The Unstable Lens in the Adult Patient

6

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Introduction

Zonular compromise poses serious challenges at every step of cataract surgery. The continued refinement of phacoemulsification techniques and platforms and the development of novel devices for capsular bag stabilization, together with a thorough understanding of the challenges of subluxated lens, as well as their management strategies, allow to approach these cases with more safety and better outcomes through a 2 to 2.2 mm microincision, resulting in a rapid and safe visual recovery.

It is of paramount importance for the decision-making during surgery, to know the etiology of the condition, regarding mainly its stable or progressive nature, as surgical strategy will change. An exhaustive preoperative exploration and planification is mandatory, as well as a deep understanding of the mechanical challenges that this surgery poses to the surgeon together with the knowledge of each of the alternatives to stabilize the capsular bag, how each of them works, and how they can be combined.

Etiology

Subluxated lens is the term used to refer to any displacement of malposition of the crystalline lens of whatever cause or association.

The causes of lens subluxation are multiple and they have been classified based on different criteria. From the surgical point of view, the most important issue to consider is whether the condition is progressive or not [1]. For example, in trauma, which is the cause of more than 50% of cases [2] (Fig. 6.1), we know that the remaining zonules are healthy so that further increase

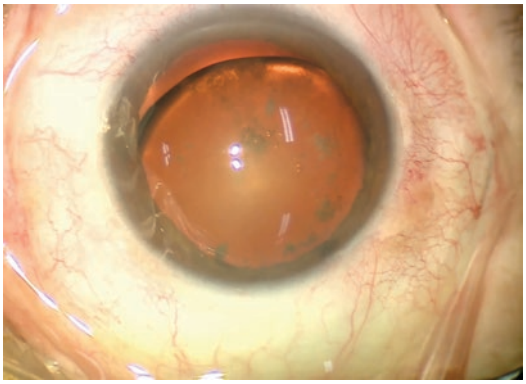

Fig. 6.1 Traumatic lens subluxation, with 180° of zonular dehiscence

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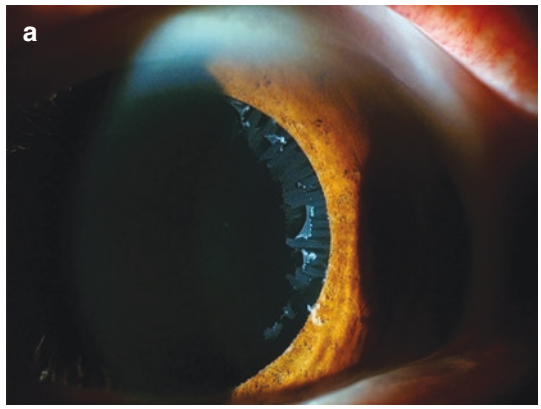
in zonular damage is not expected, neither during surgery nor afterward. The opposite occurs in pseudoexfoliation (Fig. 6.2), a progressive condition in which the surgery poses significant challenges, because of the generalized weakness of the zonules, together with the possibility of progression of the subluxation over the years (in-the-bag IOL dislocation) [3, 4]. The progressive nature of the disease in this and other cases (Marfan (Fig. 6.3), etc.) may change the surgeon's decisions during surgery, regarding scleral fixation to secure the capsular bag even in cases in which that fixation is not needed according to the degree of zonular dehiscence during surgery, due to the uncertain evolution in the future.

Another important point to consider regarding the etiology is the association of some conditions with systemic alterations that can be potentially severe (Marfan and cardiac involvement, cardiovascular abnormalities) [1, 2, 5].

The causes of lens subluxation are summarized in Table 6.1 [1].



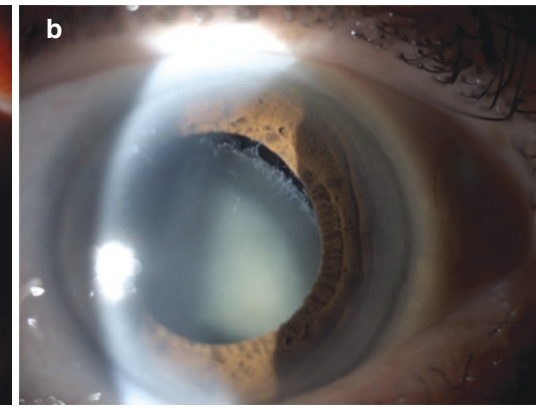


Fig. 6.2 (**a**) Pseudoexfoliation is characterized by generalized zonular weakness. Usually, significant subluxation is not observed, but frequently, pseudophacodonesis is observed before pupil dilation or anterior chamber asymmetry is detected. (**b**) Rarely, lens subluxation is observed, as in this case in which, in addition to present pseudoexfoliation, a blunt trauma triggered the subluxation

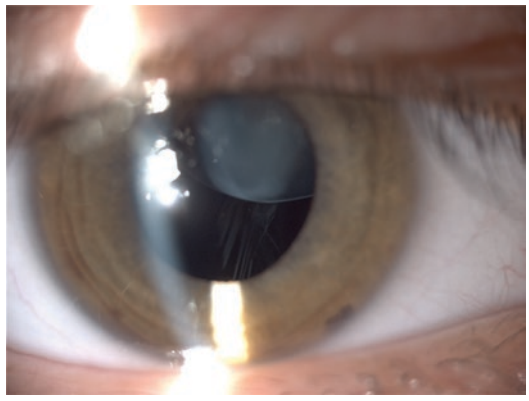


Fig. 6.3 Superior subluxation and elongated zonular fibers in Marfan syndrome

Table 6.1 Causes of lens subluxation

Traumatic	
Endogenous	
Hereditary	Marfan syndrome Homocystinuria Weill-Marchesani syndrome Deficit of sulfite oxidase Essential idiopathic familial ectopia Retinitis pigmentosa
Acquired conditions	Uveitis, myopia, glaucoma
Pseudoexfoliation	
Iatrogenic	Iridectomy, trabeculectomy, vitrectomy

Preoperative Evaluation

A detailed preoperative evaluation is mandatory, beginning with the anamnesis, including family history, any relevant trauma, and onset and types of visual symptoms. Since several hereditable syndromes have associated systemic anomalies, patients should be referred to their primary physician for systemic examination and metabolic workup (Marfan syndrome, homocystinuria, etc.) [1, 2, 5]. Also, in these hereditable conditions, family should be informed. The main symptom is the decrease of visual acuity.

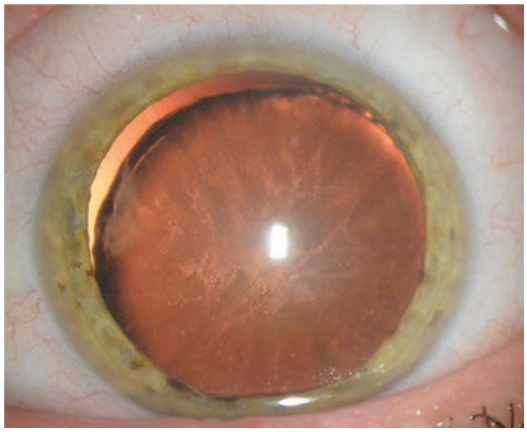


Fig. 6.4 Traumatic subluxated contusive cataract after blunt trauma, involving more than 180° of zonular fibers

Ocular examination should include anterior and posterior segment. Both near and distant distance corrected visual acuity should be determined, keeping in mind that the patient may best see with an aphakic correction if the lens is markedly subluxated. The patient must be examined under full pupil dilatation in the slit lamp before surgery to evaluate the extent of zonular deficiency, since the surgical strategy for the management of subluxation will depend on the number of hours of zonular dehiscence [6] (Figs. 6.4 and 6.5).

The exact degree of zonular loss, location of defect, and presence or absence of vitreous in the anterior chamber should be noted. The position of the crystalline lens at the slit lamp and in the supine position should be compared. Gravity pulls lens downward and the defect is usually noticeable. An inferior subluxation is a sign of extreme zonular weakness and often indicates 360 degrees of zonular insufficiency combined with the effect of gravity [2, 5]. If available, ultrasound biomicroscopy and anterior segment OCT are specially useful for zonular and angle assessment in patients where the pupil fails to dilate, and the UBM has the advantage of being performed in supine position, which is the position during the surgical procedure [7]. Zonular weakness is not always evident at first glance. Of course phacodonesis (Video 6.1), better per-

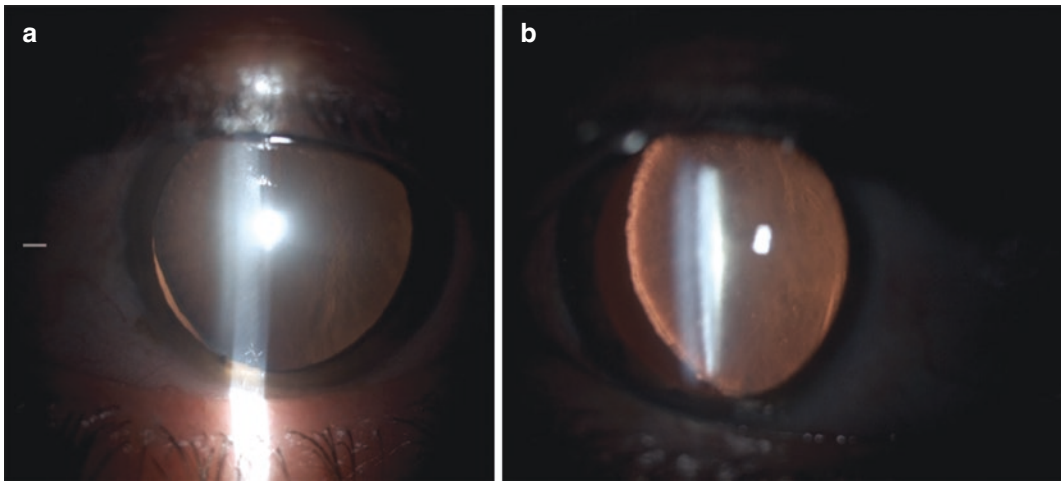


Fig. 6.5 (**a**) Inferonasal zonular deficiency in primary gaze position, involving apparently one quadrant. (**b**) The full extension of zonular dehiscence is better observed in extreme gaze

ceived without dilating the pupil, is the main sign of impaired zonules. Other signs of zonular deficiency include iridodonesis, visibility of lens equator in extreme gaze positions (Fig. 6.5), scalloping of the lens capsule or flattened lens edge (Fig. 6.6), higher space between the iris and the lens, and herniated vitreous. A subtler sign of zonular weakness is the asymmetry in anterior chamber depth; either a shallow or hyperdeep anterior chamber may be caused by zonular dehiscence (Fig. 6.7). Biometry, with the measurement of anterior chamber depth, can confirm anterior chamber depth asymmetry between eyes.

In traumatic cases, any damage of the anterior capsule must be noted and recorded. The density of the cataract should be evaluated, since, together with the extension of zonulopathy and the etiology, it will dictate the surgical strategy. Any vitreous prolapse should be recorded, since vitrectomy will be needed to accomplish the case [6].

Gonioscopy is performed to detect any developmental defects, pseudoexfoliative material, and deformities secondary to trauma or as a sequela of subluxation. The fundus examination is done to look for lattice degeneration, cyclitic membranes, retinal detachment, or posttraumatic pathology. Retinal detachments occur in 10% of eyes with Marfan syndrome, and any evidence of retinal tears, breaks, or tufts should be treated prior to performing the elective cataract surgery. If opaque media preclude fundus examination, B-scan ultrasonography is indicated. Also, the presence of uveitis, glaucoma, corneal edema, and amblyopia should be noted. High IOP may be related to pseudoexfoliation, vitreous prolapse, or angle trauma with recession. An endothelial cell count is advisable before surgery since either trauma or vitreous prolapse may damage the endothelium. Traumatic cases may be associated with damages in other structures, recession, iris trauma, or retinal involvement.

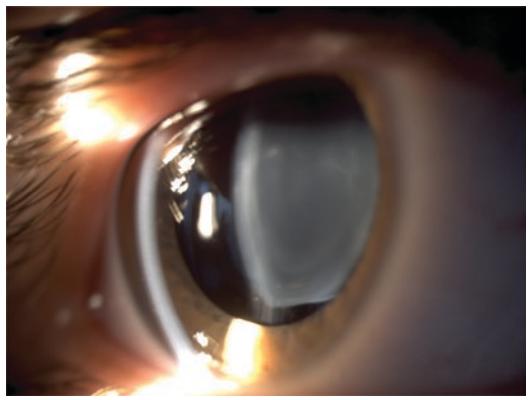


Fig. 6.6 Scalloped or flattened lens edge, which indicates that adjacent remaining zonular fibers should be healthy

Even with a detailed exploration, the full amount of zonular dehiscence may not be detected, or the dehiscence may worsen during surgery (pseudoexfoliation), so the surgeon must be ready to face different scenarios, and the proper instrumentation should be available. The surgeon must be familiar with intraoperative signs that alert about zonular deficiency, in case it has not been detected preoperatively (Fig. 6.8):

- Radial folds when puncturing anterior capsule (Fig. 6.8a).
- Movement of the lens during capsulorhexis (Video 6.2), hydrodissection, or hydrodelineation.
- Difficulty to rotate the nucleus.
- Excessive posterior displacement of the lens when irrigation starts; hyperdeep chamber.
- Ovalization of the capsulorhexis margin.
- Visibility of the capsule equator (Fig. 6.8b) (Video 6.2).
- Vitreous prolapse in the area of dehiscence (Fig. 6.8c) (Video 6.3).

It is of paramount importance to obtain an informed consent from the patient before cataract surgery, considering the risks and complicated nature of surgery, the possibility of changing plans intraoperatively, as well as the need for postoperative monitoring and follow-up.

