›

8 Operations on the Lens

8.1 General Problems of Surgical Technique

Cataract extractions may be performed in two ways: by removing the lens intact in its capsule (*intracapsular cataract extraction*) or by leaving a portion of the capsule in the eye (*extracapsular cataract extraction*) (Fig. 8.1).

From the standpoint of surgical technique, the lens behaves as a *pressure chamber* consisting of a closed capsular bag filled with a more or less fluid material. The effects of externally applied forces depend on the *capsular tension*. If the capsule is very tense, applied forces will be transmitted to the entire capsule system including the zonule, regardless of the site of application. But if the capsule is lax, the force will act mainly at the site of its application. Capsular tension is lowest when the capsule has been *breached*. Then the capsule no longer forms a pressure chamber, and forces are transmitted to the zonule only when applied close to the attachment of the zonular fibers.

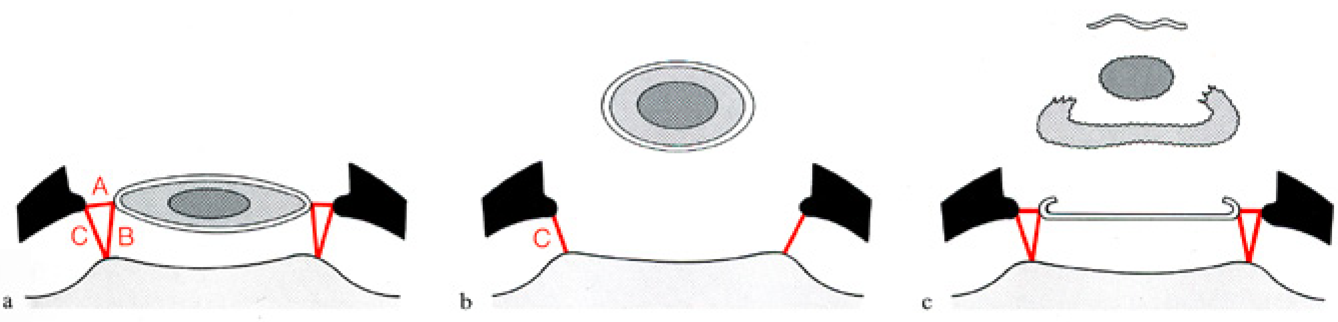


Fig. 8.1. **Methods of lens delivery**

a The normal lens is suspended by zonule fibers, some passing to the ciliary body (ciliocapsular ligament *A*) and some to the anterior hyaloid membrane (hyalocapsular ligament *B*). A third fiber system links the anterior hyaloid to the ciliary body (hyalociliary ligament *C*).

b In an intracapsular lens extraction, the lens is delivered intact. The hyalocapsular and ciliocapsular portions of the zonule are divided, leaving behind the hyaloid membrane with its hyalociliary fibers. It alone forms the anterior boundary of the vitreous chamber (see also Fig. 1.39).

c An extracapsular extraction leaves behind the lens capsule with all its zonular attachments, so there is less weakening of the anterior vitreous boundary. The lens components – the anterior capsule, cortex, and nucleus – are removed in separate maneuvers

back to index

From the standpoint of **spatial tactics**, the lens is considered *part of the vitreous chamber*. Therefore any manipulation on the lens affects the entire vitreous body, and all measures must be evaluated in terms of their overall effect. If the vitreous pressure is to remain constant, forces must be applied to the lens in such a way that their vector components are parallel to the vitreous surface (see Fig. 1.45b). Conversely, a deliberate change in vitreous pressure is produced by applying vector components perpendicular (centrifugal or centripetal) to the surface. Thus, shifting the lens horizontally does not alter the vitreous pressure, whereas lifting or depressing the lens is apt to cause pressure changes (Fig. 8.2).

A low vitreous pressure can be maintained only if the lens delivery is effected by traction (*extraction*). If the lens is removed by *expression*, a rise of vitreous pressure is inevitable since it forms the basis of the maneuver.

The **manipulations for lens removal** can be divided into several phases:

- *mobilization* of the lens by detaching it from structures that are to remain in the eye;
- *alignment* of the lens so that it can negotiate the pupil and incision;
- *locomotion*, i.e., delivery of the lens from the eye.

All these basic manipulations can be synthetized into a single action by the operator, but separating them into their individual components is useful in that it provides a greater *safety margin*: The force of the individual manipulations is smaller than that of the procedure as a whole, and the direction of the forces can be optimized for each step, making the maneuver easier to control.

The *objective* is to remove only the intended structures from the eye while leaving all other structures in place. Therefore, monitoring the tissues remaining in the eye is no less important than monitoring the parts that are to be removed. **Efficiency control** in lens removal is a matter of confirming that each applied force elicits an adequate, corresponding movement of the lens. Failure to elicit this movement is a warning sign that mechanical energy is being stored and may be released unexpectedly. **Safety control** in lens removal must ascertain that motion of the part to be removed does not elicit motion of parts that are to remain. Thus, the operator directs his attention not only toward the movements of the lens in response to his instrumentation but also toward the anatomic landmarks that confirm total immobility of the structures to be left behind.[1]

[1] In an *intracapsular* extraction, for example, attention is given to the iris position: If the iris retains its position during forward motion of the lens (i.e., "falls back into place"), this is a sign that the remaining parts of the diaphragm are not following the motion of the lens. In an *extracapsular* extraction, attention is given to the free margins of the incised lens capsule; these must remain stationary during motion of the lens nucleus and cortex.

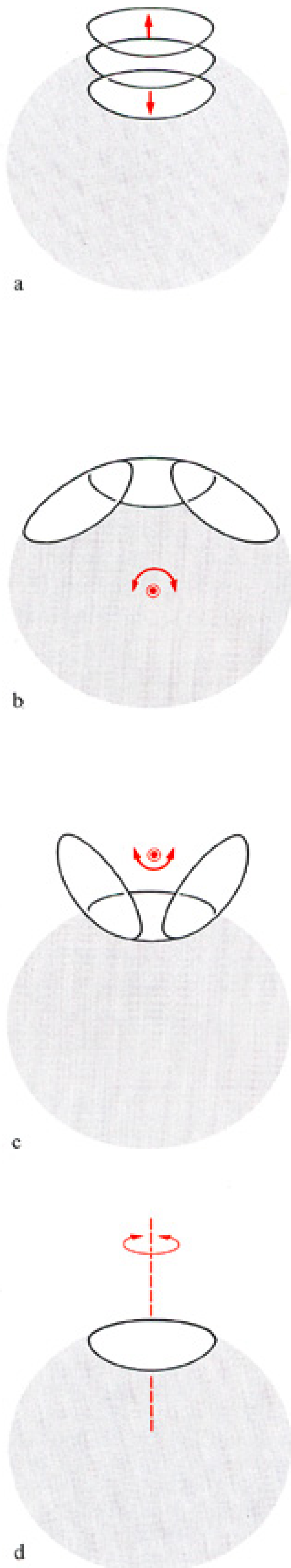


Fig. 8.2. **Space-tactical consequences of lens movements**

a Perpendicular (i.e., centrifugal or centripetal) vector components alter the vitreous volume, creating a positive or negative pressure.

b Movements along the vitreous face cause shifts of vitreous substance but do not affect its volume.

c Movements about the center of curvature of the posterior lens surface affect neither the shape nor the volume of the vitreous body.

d Rotational movements about the sagittal lens axis do not affect the vitreous shape or volume

back to index

8.2 Intracapsular Lens Delivery

In an intracapsular lens delivery, destruction of the diaphragm is controlled in such a way that only the zonular fibers that bridge from the capsule to the ciliary body and to the anterior hyaloid are divided. The *lens capsule* and *anterior hyaloid* themselves should remain intact.

