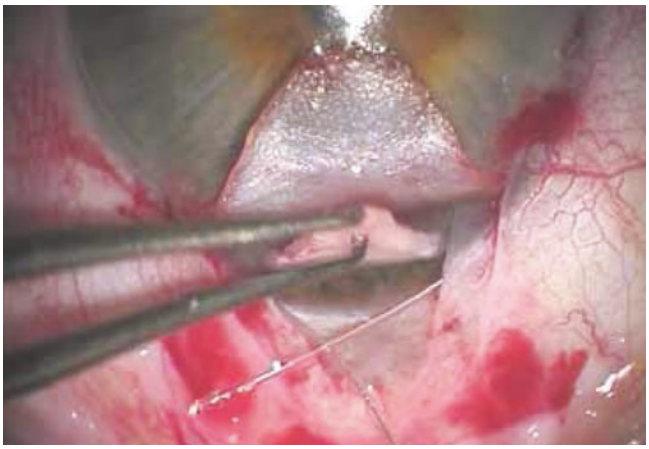

Fig. 18.13 Complete 360° Schlemm's canal incannulation

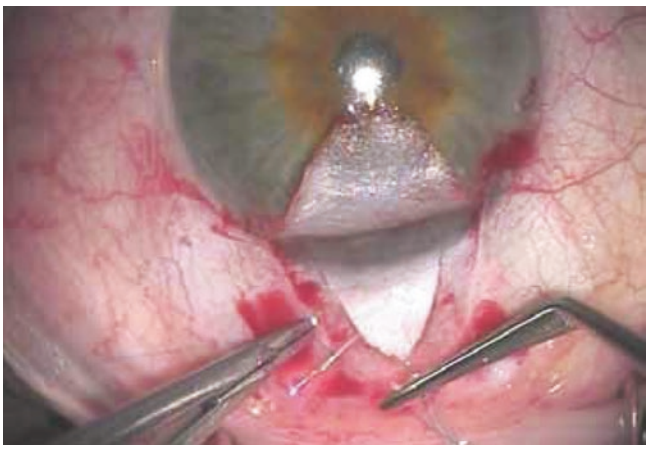

Fig. 18.14 A 10.0 Prolene tensioning suture is fixed to the micro–catheter

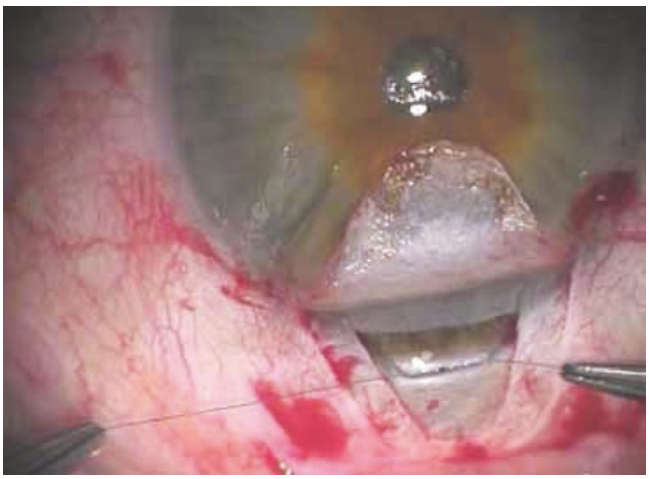

Fig. 18.15 When the micro-catheter is pulled back the suture is cut and tight knotted to stretch the inner Schlemm's canal wall and the Descemet window towards the anterior chamber. This procedure is made to avoid the surgery failure due to the collapse of these structures

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