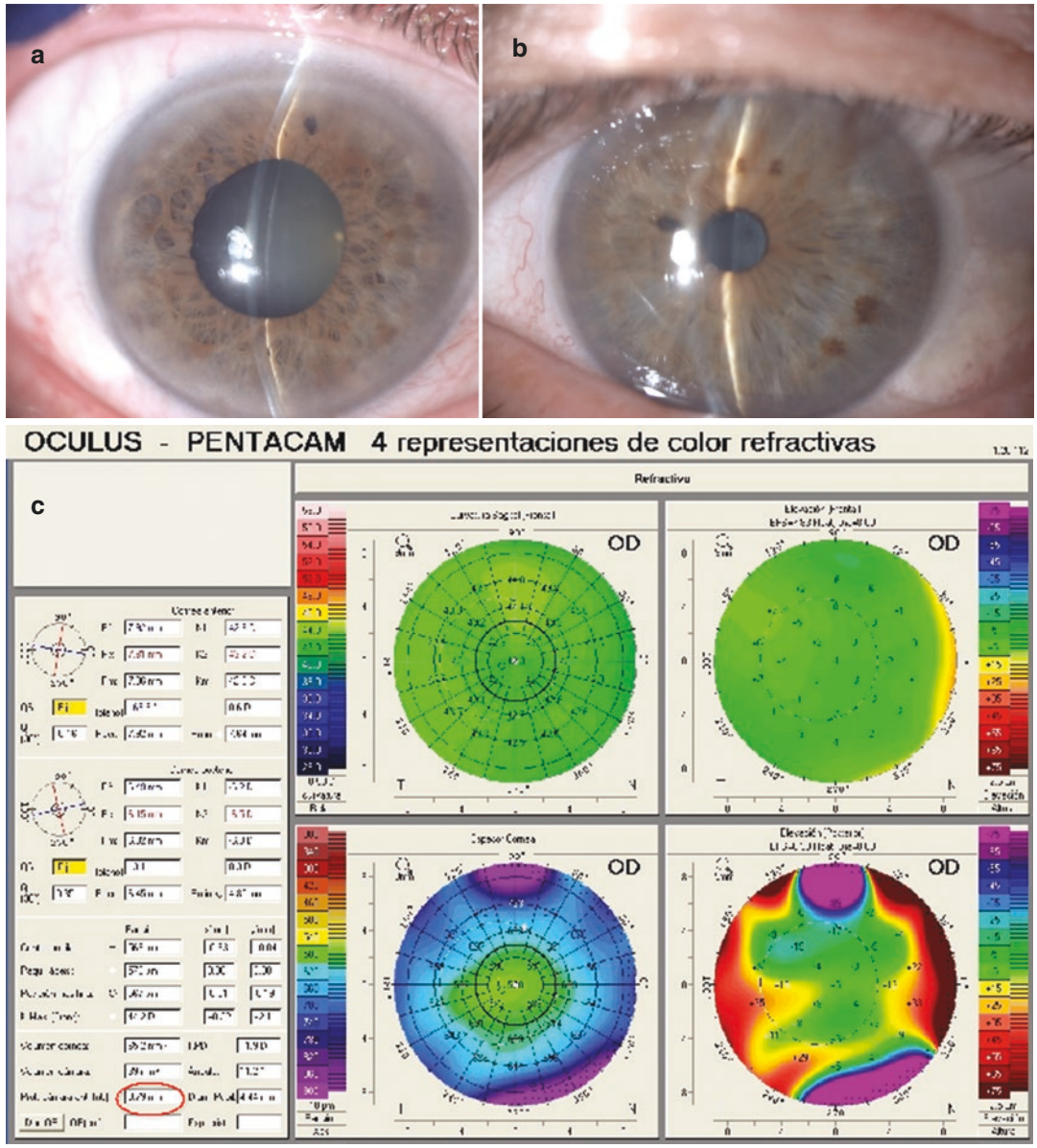


Fig. 6.7 Traumatic cataract, without evident subluxation at first glance. (**a**, **b**) The anterior chamber depth shows asymmetry between eyes, (**c**) measuring 0.75 mm in the right eye and (**d**) 2.04 in the left eye as Pentacam display shows. (**e**, **f**) Scheimpflug images showing the forward displacement of the lens in the right eye as compared to the fellow eye. (**g**) Two Ahmed segments (arrows) combined with a capsular tension ring were necessary to stabilize the capsular bag. **h**) Anterior chamber depth increased to 3.21 mm after surgery

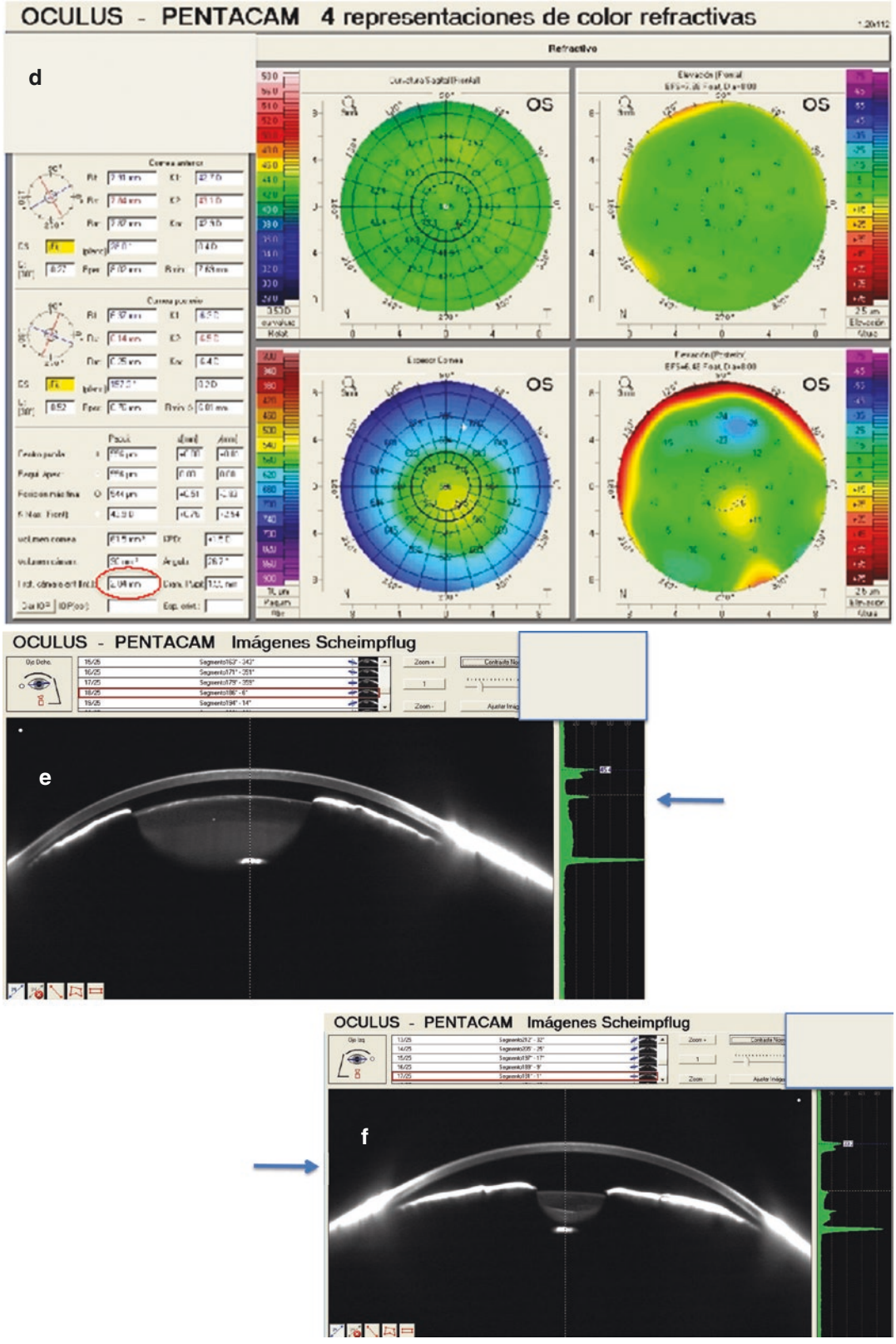


Fig. 6.7 (continued)

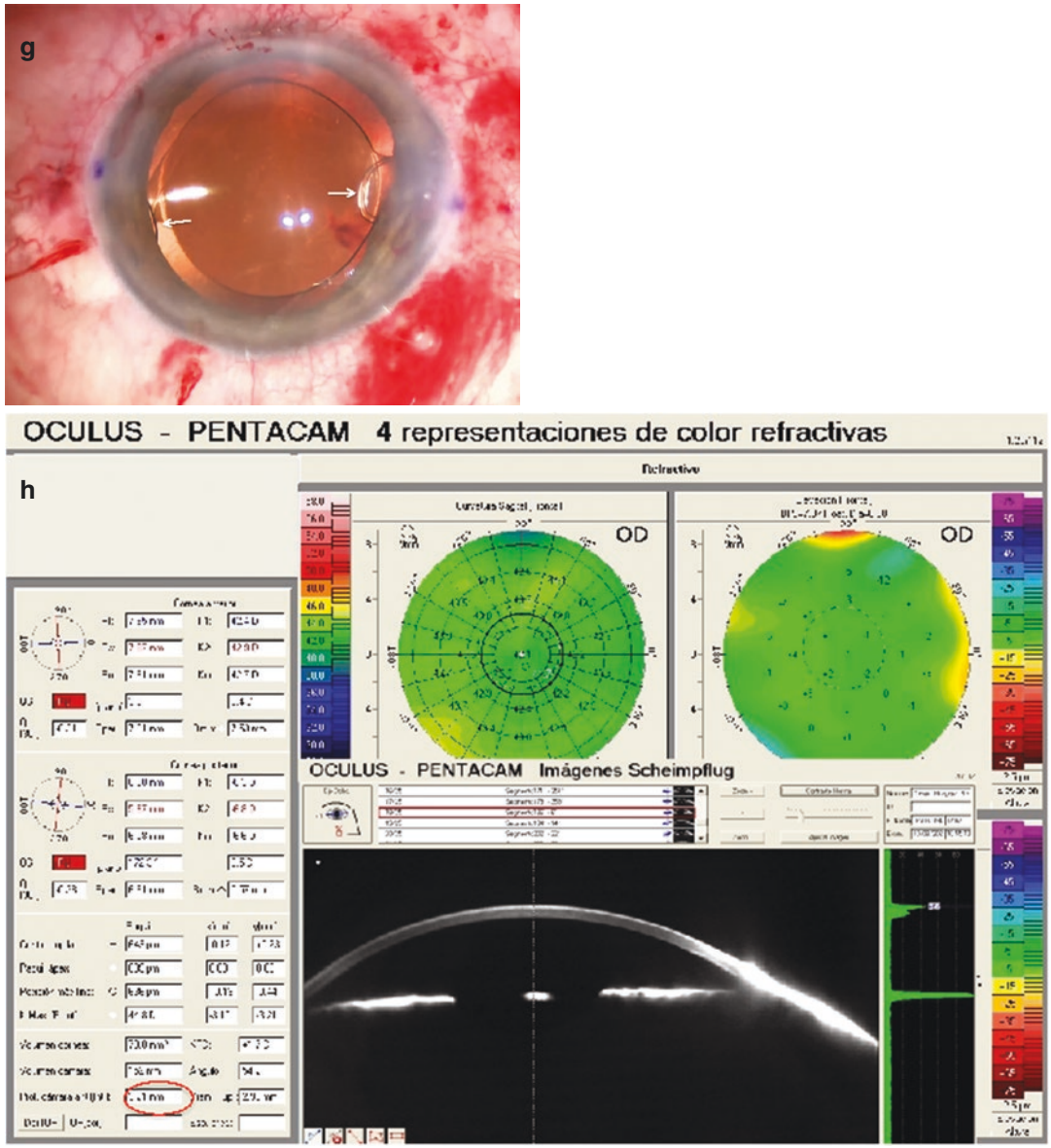


Fig. 6.7 (continued)

Instrumentation

During cataract surgery of subluxated lenses, stabilization of the capsular bag is needed; we need to stabilize the bag in the anterior to posterior axis and also to distend the posterior capsule centrifugally. Depending on the stage of the surgery, we will need one of them or both.

Several devices exist that may help for this two purposes, and the surgeon should know which function each of them serves better in order to utilize them properly. Hooks, capsular tension rings, and related endocapsular devices for scleral fixation have become very useful tools in the armamentarium of cataract surgeons.