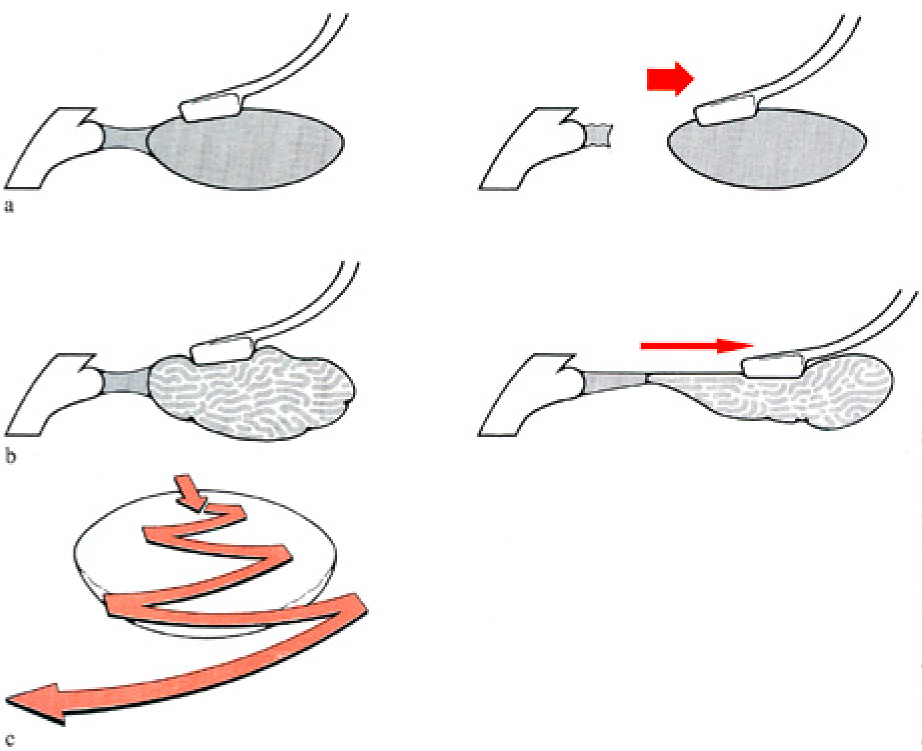
8.2.1 Mobilization (Zonulolysis)

Destruction of the diaphragm is localized to the *zonule* by concentrating the applied forces (maximizing pressure) precisely at that site while distributing the forces as broadly as possible (minimizing pressure) over the *lens capsule*.

The forces may be transferred indirectly to the zonule via the lens capsule, or they may be applied to the fibers directly. An **indirect transfer** of forces during lens *expression* is accomplished by a general tensing of the diaphragm. In this case the site of zonular rupture may not coincide with the site of application of the expressing instruments, but depends on local variations in fiber resistance.

The forces in a lens *extraction* are transferred indirectly to the zonule by traction on the lens capsule (Fig. 8.3). The *force* necessary for the indirect rupture of the zonule depends on the capsular tension. The more lax the capsule, the greater the tension that must be supplied by the operator. Since the capsule becomes increasingly lax as division of the zonule proceeds, the amplitude of the lens excursions in an extraction should be steadily increased in order to transmit the necessary force (Fig. 8.3c).

Traction toward the pupil ("centripetal traction") exerts tension on *circumscribed fiber groups* and is effective for a localized rupture of the zonule (Fig. 8.4b, A'), although the amplitude of this maneuver is limited by anatomic constraints. *Traction by rotation* ("circumferential traction") has an unlimited amplitude (Fig. 8.4c, B'), but the tension affects all the fibers equally. Once an initial gap is created, though, the effect becomes localized as the fibers adjacent to the gap are ruptured first.



a

b

c

Fig. 8.3. **Applying indirect tension to the zonule**

a If the lens capsule is tense (*left*), little traction need be applied to the capsule to make the zonule fibers tense (*right*).

b If the capsule is lax (*left*), much greater traction is required, because first the capsule must be made tense before tension is transferred to the zonule (*right*).

c Since capsule tension dwindles as separation of the zonule proceeds, the amplitude of the traction must be gradually increased to compensate

back to index

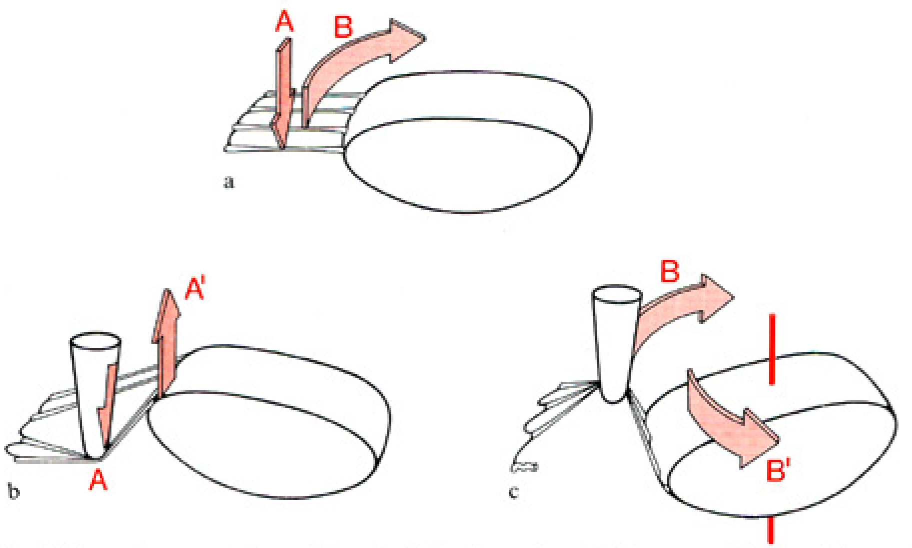


Fig. 8.4. **Direct separation of the zonule**

a Direction of fiber stretch: The fibers can be ruptured by overstretching them either perpendicular (*A*) or parallel (*B*) to the vitreous surface.

b The zonulotome can act perpendicularly by thrusting it into the zonule (*A*) or by elevating the lens (and thus the zonule) toward the stationary zonulotome (*A'*). Motion *A* produces force vectors directed toward the vitreous chamber, jeopardizing the anterior hyaloid. In motion *A'*, the zonule fibers are pulled away from the anterior hyaloid. This also creates a negative pressure in the vitreous space which retracts the anterior hyaloid from the danger zone and thus reduces the risk of hyaloid injury. The necessary depth of penetration of the zonulotome (*A*) depends on the compliance of the fibers, and this can be reduced by combining it with indirect primary tension (*A'*).

c The zonulotome can act parallel to the vitreous surface either by moving the instrument along the lens equator (*B*) or by rotating the lens about its sagittal axis (*B'*) to press the fibers against the stationary zonulotome. Large excursions are possible with no danger to the vitreous chamber.

Motions *A* and *B* affect only the fibers directly ahead of the zonulotome, while motions *A'* and *B'* tense the fibers indirectly and can produce primary tension over a large area

The **direct application** of forces allows a highly selective division of the zonule fibers. In this method the fibers are engaged directly with an instrument (zonulotome),[2] which stretches the fibers to the point of rupture in a direction perpendicular or parallel to the vitreous surface (Fig. 8.4a). *Perpendicular* vector components (Fig. 8.4b) affect the vitreous chamber. They can be minimized however, because perpendicular forces are necessary only for making the initial rupture in the zonule. Once this initial gap has been created, all the remaining fibers can be divided *parallel* to the vitreous surface (Fig. 8.4c).

The critical phase of the zonulolysis, then, is the creation of the initial gap. Once that has been accomplished, division of the fibers can proceed using maneuvers that no longer jeopardize the vitreous.

Chemical dissolution of the zonule with alpha-chymotrypsin[3] reduces the force necessary to effect delivery of the lens. However, a liquid enzyme is difficult to control both in its intended action and its side-effects.