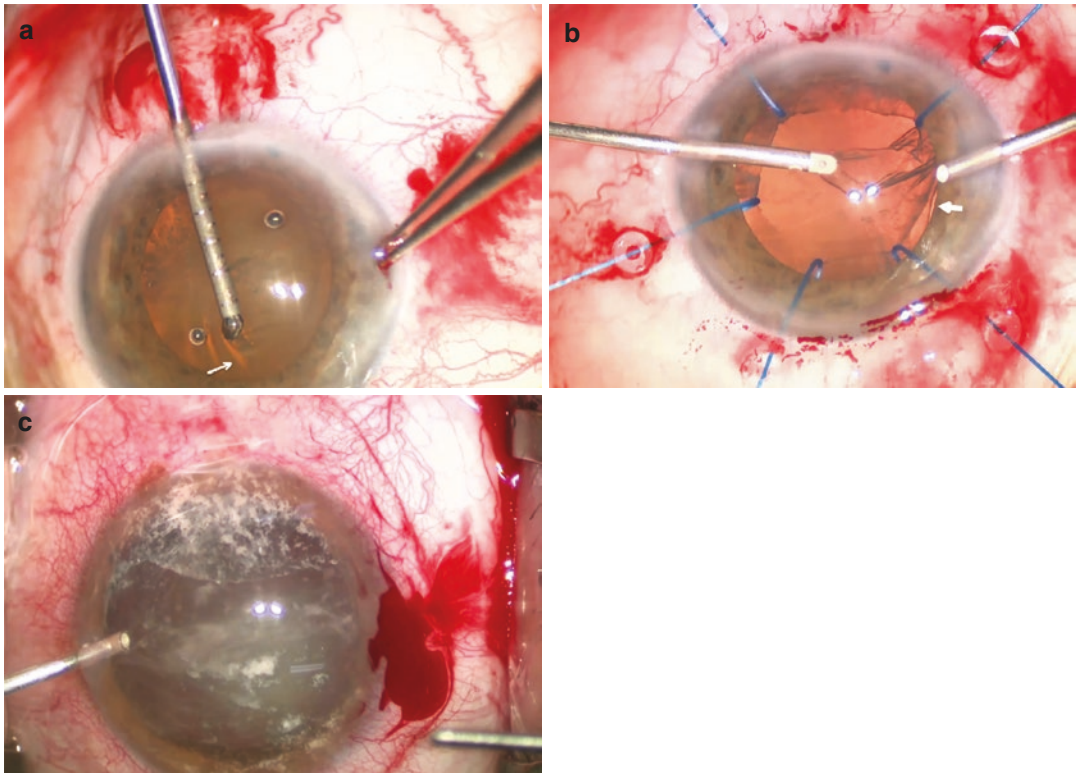


Fig. 6.8 Intraoperative signs of zonular weakness. (**a**) Capsular folds or wrinkles of the anterior capsule during capsulorhexis (arrow). (**b**) Visibility of the capsular bag equator during surgery (white arrow). (**c**) Vitreous prolapse into the anterior chamber

Hooks

Iris Hooks

Iris retractors can be placed at the capsulorhexis edge over the area of zonular weakness to stabilize the loose capsular-zonular complex during surgery.

Flexible iris hooks may stabilize the capsular bag by providing a counterforce to that applied by the surgeon and provide anterior to posterior stabilization of the bag, but they do not expand the capsular fornix. They can be useful as an aid in the completion of the capsulorhexis, hydrodissection, and nuclear rotation. They do not trap the cortex as the capsular tension ring [5, 6, 8, 9] (Fig. 6.9) (Video 6.2).

However, close attention must be paid to the risk of inadvertent dislocation and resultant anterior capsule tear. The capsulorhexis margin must be of adequate size and excessive tension on the hook should be avoided [10].

Sometimes the outer extreme of the hook, the one that is outside the eye, contacts with the blepharostat or the lids, and rotates, inducing a torsion in the capsulorhexis margin, posing the risk of an anterior capsule tear. If the outer extreme of the hook contacts with any surface of the surgical file, it should be cut.

An important point to consider is that if hooks are needed as a counter-traction during capsulorhexis creation, the hooks should be placed at least 2 to 3 clock hours from the leading edge of the capsulorhexis to avoid tractional forces that will cause the leading edge to extend peripherally toward the bag equator [6].

Capsule Hooks

Capsule hooks, in contrast to iris hooks, support the bag by its equator, not the capsule margin, thereby keeping the bag distended and also reducing the likelihood of aspiration of the bag

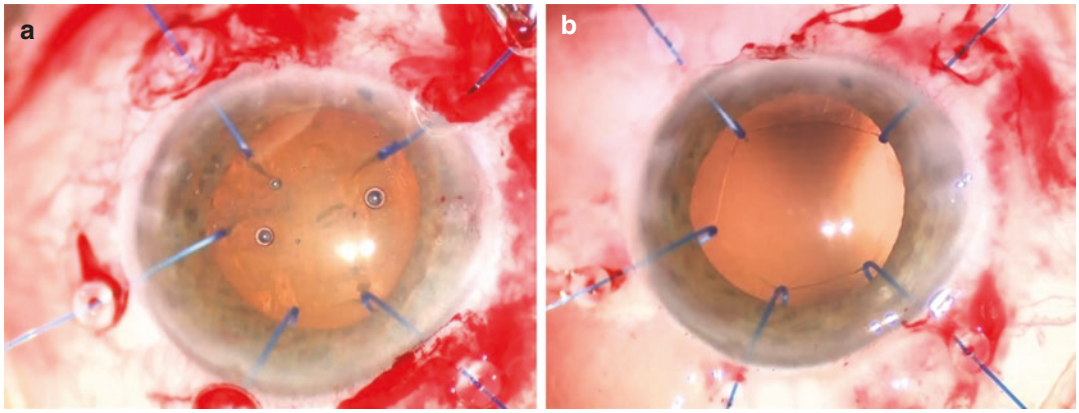


Fig. 6.9 (**a**) Iris hooks can be placed to hold the capsulorhexis edge and provide anterior to posterior support (vertical) during surgery. (**b**) Intraoperative photograph at the end of phacoemulsification and cortical aspiration

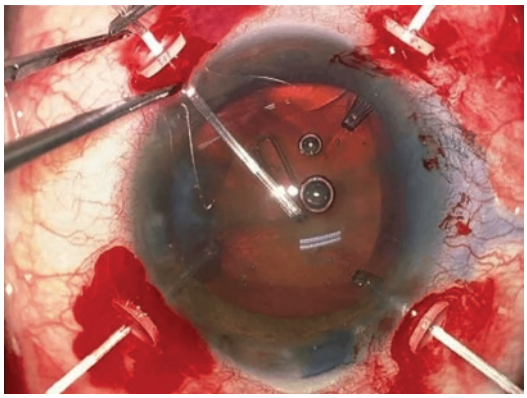


Fig. 6.10 Capsule hooks are another alternative. In contrast to iris hooks, capsular hooks support the bag by its equator, not the capsule margin, thereby keeping the bag distended and also reducing the likelihood of aspiration of the bag equator as the lens material is evacuated. However, they are too large and may interfere with surgical maneuvers, and differently from iris hooks, they cannot hold the iris if it would be necessary

equator as the lens material is evacuated (Fig. 6.10).

A system of titanium or plastic capsule retractors with hooked ends, which are elongated enough to support the peripheral capsular fornix as well as the capsulorhexis, was designed (reusable (Duckworth and Kent Ltd., Hertfordshire, England) or a single use design (Impex, Staten Island, NY), MST capsule retractors (MicroSurgical Technology Inc., Seattle, WA, USA)) [5, 8, 9].

In any case, the tension of the hooks must be enough to stabilize the capsular bag, but one should not try to completely recenter the bag by hooks alone, as they may damage the opposing zonular fibers or place undue stress on the capsulorhexis during phacoemulsification.

In our experience, the length of the capsule hook which is intended to support the bag from the capsule equator is too large and exceeds the capsulorhexis margin, interfering with the maneuvers during phacoemulsification, and thus, it is the author's preference to use flexible iris hooks. The latter can be used to hold the pupillary margin as well if needed.

Capsular Tension Rings

Conventional Capsular Tension Rings

The standard capsular tension ring (CTR) is an open-ring structure made of PMMA. This compressible circular ring has an oval-shaped cross section with two smooth-edge end terminals. The "ski ramp" design of the end terminals aids to avoid entrapment of the capsular equator on insertion and also allows for placement of secondary instrumentation [11, 12] (Fig. 6.11).

The CTR are available in various sizes according to their diameter. The most common, the Morcher ring, has three sizes based on their uncompressed diameter [10]:

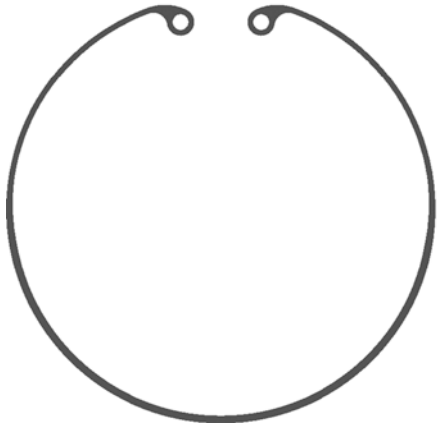


Fig. 6.11 Conventional capsular tension ring

Type	Uncompressed diameter	Compressed diameter
14	12.3 mm	10 mm
14 C	13 mm	11 mm
14 A	14.5 mm	12 mm

The selection of capsular ring size is based on capsular bag dimensions, with larger bags requiring larger CTR. The size of the bag correlates with axial length and corneal diameter, and these two parameters may be used for CTR size selection [13, 14].

However, it is our experience and that of other authors that the use of the larger size of the ring may be chosen since overlap of the end terminals is needed to provide for complete circumferential support, although it may be more challenging to insert. Several studies support the efficacy and safety of CTR in cataract surgery [12].

Because the diameter of the CTR is larger than that of the capsule bag, the centrifugal forces inherent within the ring expand the capsular equator and buttress areas of poor zonular support, providing equal distribution of support from remaining zonules. The CTR re-expands the capsular bag, provides counter-traction, and tautens the posterior capsule intraoperatively. By distending the posterior capsule, the CTR prevents it from being aspirated into the phaco tip or the I/A tip. The CTR also recruits tension from existing zonules and redistributes the forces to the remaining weaker zonules, thereby stabilizing the entire zonular apparatus [5, 6, 9, 11, 12, 15]. The CTR also plays a role in keeping the vitreous in the posterior chamber, because of the seal it creates by the distension of the capsular bag toward the periphery. This added support of the CTR may also help to recenter a mildly subluxed capsular bag to avoid decentration and dislocation. However, they do not provide anterior to posterior support, and standard CTR fail to recenter severely subluxed capsular bags, and do not prevent progressive zonular loss [3, 4]. In these situations, scleral fixated devices like the modified CTR or the capsular tension segment are more appropriate.

The implantation of a CTR is contraindicated if there is an anterior radial or posterior tear of the capsule [5, 6, 9, 11, 12, 15].

There is some controversy about the optimal timing of CTR insertion. Early implantation of the CTR may facilitate phacoemulsification, reducing the risk of aspirating a floppy posterior capsule, since it is stretched by the CTR. However, as a drawback, the entrapment of cortical material by the CTR in the capsular bag fornix may hinder its removal. Also, if a posterior capsule tear or complete zonular dehiscence occurs during lens extraction, the early placed CTR is a risk factor for dislocation into the vitreous cavity. Furthermore, CTR implantation before cataract removal may result in further iatrogenic zonular damage. Ahmed et al. showed, using the Miyake-Apple video camera, that, in terms of minimizing further zonular stress and damage and capsular destabilization, the ideal timing for CTR placement is after lens extraction and decompression of the capsular bag [16].

Insertion and rotation of a CTR in the capsular bag in the presence of crystalline lens is challenging and results in significant zonular stress and capsular bag displacement as confirmed in the Miyake-Apple study, running the risk of intraoperative or postoperative capsular bag dislocation [16]. This risk is likely increased with denser cataracts. Jacob et al. reported on the use of CTR in 21 eyes with mild to moderate zonular dialysis in which the CTR was placed prior to phacoemulsification and found a 9.5% incidence of clinically significant extension of zonular dialysis [17].

One dictum that is followed by many surgeons is to place the CTR “as late as you can, but as

soon as you must" (Rosenthal K, Personal communication, circa 2005) [6], or in other words, "as late as safely possible" [6, 8] (Video 6.4).

How to implant a CTR (Fig. 6.12) (Video 6.2)?

Implantation of the CTR may be performed manually (authors' preference) or with an injector [5]. Forceps are necessary in order to use a modified capsular tension ring which has appendages. The injector is only useful for the standard capsular tension ring. The injector delivers the ring in the center of the anterior chamber, avoiding the pressure of the CTR against the capsulorhexis margin.

A complete and intact capsulorhexis is a mandatory prerequisite in order to implant a CTR. The capsular bag must be fully distended with a cohesive ophthalmic viscosurgical device (OVD) [5]. The CTR must be inserted in the direction of the zonular deficiency and with an acute angle, in a tangential direction, to avoid radial pressure from the leading eyelet on the equator. We strongly advise to place a suture in the leading hole of the CTR. The suture has two functions. First, it can be used to retrieve the CTR in case of capsular tear or disinsertion, and second, if a fold at the equator occurs during the dialing of the CTR, pulling the suture through the main incision will help to disengage the CTR from the fold (Video 6.5). A Lester hook may be introduced trough the lateral paracentesis to avoid the contact of the CTR with the capsulorhexis margin and decrease the tension over it while dialing the ring (Video 6.2).

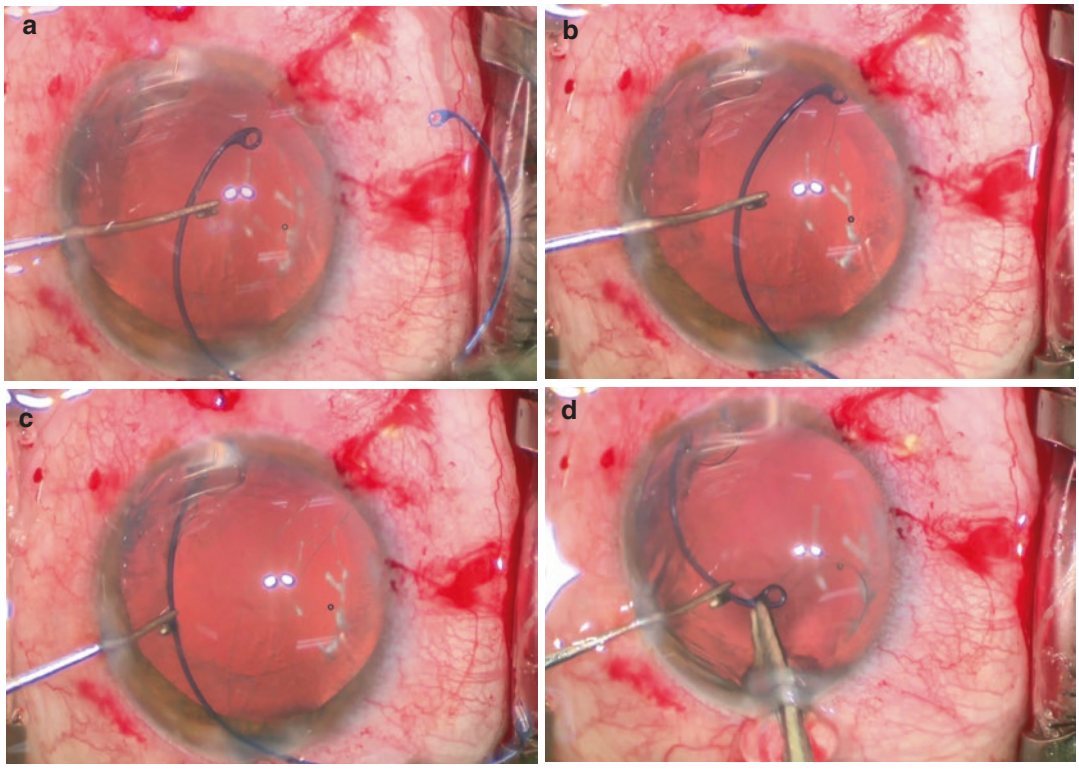


Fig. 6.12 Maneuvers to implant a capsular tension ring. (**a** and **b**) The capsular bag must be fully distended with a cohesive OVD. The CTR must be inserted in the direction of the zonular deficiency and with an acute angle, in a tangential direction, to avoid radial pressure from the leading eyelet on the equator. We strongly advise to place a suture in the leading hole of the CTR. (**c** and **d**) A Lester hook may be introduced through the lateral paracentesis to avoid the contact of the CTR with the capsulorhexis margin and decrease the tension over it while dialing the ring

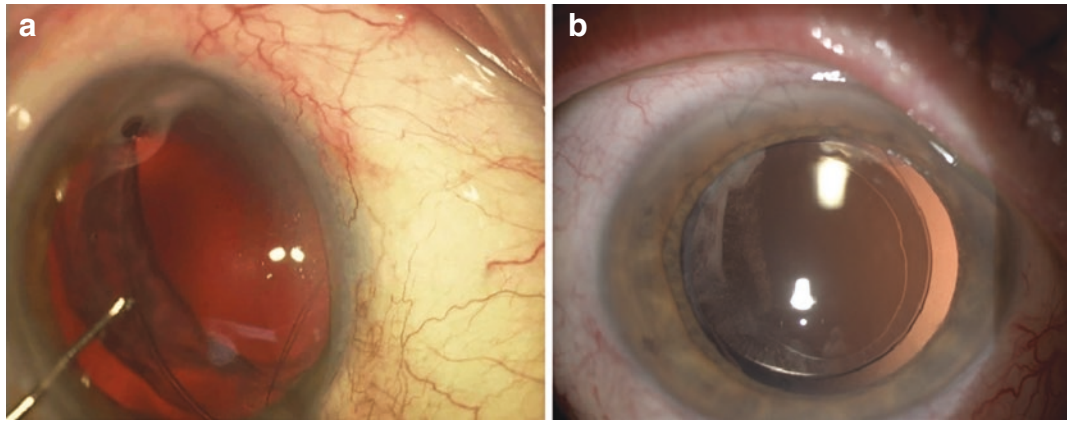


Fig. 6.13 (**a**) During capsular tension ring insertion, an extension of the zonular dehiscence may occur, specially in cases of generalized zonular weakness, as in pseudoexfoliation. In this case of pseudoexfoliation syndrome, an increase in the area of zonular deficiency was noted during insertion. The ring was dialed until this eyelet was adjacent to the area of zonular disinsertion, and the prolene suture that had been threaded through the leading eyelet was used to suture the ring to the scleral wall after creating a Hoffman pocket, without violating the integrity of the capsular bag. (**b**) Postoperative appearance

In order to minimize the stress on the residual zonules in these eyes with already extensive zonule loss, a Sinskey hook may be introduced in the leading eyelet, supporting it away from the equator, in order to avoid stress on the damaged zonules, facilitating the dialing of the CTR during implantation. When more than half of the CTR has been introduced, the eyelet is disengaged from the Sinskey hook. A fishtail technique using a suture has been also described [18, 19].

Complications of CTR implantation include inadvertent anterior capsule tear, posterior dislocation of the capsular tension ring, intraoperative dislocation after early CTR placement, and increase in the extension of zonular deficiency during implantation (Fig. 6.13). Jacob et al. reported intraoperative extension of dialysis in 9.52% of eyes, and in one case, conversion to pars plane vitrectomy to remove nuclear fragments luxated in the vitreous [17]. Regarding tears in the margin of the capsulorhexis, Praveen et al. showed that this prevented implantation of a CTR in two eyes [20].

The implantation of a CTR does not change refractive outcome and modification of IOL power calculation was unnecessary [12].

Cionni Ring

The standard CTR is unable to provide intraoperative support and center the capsular bag in situations of severe zonulolysis (more than 4 h). Alternatives included suturing the standard CTR through the capsule bag (Fig. 6.14) with the added risk of creating a capsular tear [1, 5].

In 1998, Cionni designed the modified CTR which allows the surgeon to suture the CTR to the sclera. The modified CTR (Morcher GmbH, Stuttgart, Germany) has one (model 1-L or 1-R) or two fixation eyelets attached to the central portion of the ring which protrude 0.25 mm forward from the body of the CTR, sitting in front of the anterior capsule, preserving the capsular bag's integrity on suturing [1, 5, 8, 21, 22] (Fig. 6.15a–c).

A double arm 9/10 polypropylene suture on straight needles is pre-placed in the fixation eyelet. Polypropylene 10/0 is not recommended given the risk of hydrolyzation over time with a roughly 5- to 10-year survival time [23]. Another alternative is polytetrafluoroethylene CV-8 suture which is off-label and has cumbersome needles or the use of 9/0 polypropylene. The modified capsular tension ring is injected just under the anterior capsule. The modified CTR is rotated

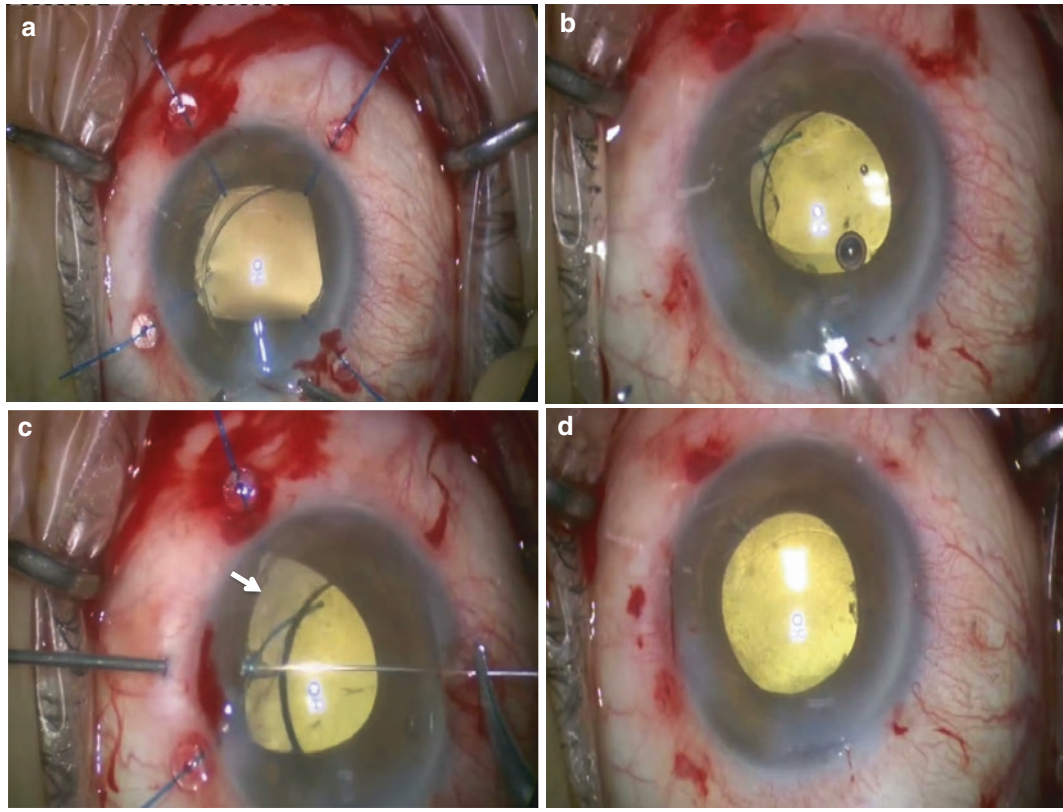


Fig. 6.14 Scleral fixation of a conventional CTR with prolene sutures through a Hoffman pocket. The docking needle punctures the capsular bag, and thus, this maneuver poses the risk of inducing a capsular tear. (**a**) In a case of high myopia and pseudoexfoliation, phacoemulsification had been carried out holding the capsular margin and the iris with iris hooks. A CTR is implanted using the fish-tail technique in order to decrease further damage in the zonular apparatus. (**b**) In spite of all these measures, after removing the OVD from the anterior chamber, an inferior zonular dehiscence was evident (arrow indicates the CTR at the equator of capsular bag). (**c**) Using the technique described by Crandall [25], the CTR and the inferior PMMA haptic were sutured to the sclera. (**d**) Intraoperative view at the end of surgery showing a centered IOL (note the good centration of the capsulorhexis margin)

until the eyelet is situated at the area of greatest zonular dehiscence. A scleral flap, Hoffman pocket [24], or scleral groove is created adjacent to the area of dehiscence, and using an *ab externo* technique similar to that described by Ahmed and Crandall [25], the sutures are placed 1.5 mm posterior to the limbus. The suture ends are tied adjusting the tension so that the IOL remains centered (Fig. 6.16) (Video 6.6). An alternative technique using 6/0 polypropylene for sutureless scleral fixation of MCTR has been recently described [26].

Cionni ring either with one or two eyelets has been shown to be useful in the management of severe subluxated traumatic cataracts [15]. Excellent long-term capsule centration and scleral support was reported with this device [22, 27–29].

The most frequent complication of modified CTR is posterior capsule opacification. Other complications include late IOL decentration, elevated intraocular pressure, pigment dispersion, mild iritis, and CME [29].

Malyugin modified Cionni ring so that it could be delivered into the bag using an injector (Morcher GmbH), by moving the fixation element to the very tip of the ring. This makes the device completely retractable into the injector,

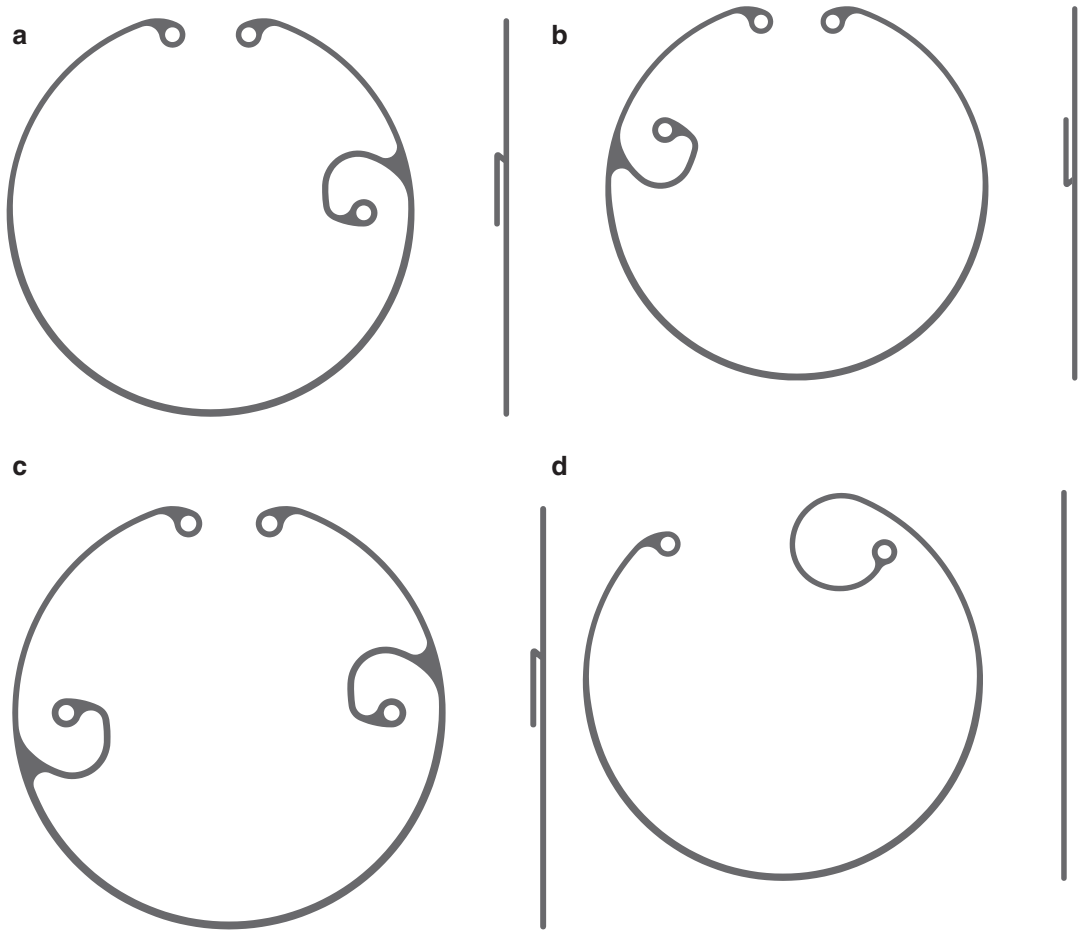


Fig. 6.15 (**a**–**c**) Cionni modified capsular tension ring with one or two fixation eyelets. (**d**) Malyugin modified capsular tension ring

subsequently allowing it to be inserted into the eye in a very controlled manner [30] (Fig. 6.15d).