The enzyme dose can be reduced by *combining* chemical zonulolysis with mechanical zonulotomy. For example, alpha-chymotrypsin may be injected to produce the initial zonule gap, whereupon the remaining fibers are ruptured mechanically with a zonulotome.

The enzyme is applied as close as possible to the elected site of action (Fig. 8.5). On completion of the zonulolysis (Fig. 8.6), residual enzyme and zonule debris are removed by irrigation of the anterior chamber. At this point the lens is in a subluxated condition.

[2] Besides specialized instruments, an iris retractor (Fig. 8.18b) or even an expressor indenting the sclera (Fig. 8.16) can function as a zonulotome.

[3] Alpha-chymotrypsin is a proteolytic enzyme that dissolves the zonule fibers when applied in concentrations of 1:5000 to 1:10000. It acts in 1–5 min at a temperature of 25°–35° C; the waiting time depends in part on whether the enzyme is cold or warm when applied. It is inactivated by acids and alkalis, serum and blood, DFP and chloramphenicol (which can be used intraoperatively to inactivate the enzyme), detergents, disinfectants, alcohol (needles and cannulas must contain no residues from these substances and must be heat-sterilized), and temperatures above 40° C. The enzyme preparation is sterilized by filtration only. No preservatives may be added. For this reason, only fresh solutions should be used to reduce the risk of contamination.

The major reported side-effect of alpha-chymotrypsin is a postoperative rise of intraocular tension. There are also reports of corneal damage if the endothelium is disrupted, hyaloid membrane damage, and retinal morbidity if the enzyme enters the vitreous.

back to index

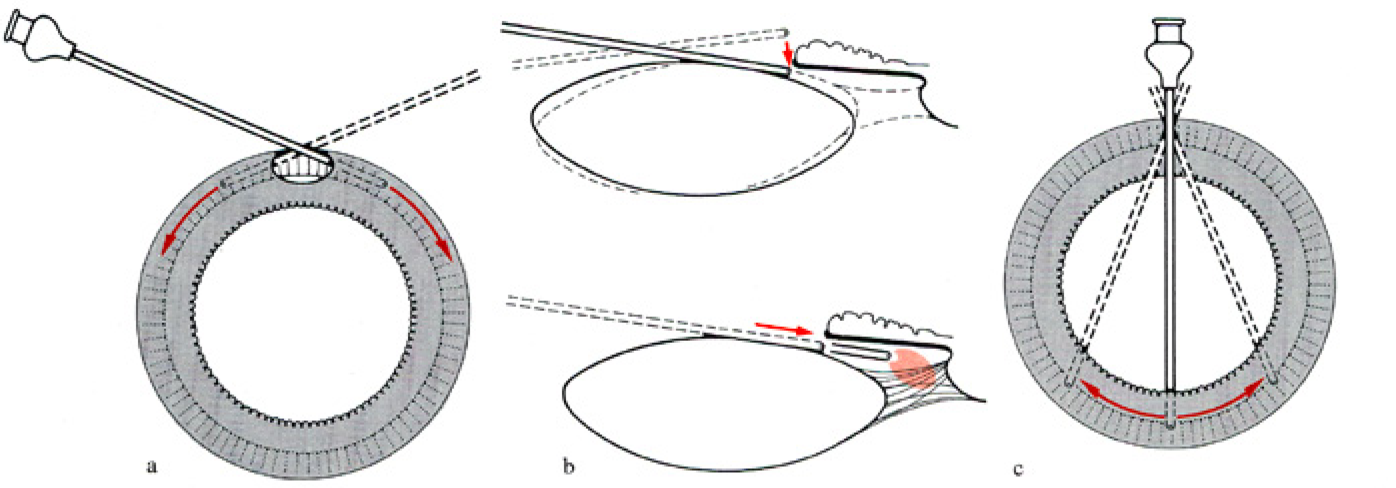


Fig. 8.5. **Application of zonulolytic enzyme**

a To apply the enzyme directly to the zonule, it is injected behind the iris. The upper circumference of the zonule is accessible through a peripheral iridectomy.

b The lower circumference is reached by crossing the pupil. Lens damage is avoided by keeping the cannula raised away from the lens until the opposite pupil margin is reached. Once there, the cannula tip is lowered and is then passed beneath the iris (*above*); it is always directed tangentially away from the anterior lens surface. So the tip of the cannula does not come in contact with the lens capsule (*below*).

c The enzyme is distributed along the lower zonule with a sweeping movement of the cannula

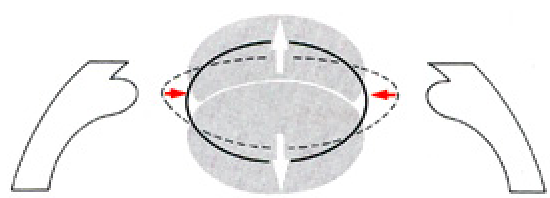


Fig. 8.6. **Confirmation of total zonulolysis.** When all the suspensory fibers of the lens have been divided, the lens acquires a more spherical shape (*red arrows*). It may also move outward if there is a slight vitreous overpressure, or it may sink inward from its own weight if the hyaloid membrane is lax (*white arrows*)

8.2.2 Aligning the Lens for Delivery

By deciding which *pole* of the lens will lead the delivery, the operator establishes the site for making the *initial gap* in the zonule (Fig. 8.7). That site will determine whether it is technically more convenient to tamponade the gap during the delivery or leave it open.[4] In addition, the lens alignment determines the *relationship between the lens cross-section and the cross-section of the*

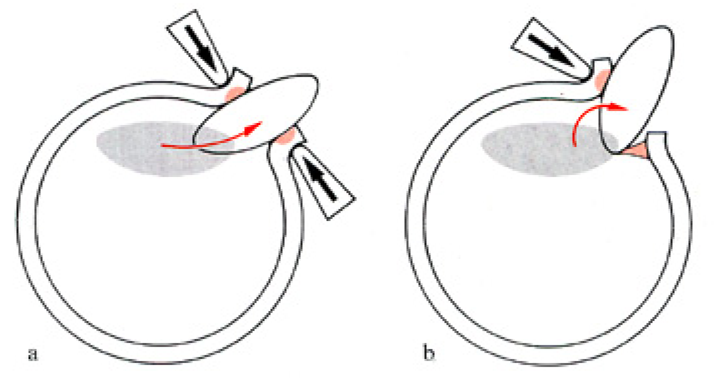


Fig. 8.7. **Lens alignment during delivery**

a Sliding: The superior pole of the lens emerges through the pupil and incision first. There are gaps in the incision side of the zonule as well as in the opposite side. Tamponade is difficult because it must involve both lips of the incision.

b Tumbling: The inferior pole of the lens emerges first. The initial gap is on the inferior side, and from that point separation of the zonule progresses toward the corneal opening. Tamponade is easier because only the superior lip of the incision needs to be controlled

[4] Sealing the zonule gap or leaving it open affects the pressure in the vitreous chamber during the delivery; see Figs. 8.10 and 8.11.