Scleral Fixation Devices

The possibility of directly suturing a conventional CTR inserted in the bag to the sclera with a loop of suture around it has been described, but it poses the risk of causing a posterior capsule tear. Currently, different options to perform scleral fixation of the bag are available which respect the bag – apart from the already mentioned modified capsular tension rings – and include the capsular tension segment (CTS), the Assia anchor, and the T-shaped and the endocapsular glued segment.

Ahmed Segment

Designed by Ahmed in 2002, this special device combines the concept of the modified CTR and a capsular retractor. It is a PMMA segment of 120° of arc, with a modified element (appendage with an eyelet) that can be sutured to the sclera if needed, or can be hooked with an iris hook during phacoemulsification. The difference from hooks is that one segment distends 120° of arc of the capsular bag, and at the same time, provides anterior to posterior stabilization (Fig. 6.17) [11, 12].

However, the segment must be complemented with a CTR, since the distension of the bag in 120° is not enough to prevent posterior capsule to be aspirated by the phaco tip.

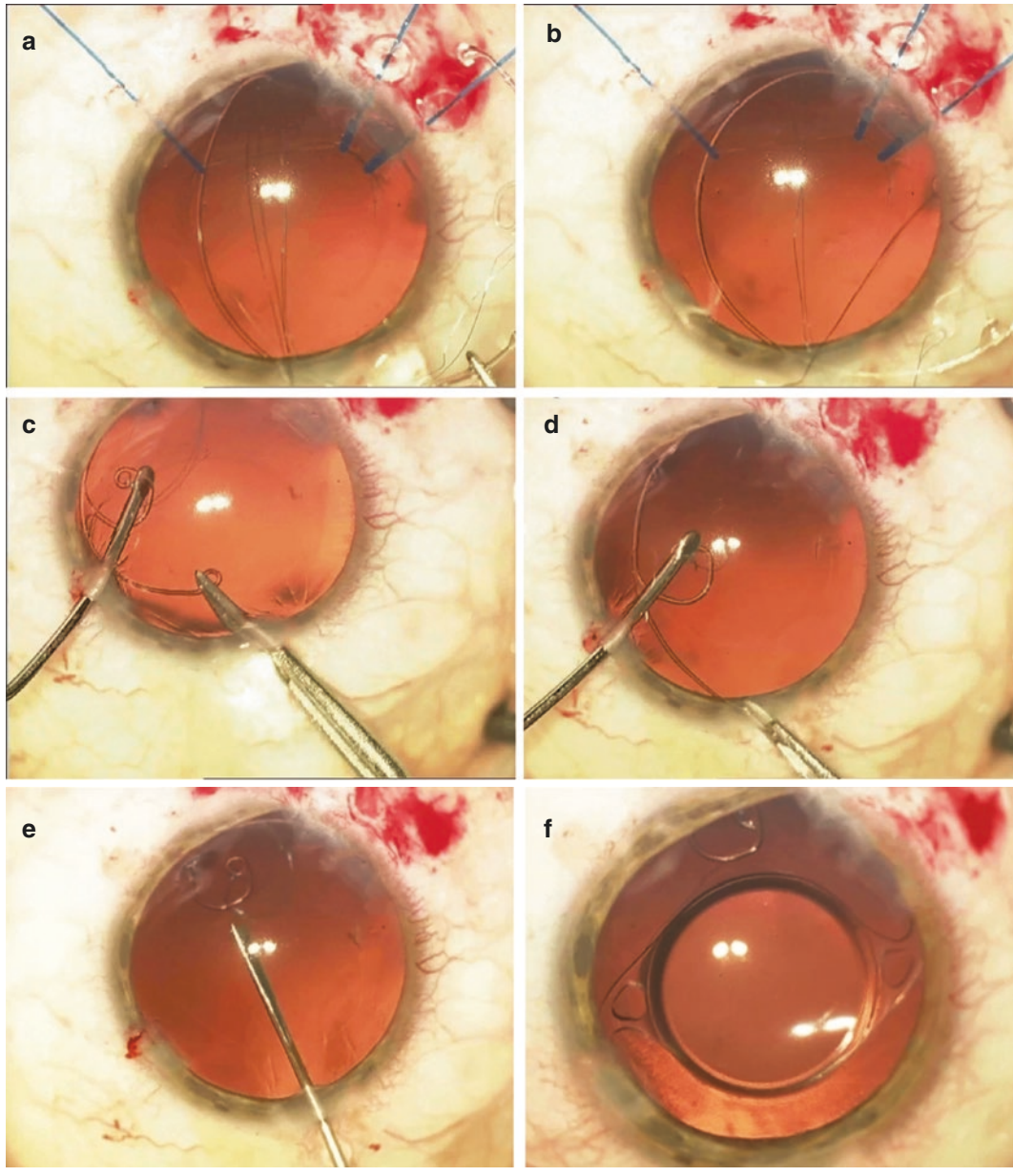


Fig. 6.16 Implantation of Cionni ring. (**a**) Two prolene sutures are placed, one through the leading eyelet and the other through the fixation eyelet. The suture placed on the fixation eyelet must be passed toward the sclera adjacent to the area of zonular dehiscence, before inserting the ring into the anterior chamber. Double needles are inserted into a nesting needle using an *ab externo* technique similar to that described by Crandall [25]. (**b**) The ring is inserted pointing toward the area of dehiscence and dialed until the fixation appendage is in front of the area of zonular deficiency, (**c**–**e**) taking care that the appendage remains over the capsulorhexis after the implantation. (**f**) Final appearance with good centration of the intraocular lens

Compared to CTR implantation, Miyake-Apple video analysis of CTS placement shows minimal zonular stress on insertion prior to lens extraction (A).

The CTS has several advantages (Videos 6.2, 6.3, 6.7, 6.8, 6.9, and 6.10). Differently from the modified CTR or the Malyugin ring, it can be implanted without sutures, and sutures may be placed later if scleral fixation is needed. It can be used just for vertical support during surgery, instead of hooks, and be easily removed at the end, or it can be sutured at the end of surgery. It is fixated with an iris hook at the beginning of surgery to provide vertical support, instead of placing several iris hooks, in the area of capsular deficiency. Only one hook will be necessary to fixate it, with the added benefit of the capsular tension induced by the 120° arc of ring; and it is possible to place it at the beginning of surgery, when implanting a conventional CTR would be challenging and would pose the risk of increasing the dehiscence. The implantation of the segment, after viscodissection of the space between the capsule and the peripheral cortex, is easier and less risky since a dialing technique is not necessary. When used for intraoperative support, an inverted iris retractor (by a paracentesis) is placed through the eyelet acting as a coat hanger to support the capsular bag in the area of zonular weakness [11, 12]. When the segment is used early in a case, OVD is placed under the anterior capsule leaflet, and a space is created between the cortex and the capsule equator in the quadrant of interest. The segment is then slipped into the bag fornix, with the fixation element remaining anterior to the capsulorhexis. A flexible iris retractor is used to stabilize the segment, placing the hook through the Ahmed fixation eyelet (Fig. 6.18) [11, 12]. The risk of dislodgement and anterior capsular tear is less likely with CTS than with flexible iris or capsule retractors.

Fig. 6.17 Ahmed segment (CTS)

Multiple CTS devices may be used in a similar fashion, allowing to customize the surgery for cases of severe weakness (Fig. 6.7g) (Video 6.2a), and to address circumferential support, a CTR may be implanted in conjunction with an already positioned CTS which is the author's preference. The CTS provides enough support to implant also an artificial iris implant within the capsular bag (Video 6.10).

Several studies provide evidence of the safety and efficacy of the use of modified CTR or CTS with CTR for the management of subluxated cataract both in adults and pediatric patients [31–33].

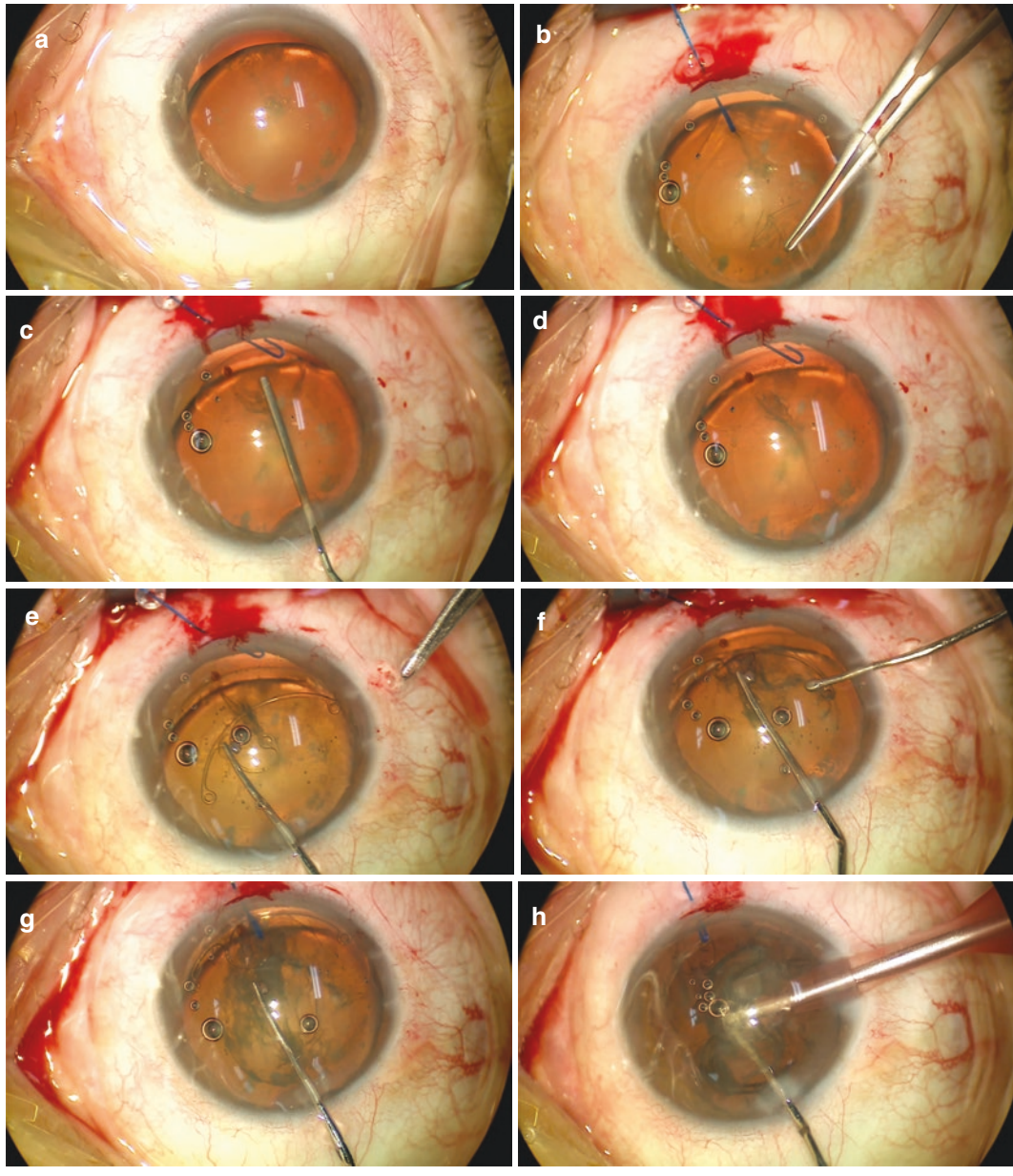


Fig. 6.18 Ahmed segment implantation in a case of traumatic subluxation. (**a**) 180° of zonular dehiscence. (**b**) Capsulorhexis is performed with the aid of an iris hook. (**c**, **d**) Viscodissection between the capsular bag and the cortical material. (**e**, **f**) Implantation of the capsular tension segment; the central eyelet must remain anterior to the capsule. Differently to Malyugin or Cionni ring, a dialing technique is not necessary to implant the device. (**g**) An inverted iris retractor is placed through the eyelet acting as a coat hanger. (**h**) Phacoemulsification. (**i**) Insertion of the capsular tension ring. (**j**) The CTS is removed from the capsule equator and is placed vertically in the middle of the anterior chamber. (**k**) The eyelet is threaded with the suture (**l**) creating a loop around it [25]. (**m**) Final appearance

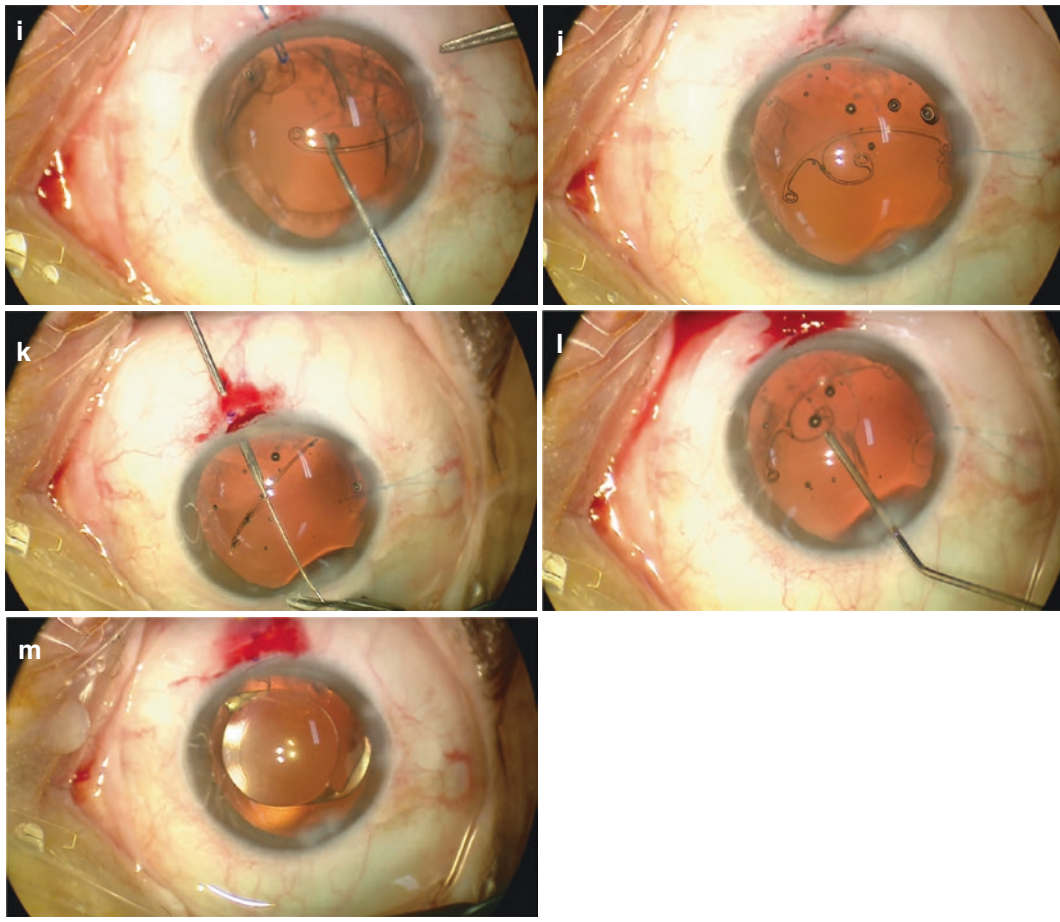


Fig. 6.18 (continued)

Other Devices

Other alternatives to fix the capsular bag and to provide vertical support include the Assia anchor, the Yaguchi hook, and the glued endocapsular tension ring.

The Assia anchor (capsular anchor) is a flat intraocular PMMA implant that consists of a central rod positioned in front of the anterior capsule and two side arms positioned behind the anterior capsule. It is sutured to the sclera [34] (Fig. 6.19).

The T-shaped ending Yaguchi hook is a flexible T-shaped device made of 5–0 polypropylene attached to a curved needle which is sutured to the sclera. The contact portion is bent at 1.25 mm and the end bifurcates in a T configuration to form a 3.75 mm footpad [35].

The glued endocapsular tension ring (Epsilon Eye) is a one-piece device made of polyvinylidene fluoride with three parts: arms on either side to expand the fornix, a Malyugin-type scrolled mechanism to engage the capsulorhexis, and a haptic that goes through the sclerotomy to anchor the device, and thereby the capsular bag, to the sclera by means of fibrin glue-assisted sutureless transscleral fixation of the bag [36].

Fig. 6.19 Assia anchor

Either the CTS or any of these devices provide only focal support of the capsular bag, and they neither do not distend the capsular bag equator nor provide circumferential distribution of forces, and thus, they should be combined with conventional of modified CTR.

In order to perform scleral fixation, we use an *ab externo* technique similar to that described by Ahmed and Crandall [25]. Once both sutures are externalized, the IOL is implanted, and with the globe pressurized, suture tension should be titrated to achieve maximal IOL centration. The sutures and knots can be placed under scleral flaps, in a Hoffman pocket [24], into a scleral groove, etc. according to the surgeon's preferences since no system has proven to be superior. A sutureless technique has been reported for the scleral fixation of Ahmed segment using 5/0 prolene [37]. We have used a modified approach to use 6/0 prolene docked into a 30 g ultrathin wall needle (C, D) (Figs. 6.7 and 6.20) (Video 6.2).

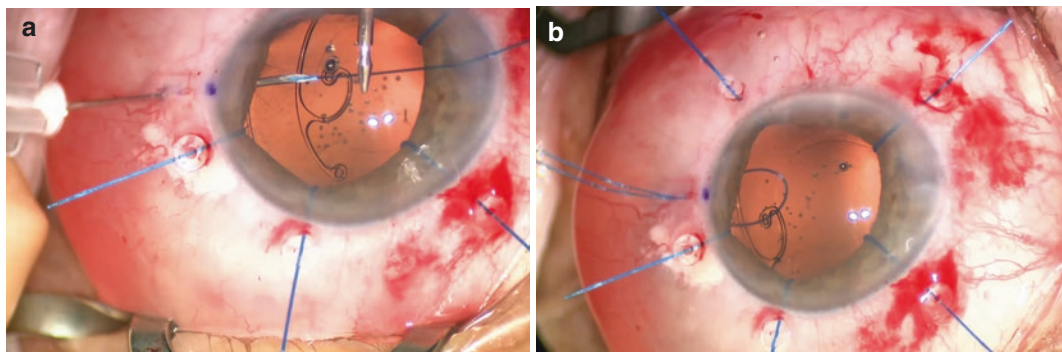


Fig. 6.20 Surgery of a subluxated cataract – preoperative and postoperative details are shown in Fig. 6.7 – with implantation of a CTR and two CTS which were fixated to the sclera using flanged 6/0 prolene without knots. We have used a personal modification of the technique previously published in order to use a 6/0 prolene into a 30 g needle, instead of using 5/0 prolene into a 26 g needle. (**a**) After implanting the CTR, a CTS is inserted into the anterior chamber, and one extreme of 6/0 prolene is threaded through the eyelet and docked into the barrel of a 30 g ultrathin wall needle which has been inserted 2 mm from the limbus. (**b**) After externalizing that extreme of the prolene, the same maneuver is repeated with the other extreme to create a loop around the eyelet. (**c**) The intraocular lens is implanted and another CTS is implanted with the same technique 180° apart from the first one. The appropriate tension is applied to obtain good IOL centration, and the tops of the prolene suture are cut and flanged using a cautery. The flanged tops are buried into the sclera. (**d**) Final appearance

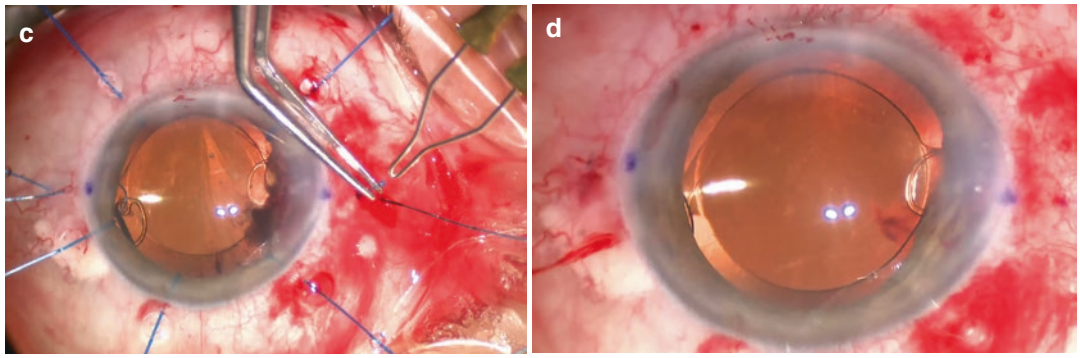


Fig. 6.20 (continued)

Our Surgical Strategy

The surgery of a subluxated lens faces two mechanical challenges. Firstly, the vertical stability of the lens is compromised by the lack of zonular support, and secondly, the distension of the posterior capsule is altered by the lack of zonular fibers.

At the beginning of surgery, the main problem is the vertical support, that is, keeping the lens in the proper horizontal plane, and that is best achieved through the use of iris hooks, or Mackool hooks or CTS implantation. They hold the lens without risking the increase in the zonular deficiency induced by the early placement of a CTR, specially in hard lenses, while dialing the CTR. During hydrodissection, and phacoemulsification, the bag is full and will not collapse until the last phase of phacoemulsification when most of the lens material has been removed. Also, the nuclear fragments themselves can be used to keep the posterior capsule far from the phaco tip [38].

Once the cataract has been emulsified, and depending on the course of hydrodissection, a CTR may be safely implanted to distend the posterior capsule and avoid its aspiration through the phaco tip. At that time, all or almost all of the cortical material must have been removed and in any case, implanting the CTR without the nucleus, induce less stress over the zonules than the implantation before the phacoemulsification, dialing it through the resistance of the bag full of lens content.

Once the CTR is in place, the surgeon must decide whether to fix the bag to the sclera or not. The decision will depend on the extension of the dehiscence (more than 4 hours of deficiency usually will need scleral fixation to get appropriate centration of the bag) and on the progressive or stable nature of the condition. The scleral fixation of the bag may be performed by means of a modified CTR, the CTS, the Assia anchor, etc. according to surgeon's preferences.

Our preference is to use a CTS at the beginning of surgery since its insertion does not pose any risk regarding the increase in the zonular dehiscence, and it provides not only the vertical support but also some distension of the bag in a 120° area. If entrapment of cortical material occurs, it can be disinserted, cortical aspiration can be carried out, and it can be implanted again later. Once most of the cortical material has been aspirated, a CTR is implanted, as the CTS do not fully distend the capsular bag, and finally, if necessary, the CTR will be fixated to the sclera. And additional CTS may be combined if required, depending on the extension of zonular deficiency (see below). The combination of the CTS and CTR allow to address vertical support or bag distension separately, as required, differently from modified CTR (Videos 6.2, 6.3, 6.7, 6.8, 6.9, and 6.10).

Surgical Algorithm

The surgical strategy will depend on the extension of zonular dehiscence and the cause of the deficiency, regarding whether it is progressive or not. Traumatic cases usually have healthy zonules outside the area of the dehiscence, while in congenital cases, as Marfan or adult onset cases such as pseudoexfoliation and retinitis pigmentaria, further damage of the zonules is expected with time.

We use the following algorithm in cases of zonular deficiency [1, 5, 6, 8]:

Extension of zonular dialysis	Management
Mild (<4 h of zonular dehiscence)	One CTR
Moderate (4–8 h of zonular dehiscence)	One CTR Hooks or CTS during surgery Scleral fixation at one point
Severe (>8 h of zonular dehiscence)	Hook or CTS, CTR, scleral fixation at two points

However, this strategy must be adjusted according to the profile of zonular weakness (stable or progressive) and the density of the nucleous.

The surgeon may choose to perform scleral fixation in mild case of Marfan, since it will surely progress. The implantation of a CTR does not halt the progression of zonulopathy in progressive cases; however, it facilitates refixation of the capsular bag IOL complex.

The management of very dangling lenses if they are soft may be accomplished by lensectomy, from a pars plana approach, followed by a secondary implant (Fig. 6.21) (Video 6.11). Severe cases of dehiscence with very hard cataracts may require intracapsular approach, as sometimes happens in pseudoexfoliative patients with important phacodonesis and very hard nucleous (Fig. 6.22).

Even after a detailed preoperative exam, unpredictable surprises may occur during surgery in these cases, so the necessary material must be available and the surgeon must be ready to use

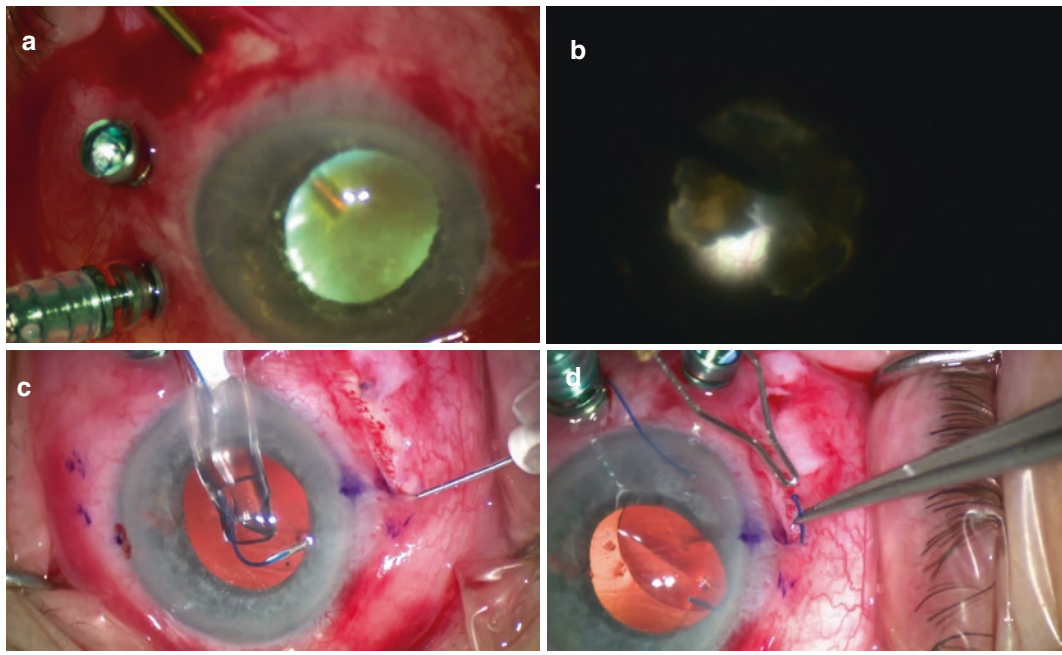


Fig. 6.21 *Pars plana* lensectomy (**a**, **b**) and secondary flanged IOL implantation in a case with severe phacodonesis (**c**–**f**)

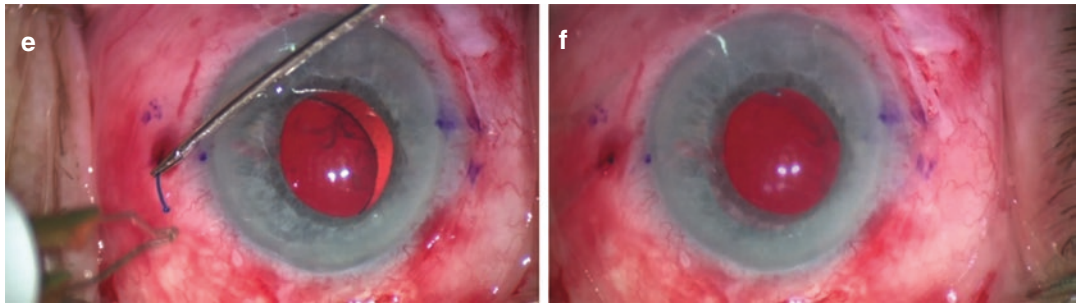


Fig. 6.21 (continued)

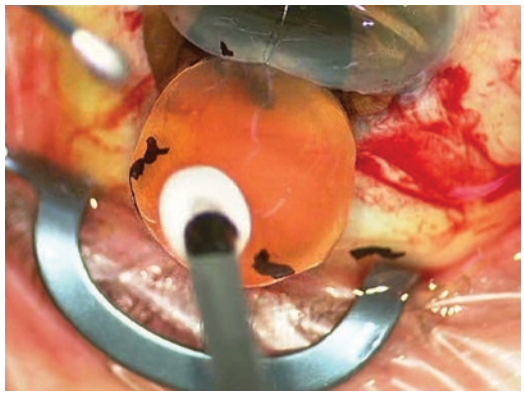


Fig. 6.22 Intracapsular extraction in a case of pseudoexfoliation with severe pseudophacodonesis and dense cataract. After the cataract extraction, a retropupillar iris claw lens was implanted

different strategies to face different degrees of zonular weakness (B).