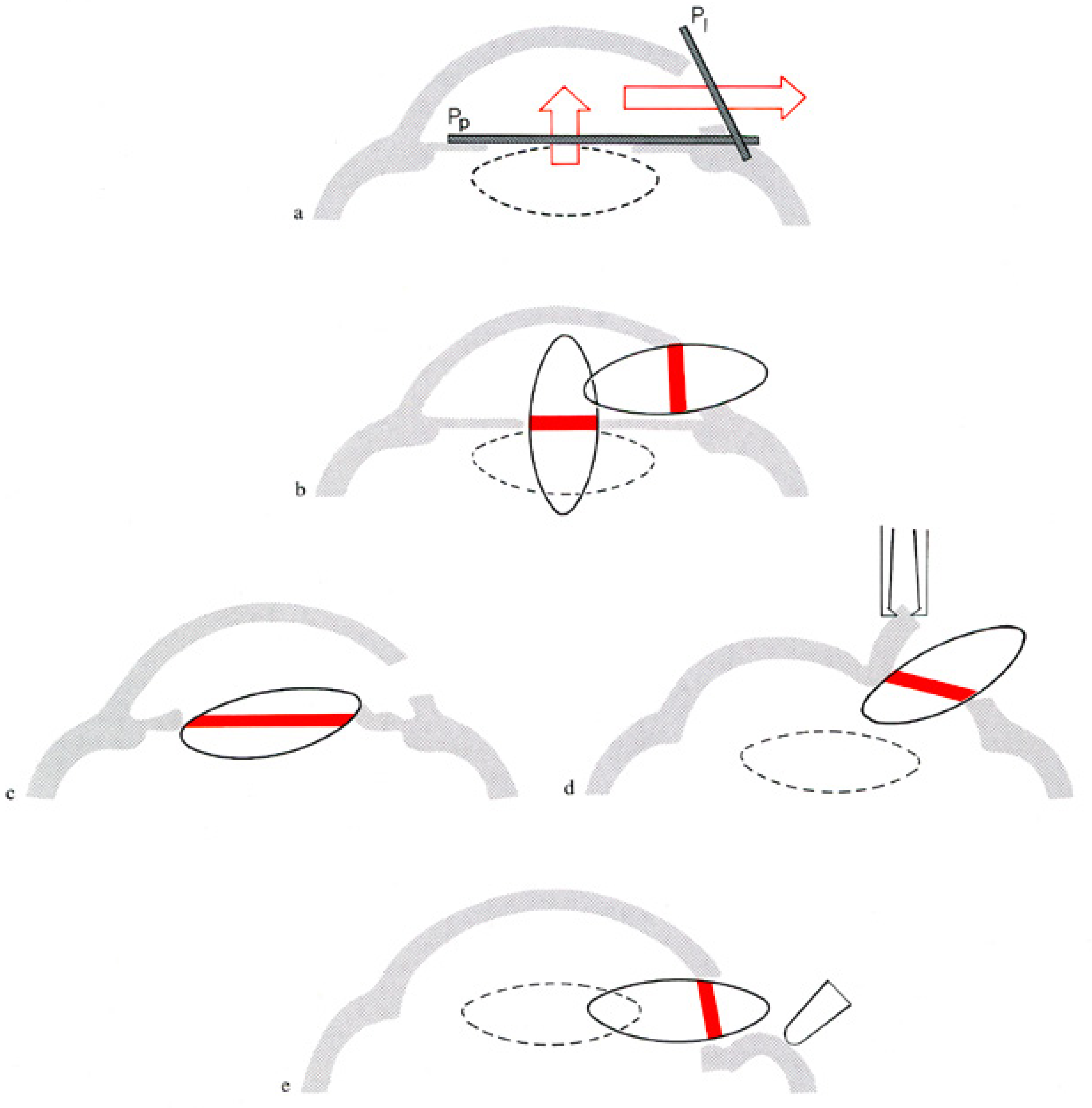


Fig. 8.8. **Criteria for lens alignment during delivery: Relationship of the lens to the pupil and incision**

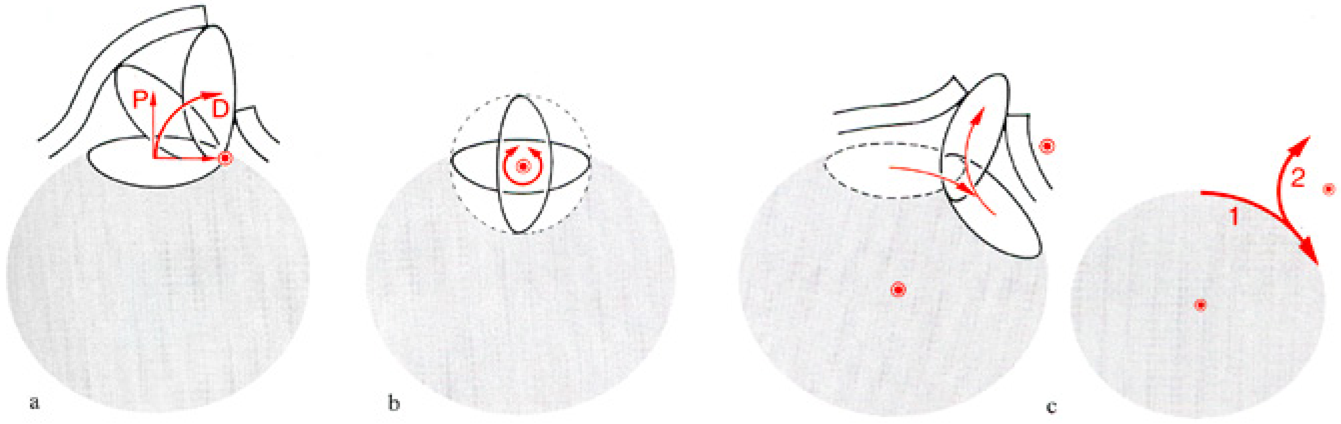
a The lens first moves vertically upward into the anterior chamber, traversing the pupil, and then horizontally outward, traversing the incision. The angle between the plane of the pupil (*Pp*) and the plane of the incision (*Pi*) is nearly 90 degrees.

b If the lens is to present a minimum cross-section to both openings, it must be rotated approximately 90°.

c This rotation can be reduced if the pupil is very large, as this allows the lens to traverse it with a larger cross-section.

d The rotation can also be reduced by raising the superior lip of the corneal incision. *Note*: This maneuver creates a corneal hinge fold.

e Rotation of the lens can be avoided by depressing the lower lip of the corneal incision, thereby reducing the vertical component of the delivery. *Note*: This creates a hinge fold in the sclera (not in the cornea), which may affect the vitreous pressure



opening as the lens traverses the pupil and the corneoscleral incision. This in turn determines the resistance to the delivery and the degree of force that must be applied.

Because the planes of the pupil and the corneal incision are nearly at right angles to each other, the lens must be rotated almost 90° in order to negotiate both openings with a minimum cross-section (Fig. 8.8a, b). The necessary degree of *lens rotation* can be reduced by modifying the openings, i.e., changing their size to accommodate a greater lens diameter (Fig. 8.8c) or repositioning them onto the path of the emerging lens (Fig. 8.8d).

In **delivery by sliding**, the lens is oriented so that the *pole closest to the incision* is the first to emerge. Therefore the *initial zonule gap* is made directly below the incision (although additional gaps may form elsewhere as a result of contralateral zonule tension). The lens presents a *relatively large cross-section* on traversing the pupil (Fig. 8.8c), so adequate mydriasis is required. The movements of the lens can follow the vitreous surface (Fig. 8.8e), so there is little or no effect on the vitreous volume.

In **delivery by tumbling** the *opposite pole* is the first to emerge through the incision. Consequently the *initial zonule gap* is made on the side opposite the incision. The ipsilateral zonule may remain intact almost until completion of the delivery. Because of its rotation, the lens can present an optimum cross-section as it traverses the pupil. Deformation of the vitreous can be minimized by guiding the lens along the vitreous surface in all maneuvers. Success in achieving these goals depends on the *axis* of lens rotation during the tumbling maneuver. If the lens is tumbled about an *axis at its upper pole*, it will present a large cross-section to the pupil and incision.[5] It moves away from the vitreous, whose pressure is correspondingly reduced (Fig. 8.9a). Tumbling the lens about an *intralenticular axis* exerts mass effects on the vitreous which can raise its pressure and increase resistance to the tumbling maneuver (Fig. 8.9b). In delivery by *reverse tumbling*, the lens is rotated about two extralenticular axes in two separate stages.[6] Neither movement significantly affects the vitreous volume, regardless of the shape of the lens (Fig. 8.9c); the lens can present a minimum cross-section for traversing the pupil and incision.

[5] Although it touches almost the whole posterior surface of the cornea in this maneuver, an intact lens produces relatively little endothelial trauma. The main danger is contact with the extracting instrument (e.g., capsule forceps), the most vulnerable area being the stiffened tissue at the hinge fold.

[6] Reverse tumbling can be compared to the backing of an automobile.

Fig. 8.9. **Center of rotation in various tumbling maneuvers**

a Tumbling the lens about an axis through its superior pole: The rotary movement (*D*) produces a vector component (*P*) perpendicular to the vitreous chamber. The lens presents its largest cross-section when traversing the pupil and incision.

b Rotation of the lens about its transverse axis. A spheroidal lens can be rotated in any direction, analogous to a spheroidal joint in a socket. The less spherical the lens, the greater the shift of vitreous substance caused by its rotation.

c Reverse tumbling about extralenticular points. Tumbling in two phases: *1* Rotation of lens about the "center" of the vitreous (analogous to Fig. 8.26). *2* Rotation about the center of curvature of the posterior lens surface (analogous to Fig. 8.2c). In this technique the lens presents its smallest cross-section to both pupil and incision

8.2.3 Locomotion

Locomotion would require very little force if performed in isolation, but it is invariably combined with concomitant maneuvers (zonulolysis, lens alignment) which dictate the *force* needed for the delivery. If the zonule has been completely separated (e.g., by chemical zonulolysis) and the pupil and incision are sufficiently large, minimal force need be applied.

The forces used for the delivery (the "motors") are either *pressure* (expression) or *traction* (extraction). In delivery by **expression**, the lens is expelled from the eye by

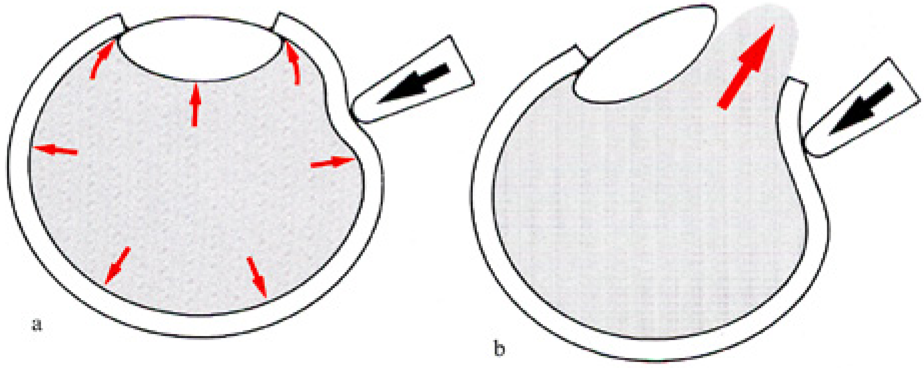


Fig. 8.10. **Pressure as a motor for lens delivery (expression)**

a The pressure is increased by deformation of the vitreous chamber. If the lowest resistance is in front of the lens, the lens will be expressed.

b If the lowest resistance is elsewhere, extralenticular tissue will protrude when the pressure is increased (e.g., vitreous prolapse due to inadequate tamponade)

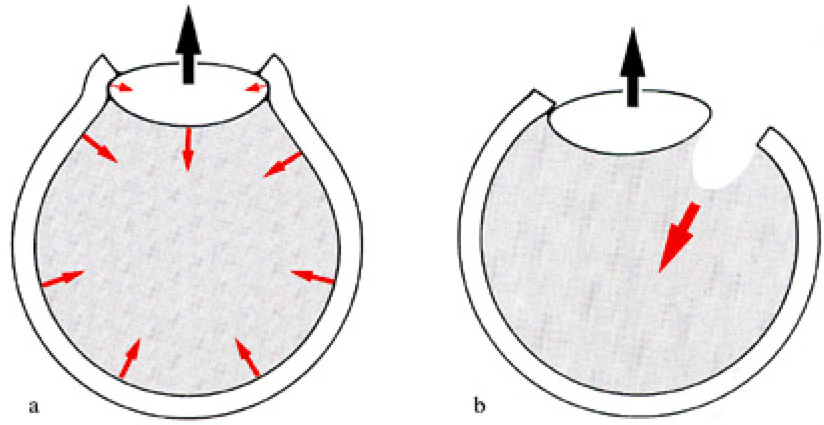


Fig. 8.11. **Traction as a motor for lens delivery (extraction)**

a Traction on the lens creates a vacuum in the vitreous chamber which holds the lens back and hinders delivery.

b Gaps next to the lens allow pressures to equalize

pressure from the anterior hyaloid. The necessary pressure rise in the vitreous chamber is produced by deforming the vitreous with instruments (expressors). As shown in Figs. 1.42c and 1.43c, the site of application of the expressors is immaterial in terms of the pressure that is produced. Their placement is determined only by considerations of resistance control: the *resistance* must be low in front of the lens itself (to clear a path for the delivery) but high over all other parts of the diaphragm (tamponade). If there are zones of low resistance adjacent to the lens, the anterior hyaloid will bulge forward at those sites while the lens itself remains stationary (Fig. 8.10).

Delivery by **extraction** is accomplished by *traction to the lens*. This may induce an expansion of the vitreous space and a negative vitreous pressure. As this tends to draw the lens backward, the *pressures must be equalized* before the extraction can proceed.[7] This requires openings in the diaphragm (iridectomy, gaps in the zonule) through which fluid and air can shift from the anterior chamber to the vitreous compartment (Fig. 8.11).

A major difference between the two methods is that open gaps in *expression* are a source of complications (by allowing pressures to equalize) and must be tamponaded during the delivery. In *extraction* they are essential for smooth conduct of the maneuver, and the operator must create such gaps and keep them open throughout the delivery.

The *degree of force* that can be applied is limited by the resistance of the anterior hyaloid in *expression* and by the solidity of the lens capsule in *extraction*. Both structures are liable to rupture if the progress of the delivery is impeded. It is essential, therefore, that obstacles to the delivery be promptly identified and cleared. The early recognition of these obstacles may rely on tactile or visual feedback. The major *tactile* warning sign is an increase of resistance manifested as an increasing force needed for the delivery; the major *visual* sign is a paucity of lens motion. If the lens does not respond to an *expression* maneuver despite increasing pressure, any further pressure increase will only exacerbate the risk of vitreous prolapse. If the lens is not moved by an *extraction* maneuver, increasing the traction may rupture the capsule.[8]

---

[7] The negative pressure can also cause iris pseudorigidity by holding the iris so tightly against the lens that delivery becomes impossible. Unlike true iris rigidity, which is manifested preoperatively by a persistent failure of mydriasis, pseudorigidity is relieved at once when pressures are equalized.

[8] The site of the obstruction is indicated by the direction of the traction folds in the capsule ("arrows pointing to the obstruction").

8.2.4 Instruments for Lens Delivery

Expressors

The vitreous pressure necessary for lens expression is produced by *indenting the ocular wall* with a blunt instrument, the expressor (Fig. 8.12). The shape of the expressor is unimportant in terms of the vitreous pressure increase.[9] However, the instrument shape is significant for secondary functions: Expressors with a *small contact area* behave as sharp instruments and can be used as "zonulotomes"; expressors with a *large contact area* can tamponade the expanding gap in the zonule.

Forceps for Grasping the Lens Capsule

Forceps grasp the lens by making a *fold* in the capsule (Fig. 8.13). To make this fold, the forceps jaws must be pressed firmly against the capsule so that friction will prevent slippage during closure of the blades. The jaw pressure should be distributed evenly along the grasping surface to avoid capsule damage.