Surgical Technique

Anesthesia

These cases should be performed under peribulbar anesthesia, as additional maneuvers, difficult to perform under topical anesthesia, may be required during surgery and the duration of surgery is usually longer [9].

Incision

The main incision must be performed in the area opposite the zonular dehiscence (Fig. 6.23) (Video 6.3) as long as the surgeon is comfortable, or 90° apart [5, 6, 9]. Whether scleral fixation of a modified CTR or Ahmed segment is planned in advance, the Hoffman pockets, or conjunctival peritomy and scleral flaps, must be performed before the corneal incision. Also, if vitreous is present in the anterior chamber and insertion of a trocar is going to be done in pars plana, it should also be inserted before performing the corneal incision.

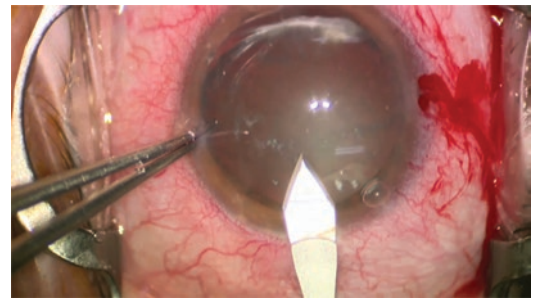


Fig. 6.23 The main incision must be performed in the area opposite the zonular dehiscence

Vitrectomy

Vitreous may be present in the anterior chamber, specially in traumatic cases. Anterior vitrectomy must be carried out before capsulorhexis (Fig. 6.24) (Video 6.3) [6, 9]. This procedure may be accomplished from a pars plana approach or form a limbal approach, always using a different incision for the vitrector and for the infusion. Triamcinolone-assisted vitrectomy is performed until no vitreous is identified in the anterior

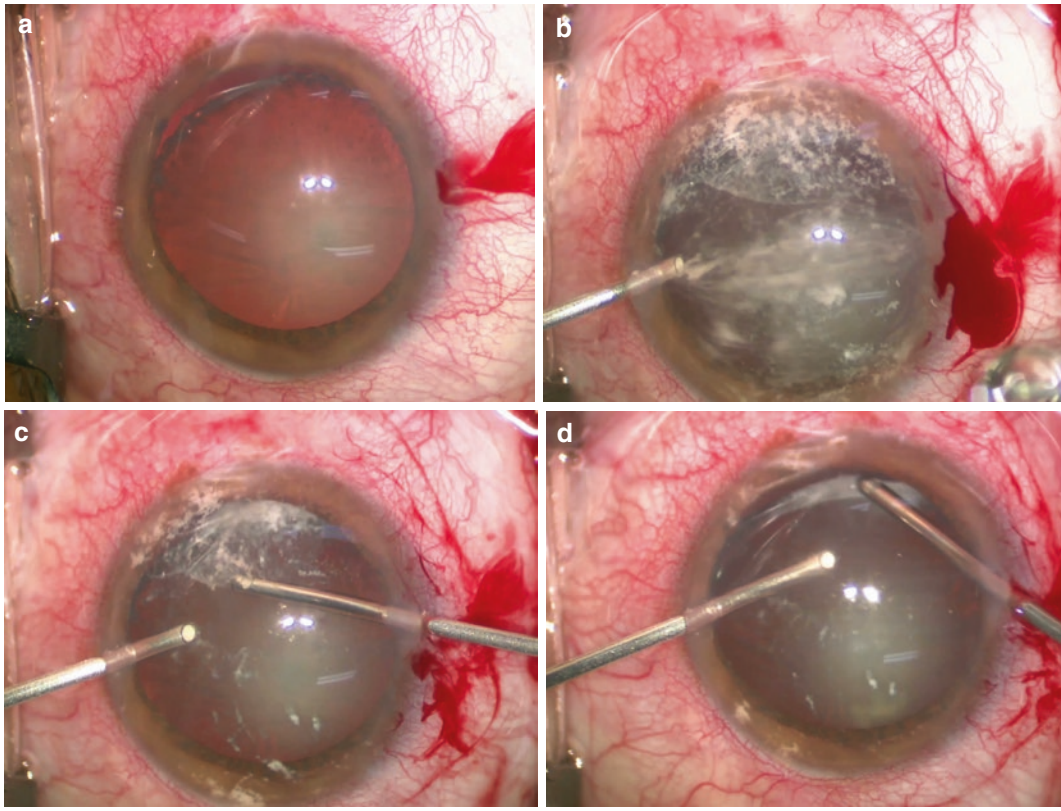


Fig. 6.24 (**a**) Traumatic subluxated cataract. (**b**) If vitreous prolapse is detected in the anterior chamber, a triamcinolone assisted anterior vitrectomy must be performed before capsulorhexis creation (**c**, **d**)

chamber. A dispersive OVD is placed over the area of zonular dehiscence to tamponade the vitreous in the posterior chamber.

In addition, the implantation of a CTR also contributes to control the vitreous prolapse through the area of zonular dehiscence, since it expands the bag and the tension of the CTR together with the use of CTS or iris hooks that lift the bag against the iris, seal the anterior chamber from the vitreous cavity. The creation of this seal between the AC and the vitreous helps to prevent further vitreous prolapse and aqueous misdirection during phacoemulsification [15].

Capsulorhexis

The capsulorhexis is a critical step in any phacoemulsification, and entails facing several difficulties in cases of subluxated cataracts. First, the counterforce produced by the normal zonules is lacking in the area of dehiscence. This is the reason of radial folds and movement of the lens during the capsulorhexis. Second, the lens is decentered, exposing the equator of the lens, while the opposite area of the lens is hidden behind the iris, making it difficult to achieve a centered capsulorhexis.

The use of trypan blue is advisable, not only because it enhances visualization during the capsulorhexis but also to identify the margins of the rhexis during the rest of the surgery. The dye must be applied after the injection of an OVD and under it, to limit the uncontrolled spread of the dye that could reach the area of zonular dehiscence and the vitreous cavity, obscuring the red reflex. In the ultimate soft-shell technique, a viscoadaptive OVD is used to coat the endothelium, and balance salt solution is then injected onto the lens surface below the OVD, creating a

low viscosity working space where the trypan blue dye is added [39, 40] (Fig. 6.25) (Videos 6.3 and 6.10).

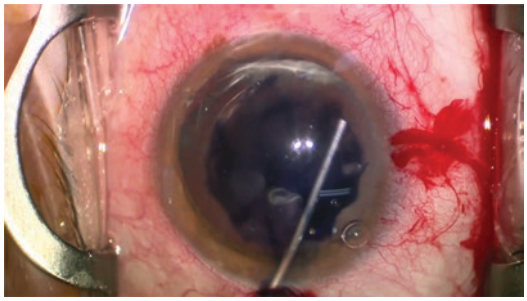


Fig. 6.25 Capsular dye must be applied below using the ultimate soft-shell technique

During capsulorhexis, we find big wrinkles on the quadrant of the zonule weakness, because the zonules cannot readily counteract the pulling force created by capsulorhexis forceps (Video 6.2).

In cases of mild decentration, it is possible to perform a centered capsulorhexis without difficulties. The anterior capsule must be punctured in an area away from the dialysis, and once the flap of the anterior capsule is formed, it is grasped and the tractions are performed in the direction of the dehiscence, not against it, in order to avoid the extension of the zonular insufficiency [5, 6] (Fig. 6.26) (Video 6.2).

In cases of moderate decentration in which it is difficult to obtain a centered capsulorhexis,

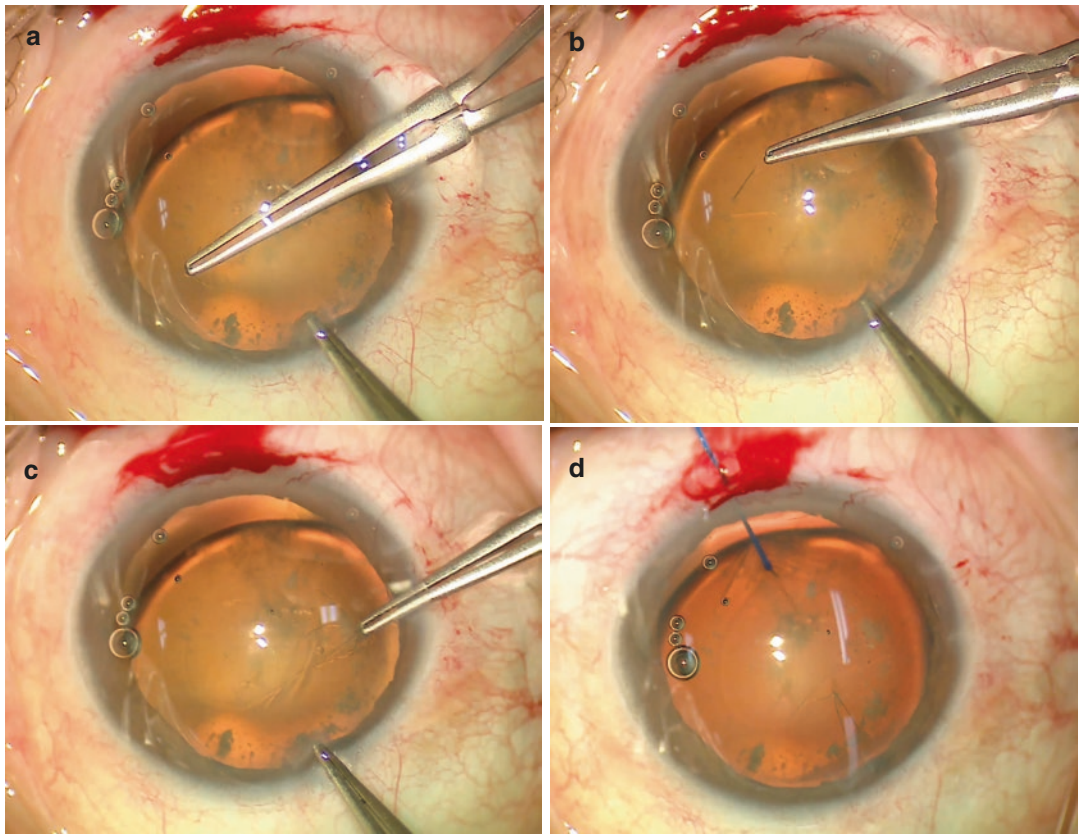


Fig. 6.26 (**a**–**c**) The anterior capsule must be punctured in an area away from the dialysis, and once the flap of the anterior capsule is formed, it is grasped and the tractions are performed in the direction of the dehiscence. (**d**–**f**) The counterforce produced by the normal zonules is lacking in the area of dehiscence. When using hooks as counter-traction during capsulorhexis creation, the hooks should be placed at least 2 to 3 clock hours from the leading edge of the capsulorhexis to avoid tractional forces that will cause the leading edge to extend peripherally toward the bag equator

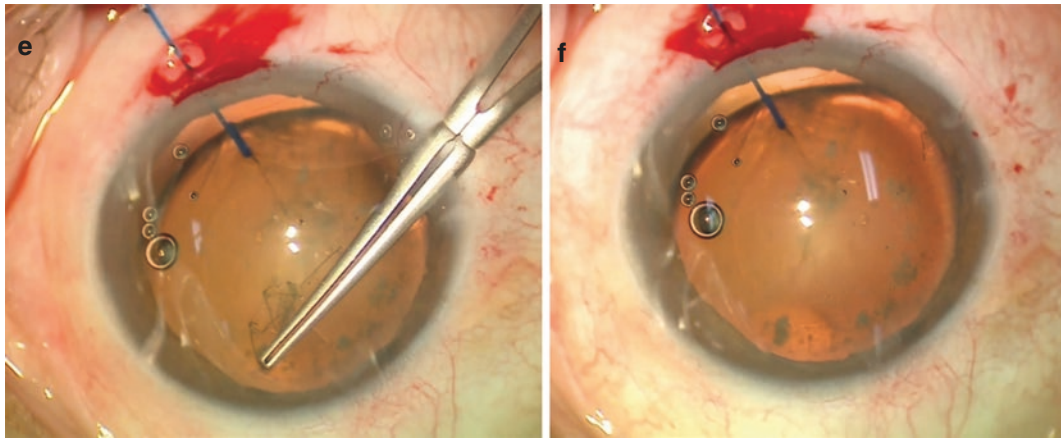


Fig. 6.26 (continued)

once the initial flap is created and part of the capsulorhexis is performed, iris hooks can be placed, which engage the margin of the rhexis, and traction is created to center the lens, so more of the anterior capsule surface is exposed, and better centration for the rhexis is possible. When using hooks as counter-traction during capsulorhexis creation, the hooks should be placed at least 2 to 3 clock hours from the leading edge of the capsulorhexis to avoid tractional forces that will cause the leading edge to extend peripherally toward the bag equator (Fig. 6.26) (Videos 6.2, 6.8, and 6.10). A Lester hook can be used as an alternative to mobilize the subluxated lens [6].