Erysiphake

The erysiphake consists of a suction cup in which a *vacuum* is created to fix the lens to the extraction instrument.

The interior of the cup is designed to exert a firm grip on the lens capsule while preserving its integrity (Fig. 8.14). As the anterior capsule partially prolapses into the cup, the whole capsule becomes tense and, with it, the zonule. The instrument is applied with just enough pressure to seat the entire rim of the cup firmly against the capsule surface.

[9] In former times some surgeons even used their finger as an expressor – a method that affords excellent tactile feedback.

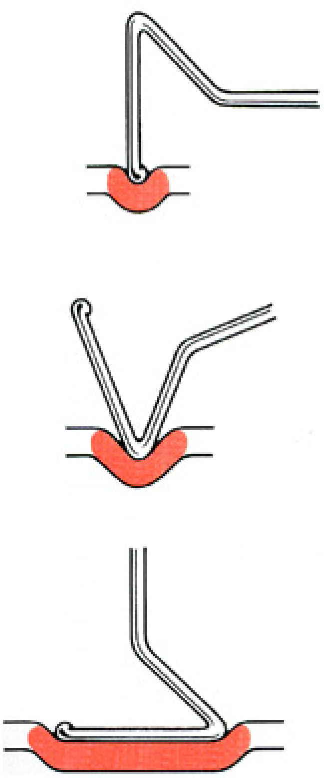
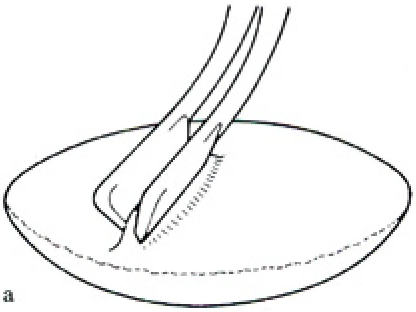
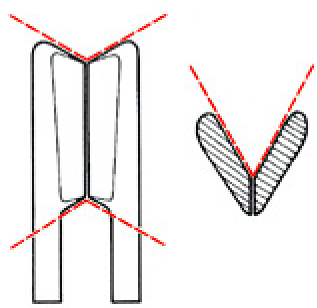


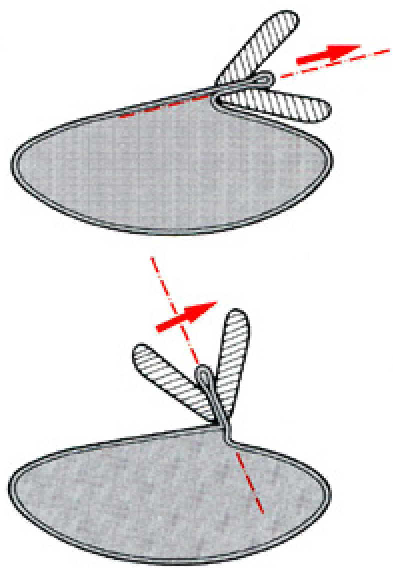
Fig. 8.12. **Expressors.** The scleral indentation (*pink*), the actual "expressor," is always larger and blunter than the instrument making the indentation. By proper application of the instruments it is possible to modify the area of contact and thus the "sharpness" of the expressor (here: A squint hook)



a



b



c

◄ Fig. 8.13. **Forceps for grasping the lens capsule**

a The lens is grasped by a fold in the capsule.

b Jaw design: To ensure a uniform pressure distribution, the opposing surfaces should be flat and smooth and their edges carefully rounded. When the jaws are closed, they should meet evenly for their full length (stabilization of grasping pressure, see Fig. 2.8). The jaws are designed to diverge where not in direct contact with the capsule to reduce the danger of inadvertent grasping of neighboring tissue (e.g., the iris).

c Position of jaws during traction. *Above*: When the fold is pulled so that its axis (*hatched line*) is parallel to the direction of pull, only the blunt grasping surfaces of the jaws act on the capsule, not the edges. *Below*: But if the fold is pulled at an angle, one edge behaves as a sharp instrument and may damage the capsule

back to index

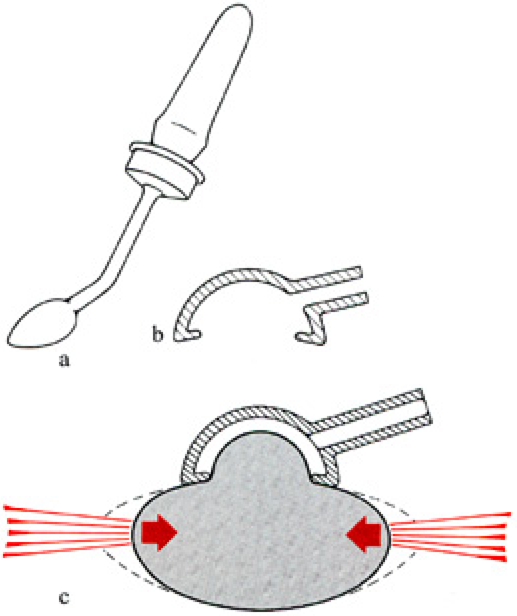


Fig. 8.14. **Erysiphake**

a Erysiphake with suction cup.

b Longitudinal section of suction cup. The rim is broad and shaped to conform to the lens surface so that it will not act as a cutting edge when suction is started. Its edges are well rounded. The size of the cup should be such that the capsule does not touch the inside of the cup or the vacuum tube, because the occlusion would occur at the wrong site and this would degrade the suction.

c The suction produces a general tensing of the zonule fibers

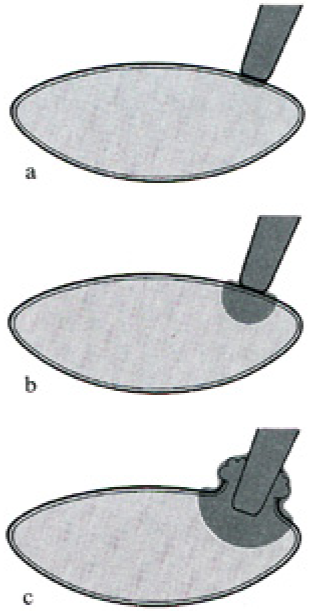


Fig. 8.15. **Cryoextractor**

a Superficial ice formation: Encompasses only the capsule.

b Large ice ball: Extends deep into the lens, encompassing the cortex and nucleus.

c Obliteration of a capsule lesion by a large ice mass

Cryoextractors

Cryoextractors form an adhesion with the lens by means of an *ice ball* that encompasses both the instrument and the tissue. Fixation is best when the ice ball extends deeply into the lens and does not tax the tensile strength of the capsule alone (Fig. 8.15b). Even if the capsule is damaged, complete extraction is still possible if all edges of the lesion can be encompassed by the ice mass (Fig. 8.15c).

The size and shape of the ice ball depend on the *shape*, *temperature* and *cold capacity* of the cryoextractor, i.e., on instrument characteristics that are predetermined in a given case. The size of the ice ball also depends on the *thermal conductivity* of the biologic media and thus on the fluid content inside and outside the lens. Differences in thermal conductivity can allow the selective cryoextraction of a lens in a liquid film within the anterior chamber or in the fluid vitreous, since the ice ball forms more rapidly in the solid lens than in the ambient fluid.[10] On the other hand, if the lens contents are highly liquid (as in intumescent cataract), the ice ball forms only superficially in the drier lens capsule, and there is an increased risk of capsular rupture (Fig. 8.15a).

Criteria for the Use of Extractors

The selection of an extraction instrument is based on its intrinsic volume, its contact area, and the lens deformation caused by the grasping mechanism (Table 8.1).

The instrument **volume** that may be introduced into the anterior chamber depends on the margin of deformation (depth of anterior chamber, vitreous pressure), for if the instrument is too bulky, the lens must be pushed toward the vitreous to prevent corneal damage, thereby *raising the pressure* in the vitreous chamber.

The **area of tissue contact** has a significant bearing on the risk of *capsule rupture*. If the extractor behaves as a sharp instrument, it will tend to rupture the capsule rather than the zonule. The contact area further affects the *intrinsic mobility* of the lens. If the contact area is small ("point fixation"), the lens can change its position ideally in response to all applied forces from the surgeon and from the zonule. If the contact area is large, the surgeon's actions are transmitted more rigidly to the lens and indirectly to surrounding structures.

The **pressure** that the instrument exerts on the lens during grasping also raises the vitreous pressure and therefore must be opposed by adequate resistance from the zonulocapsular diaphragm. If the latter is damaged (e.g., by a subluxated lens), instruments with a very low grasping pressure must be used.

Deformation of the lens on grasping is possible within the limits im-

[10] This also applies to the zonule, which freezes more quickly than the fluid film that fills its interspaces. The danger of inadvertent inclusion of the zonule in the cryoextraction is greatest when the instrument tip is applied near the lens periphery. This can be difficult to detect visually if the zonular interspaces remain transparent.

Table 8.1

	Forceps	Erysiphake	Cryoextractor
Space in anterior chamber occupied by instrument	small	very large	depends on quality of insulation (i.e. on danger of freezing surrounding tissues)
Area of contact with lens	small	very large	depends on size of ice ball
Pressure on lens during grasping	high	low	negligible
Deformation of lens during grasping	considerable	depends on extent of prolapse into suction cup	negligible

posed by its ratio of volume to surface area. If the lens is almost spherical (as in intumescent cataract), any deformation leads to a general rise of capsule tension that may contraindicate the use of deforming instruments for grasping.[11]

8.2.5 The Phases of a Lens Delivery

Lens delivery is a continuous process in which the basic maneuvers of *mobilization*, *alignment*, and *locomotion* take place concurrently and in succession. For practical purposes, however, the delivery can be divided into four main phases according to the type of force applied:

1. Application of the instruments
2. Formation of the initial gap in the zonule
3. Passage of the lens through the pupil and incision
4. Final phase

1. In the initial phase of **instrument application**, the applied forces serve only to *engage the lens* with the delivery instrument. The degree of force depends on the type of instrument used (see Table 8.1).

2. During **formation of the initial gap** in the zonule, the applied forces serve to **initiate a rupture of the zonule fibers**. Locomotion is limited to the degree necessary to make the fibers tense. If a zonulotome is thrust toward the vitreous to rupture the fibers, the vitreous pressure will rise. But if the lens is lifted and the zonule drawn past a stationary zonulotome, a negative pressure results which draws the hyaloid membrane back from the initial gap (see Fig. 8.4b). The presence of this gap is essential for the next maneuver to proceed smoothly.

3. **Passage of the lens** through the pupil and incision constitutes the *main phase of the delivery*, for it is now that most locomotion occurs and the lens is freed of its remaining zonular attachments. Consequently the *greatest forces are needed* during this phase. The *direction* of force application depends on the mode of delivery: perpendicular forces are appropriate for expression but are strictly avoided in all other maneuvers. The *nature* of the applied force (pressure or traction) determines whether the developing gaps in the zonule should be left open or tamponaded.

4. The **final phase** begins as soon as the *largest lens cross-section* has passed through the corneal incision. At that point the lens will no longer fall back through the incision when locomotive forces are discontinued, and the delivery is practically complete. The forces can be reduced to the minimum necessary for dividing the few remaining zonular fibers. This reduction of forces acting on the vitreous chamber is an important safety factor during the final phase, when the vitreous is contained only by the highly vulnerable anterior hyaloid.

The techniques described below illustrate how the foregoing principles can be combined in practice to accomplish the lens delivery.

Expression

When the lens is delivered purely by expression, as noted above, the vitreous chamber is deformed by expressors, and the resulting pressure increase is used to initiate and control a prolapse of the lens (Fig. 8.16). The main problem is the potential for unintended prolapses.

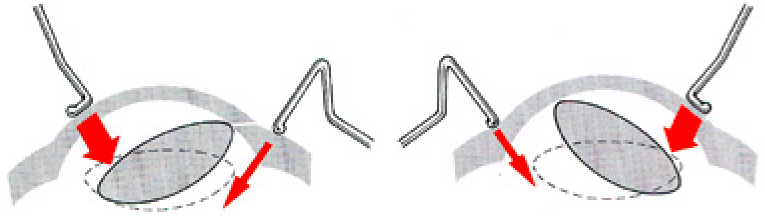
The initial gap in the zonule is produced bluntly and thus with relatively large forces. This maneuver is most successful when the lens is almost spherical. Such a lens can be rotated in any direction without affecting the vitreous volume (see Fig. 8.9b), and this permits extensive stretching of the zonule. A voluminous lens also leaves a large margin of deformation in its wake, reducing the risk of vitreous prolapse.[12]

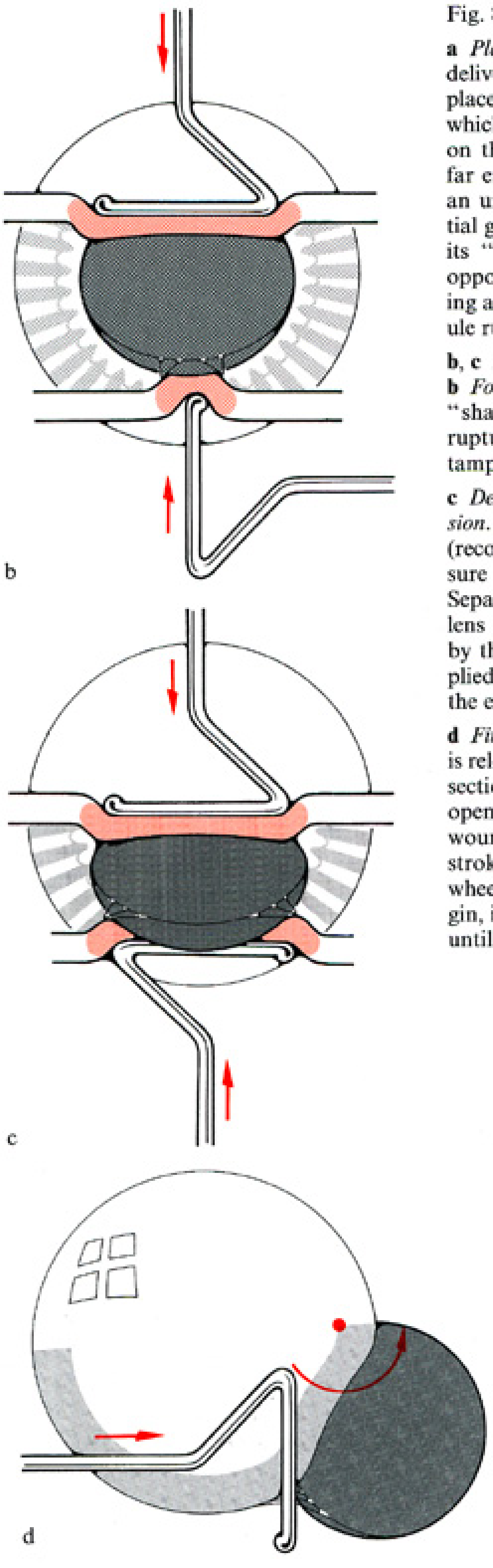
---

[11] Because forceps must raise a fold in order to function, they can be used only on lenses whose capsular tension is low. If forceps extraction is attempted on an intumescent lens, the forceps will either skid off the lens surface or rupture the capsule.