In some cases of very loose zonules, the lack of zonular tension makes it impossible for the needle to penetrate the anterior capsule. In these cases, a bimanual approach must be performed to initiate the rhexis. A coaxial forceps is used to grasp a fold of the anterior capsule, while the needle punctures the anterior capsule near the fold to be able to initiate the flap of the rhexis. In some cases, capsulorhexis must be completed with two micro capsulorhexis forceps to provide counter-traction as required [41] (Fig. 6.27) (Video 6.12).

Capsulorhexis diameter should be between 5 and 6 mm, taking care to keep at least 2 mm from the capsulorhexis margin to the equator, minimal distance required to keep a CRT or segment into the capsular bag.

Hydrodissection and Hydrodelineation

Properly performed hydroprocedures are mandatory to allow the free rotation of the nucleus in the bag, thereby decreasing zonular stress. Multiquadrant cortical cleaving hydrodissection followed by hydrodelineation should be carried out. Also, bimanual rotation of the nucleous is strongly recommended to equally redistribute the stress on the zonules (Video 6.8). The difficulty found during rotation of the nucleous can give us an idea about the extension of the zonulopathy, since the larger the zonulopathy, the more difficult it will be to rotate the nucleous.

Phacoemulsification

Although some authors recommend that soft nucleous be phacoemulsified in the anterior chamber, at a suprascapular level, to decrease stress on the zonules, the maneuver of prolapsing the nucleous through the rhexis toward the anterior chamber poses some stress on the bag, and anterior chamber phacoemulsification may damage the endothelium [1, 6]. Phacoemulsification of soft lenses within the bag does not usually cause significant traction on the zonules. For the remaining cases, direct chop and stop and chop are the nucleofracture techniques that induce less

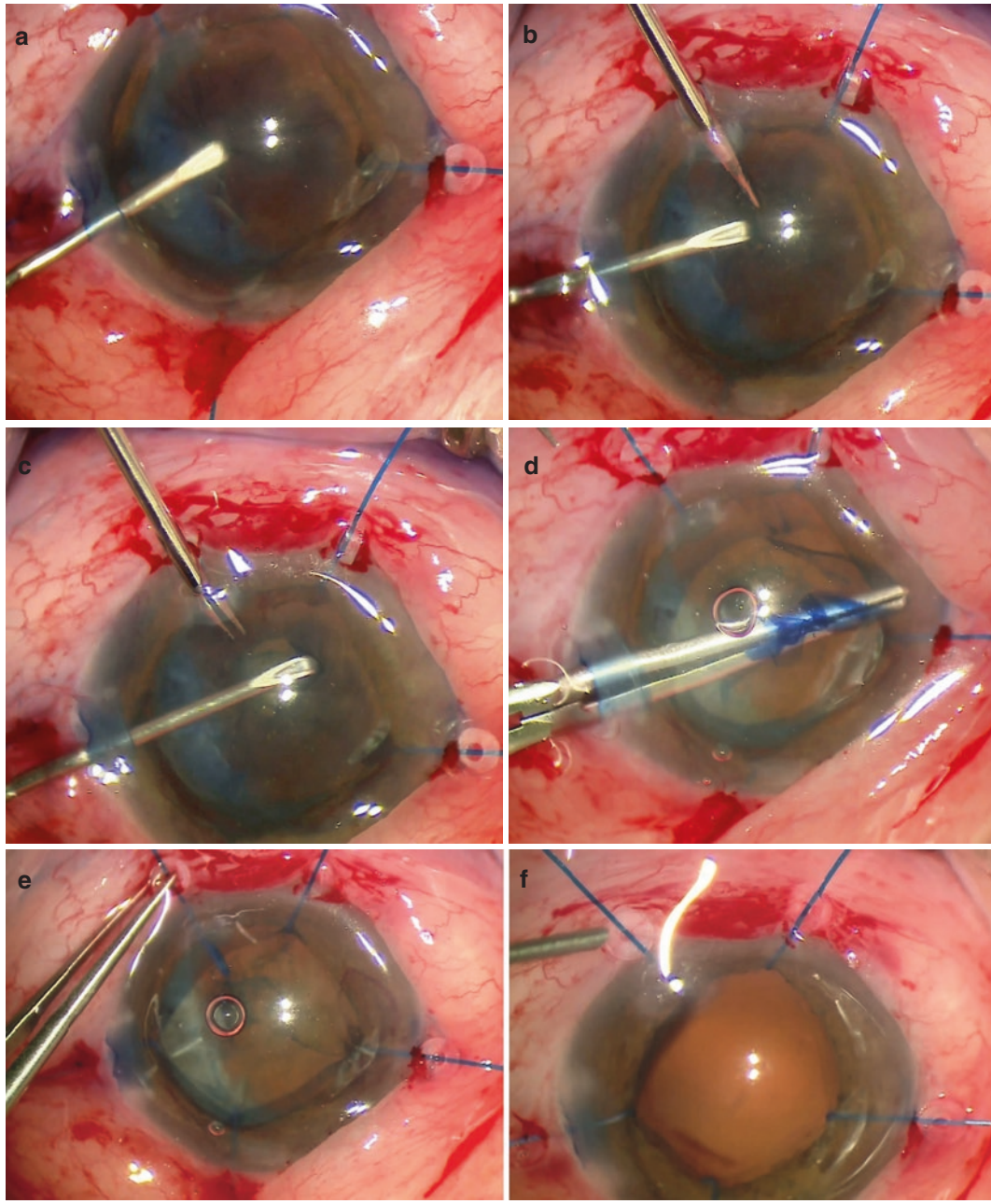


Fig. 6.27 (**a**) Pronounced folds appeared when trying unsuccessfully to puncture the capsule to initiate the rhexis, due to extensive and generalized zonular weakness. (**b**) A capsulorhexis microforceps was used to grasp a fold to create a counter-traction while puncturing the capsule with the needle holder with the other hand, using a bimanual approach. (**c**, **d**) Capsulorhexis was completed. (**e**, **f**) Iris hooks which were already dilating the pupil were transferred to the capsulorhexis margin holding at the same time the iris and the capsular bag and phacoemulsification could be carried out uneventfully

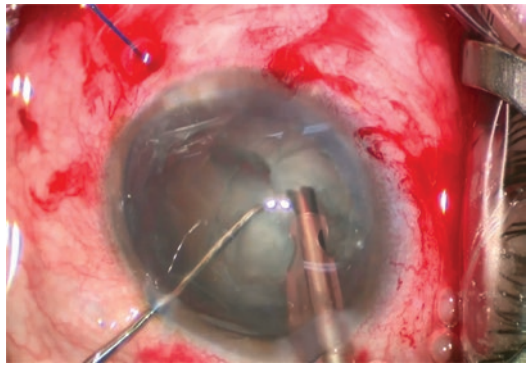


Fig. 6.28 Phaco-chop is the nucleofracture technique that induces less stress on the zonules. The use of slow motion phacoemulsification is highly recommended

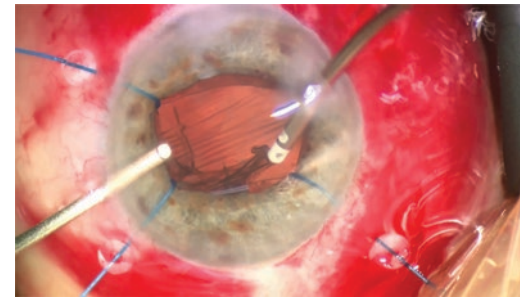


Fig. 6.29 Tangential aspiration of the cortical material using I/A tips toward the dehiscence minimizes traction on the zonules

stress on the zonules (Fig. 6.28) (Videos 6.2 and 6.3) [9]. Regarding the parameters, the use of slow motion phacoemulsification is highly recommended. In this technique, all the parameters of the equipment, ultrasound energy, aspiration rate, flow rate, and bottle height or pressure are kept to the minimum value with the purpose of decreasing turbulences in the anterior chamber and subsequently, inducing less stress on the zonules [42].

During phacoemulsification, the nuclear fragments themselves can be used as a scaffold to avoid the forward movement of the posterior capsule which is the result of lack of tension because of the absence of counteraction of zonular support [38].

Cortical Aspiration

The greatest amount of traction on the zonules is induced during cortical aspiration.

This step is facilitated by a prior hydrodissection as most of the cortex will be dissected from the capsule during this maneuver. Another recommendation is to perform tangential aspiration with the irrigation/aspiration (I/A) tip, stripping tangentially toward the dehiscence rather than away from it (Fig. 6.29) (Video 6.13). In these cases, the use of bimanual I/A tips is highly advisable, since they allow access to any meridian, according to the place where incisions are made. Also, residual recalcitrant cortical material can be mobilized after IOL implantation, when dialing the intraocular lens, and be aspirated afterward. We can also direct the irrigation flow to a point far from the dehiscence to reduce the risk of the BSS penetration toward the vitreous cavity resulting in a misdirection syndrome [1, 5, 6, 9].

The difficulty to perform cortical aspiration varies greatly from one case to another, depending on the extension of zonular dehiscence, and the presence of a CTR inside the bag or not.

If implantation of a CTR was required before cortical aspiration, part of the cortical material will remain entrapped behind the CTR. If the I/A tip aspirates and performs traction of the superior and inferior part of cortical material, it will form a loop around the CTR and it will be impossible to remove it. Instead, traction should be exerted on the material either above or below the CTR, in a tangential fashion.

If no CTR has been implanted, and when performing traction on cortical material, even with a tangential direction, either the lens equator becomes visible or the posterior capsule, which has no tension due to absence of zonular support, tends to come toward the I/A tip; thus, the implantation of a CTR is recommended, since we are

running the risk to rupture the posterior capsule. We have to balance the risk of continuing I/A step without the CTR, against the difficulty of removing the cortical material entrapped behind it once it is implanted. Usually, the second scenario is better. One useful procedure is trying to perform viscodissection of cortical material before implanting the CTR. Then it is not surprising that a higher percentage of posterior capsule opacification has been found in cases of implantation of Cionni ring [29].

Injection of dispersive OVD several times may also help to keep backward a floppy posterior capsule; however, we would rather recommend a CTR implantation. Both during phacoemulsification and cortical aspiration, it is of paramount importance to fill the anterior chamber with OVD, before removing the phaco tip or the irrigation from the eye, in order to keep a pressurized anterior chamber; otherwise, we run the risk of facing vitreous prolapse (Videos 6.2 and 6.8).

"While complete cortical removal is a noble and appropriate goal, excessive efforts to remove small strands should not risk capsular or zonular damage" [6].

Intraocular Lens Implantation

If the capsular bag is stable after the completion of I/A aspiration with a CTR, the intraocular lens is implanted within the bag.

If a Cionni or Ahmed segment has been implanted, it is important to implant the lens before tying and adjusting the tension of the suture of the device, since proper centration of the lens will be easier to achieve.

Regarding the type of the intraocular lens, we should consider whether the subluxation is progressive or not. If the subluxation is the result of a trauma, and proper centration of the capsular bag is achieved after surgery, any type of lens could be implanted, including toric and multifocal or EDoF lenses, although with these three types of lenses, we must be very sure that the case fulfills other requisites to implant these lenses.

The use of toric and multifocal lenses will be considered only in very selected and ideal cases [6].

We would recommend to choose a highly biocompatible material and design. With this purpose in mind, a single-piece hydrophobic acrylic intraocular lens with C-shaped haptics and slow unfolding is the best choice. A three-piece hydrophobic acrylic intraocular lens is a good choice also, and some years ago, it was the design of choice since the PMMA haptics could be implanted in the meridian of zonular dehiscence as counter-traction. In recent years, with a CTR in place and scleral fixation if required, a single-piece intraocular lens is adequate, since the centrifugal tension induced by the CTR is enough to keep the capsular bag distended.

Femtosecond Laser Role

Femtosecond laser may be used to perform the capsulorhexis in certain cases of subluxated cataracts [43, 44]. It is able to get a circular rhexis as well as liquefy the lens, perhaps decreasing the risk of further zonular damage, but this theoretical benefit has not been demonstrated. However, it will not be possible to perform the capsulorhexis in very decentered lenses, and excessive tilt of the lens may make a complete rhexis difficult [43, 44].

Take-Home Message

- The approach and algorithm for the management of subluxated cataract will be based on the extension of zonular dehiscence, its etiology – that will determine whether it is progressive or not – and the density of the cataract. An exhaustive preoperative examination is mandatory.
- Stabilization of the capsular bag is needed in two ways: anterior to posterior axis and centrifugal distension. Hooks work providing vertical support,

while the main purpose of conventional CTR is the centrifugal redistribution of forces and distension of the bag.

- CTR should be implanted as late and as safely as possible.
- Scleral fixation is required in cases with more than 4 hours of zonular dehiscence, and it may be advisable in cases with less than 4 hours if the condition that led to subluxation has a progressive profile. Several devices were designed for the purpose of scleral fixation, and some of them provide also 360° or 120° of capsular bag distension (e.g., Cionni ring and CTS segment, respectively).
- The combination of a conventional CTR with a CTS allows to apply the different function of each device according to the step of the surgery, and it has resulted in the best approach in our experience.

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