[12] This suitability of spherical lenses for delivery by expression may explain why Smith's expression technique was so successful in India but commonly failed elsewhere. The cataractous lenses of Indians are often large and spherical.

back to index





a

b

c

d

Fig. 8.16. **Expression**

a *Placement of instrument* (*left*: Sliding delivery; *right*: Tumbling delivery). The placement of the expressors determines which pole will emerge first. The expressor on the side of the leading pole is placed far enough from the lens border to allow an unrestricted delivery. It forms the initial gap in the zonule, so it is applied with its "sharpest" point (*small arrow*). The opposite expressor keeps the lens from rising and is applied "bluntly" to avoid zonule rupture at that site (*large arrow*).

b, c *Sliding technique*.

b *Formation of initial gap*. The upper, "sharp" expressor is pressed inward to rupture the zonule and simultaneously tamponade the resulting gap.

c *Delivery of lens through pupil and incision*. Once the leading pole has emerged (recognized by its free border), the pressure is increased to induce locomotion. Separation of the zonule proceeds as the lens slips past the scleral bulge produced by the upper expressor, which now is applied over a broader area to tamponade the enlarging zonular gap.

d *Final phase*. All pressure on the vitreous is released as soon as the largest lens cross-section has passed through the corneal opening. The delivery is completed and the wound simultaneously closed by gentle stroking with the expressor. If the lens is wheeled out over the opposite wound margin, it will tamponade the corneal opening until the delivery is completed

A major advantage of delivery by expression alone is that *no instruments* need to be introduced into the anterior chamber. *Partial expression* achieves a similar tactical goal while reducing the risk of vitreous prolapse. In this method the lens is expressed only until its upper pole presents in the incision. There it is grasped with an extraction instrument and the delivery completed by a combined technique (expression and extraction).[13]

Combined Extraction and Expression

If both pressure and traction are employed for lens delivery, the surgeon can select the most favorable "motor" for a given situation. *Traction* relieves stress on the vitreous and is indicated if there is a threat of *prolapse*. *Pressure* relieves stress on the lens capsule and is used if there is a threat of *capsule rupture*. It is important to note, however, that a rapid change between traction and pressure requires a correspondingly rapid adjustment in the management of the resulting zonule gaps (see Figs. 8.10, 8.11).

[13] If the emerging lens is grasped with a cryoextractor, care is taken not to freeze the zonule at its attachment. Whether or not the emerging pole of the lens is still attached to the zonule is judged by the curvature of the area between the lens and pupil margin. The surface of a lens still attached to the zonule extends flat toward the iris, and the pupil follows the lens movements. Conversely, a lens free of zonules presents a sharp curvature, and the pupil margin recedes on motion of the lens.

back to index

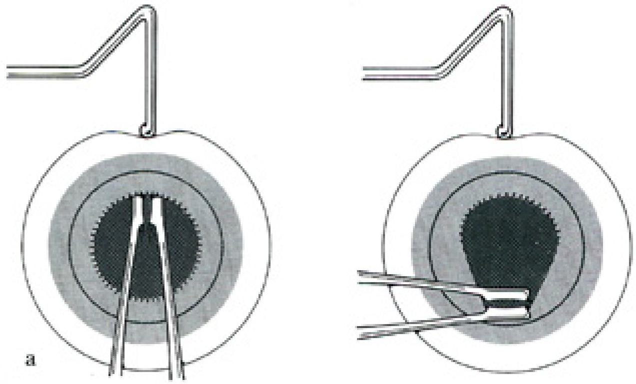


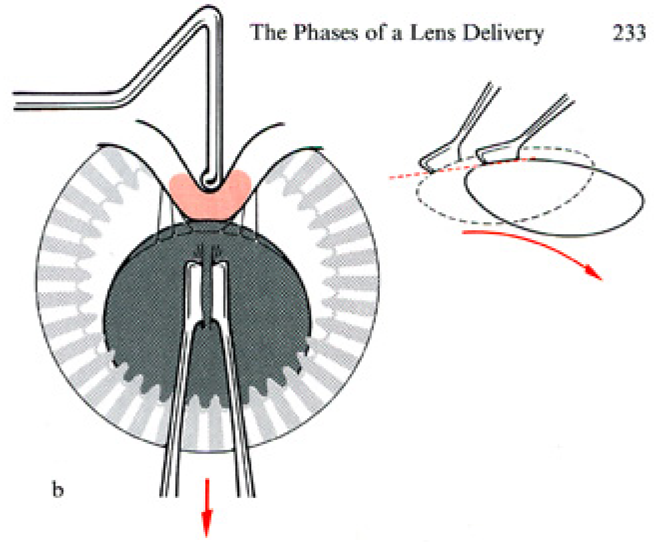
Fig. 8.17. **Combined expression and extraction (forceps)**

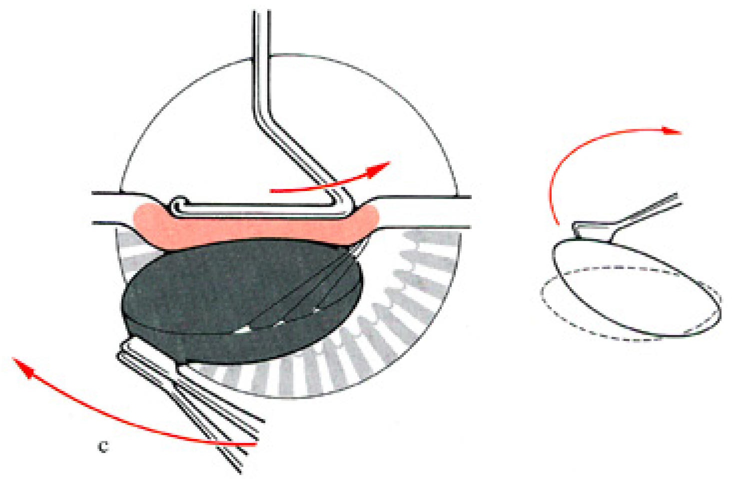
a *Placement of instruments.* In delivery by *sliding* (*left*), the forceps are applied transversely in the pre-equatorial zone, the iris being simultaneously pushed aside. In *tumbling* (*right*), the forceps are passed closed beneath the iris to the pre-equatorial zone on the opposite side and then opened. The expressor then raises the vitreous pressure until the lens is pressed against the forceps and sufficient frictional resistance is created between the capsule and jaws. Then the forceps blades are closed. A solid grip on the capsule is confirmed by tactile feedback, i.e., by noting the transmission of diaphragm tension to the forceps: The resistance to slight lateral movements of the forceps changes as the vitreous pressure is raised by the expressor.

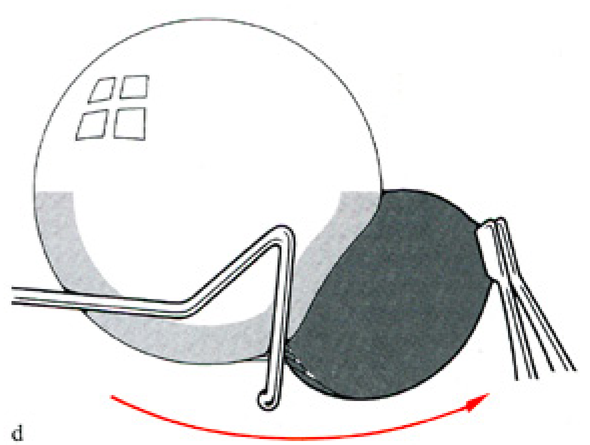
b, c *Tumbling technique.*
b *Formation of initial gap.* Traction on the forceps is directed straight toward the pupil center to make the zonule tense. If this traction is precisely *horizontal*, the initial phase of the reversing maneuver has begun (*diagram at right*). The expressor, applied as a zonulotome, simultaneously forms and tamponades the initial gap.

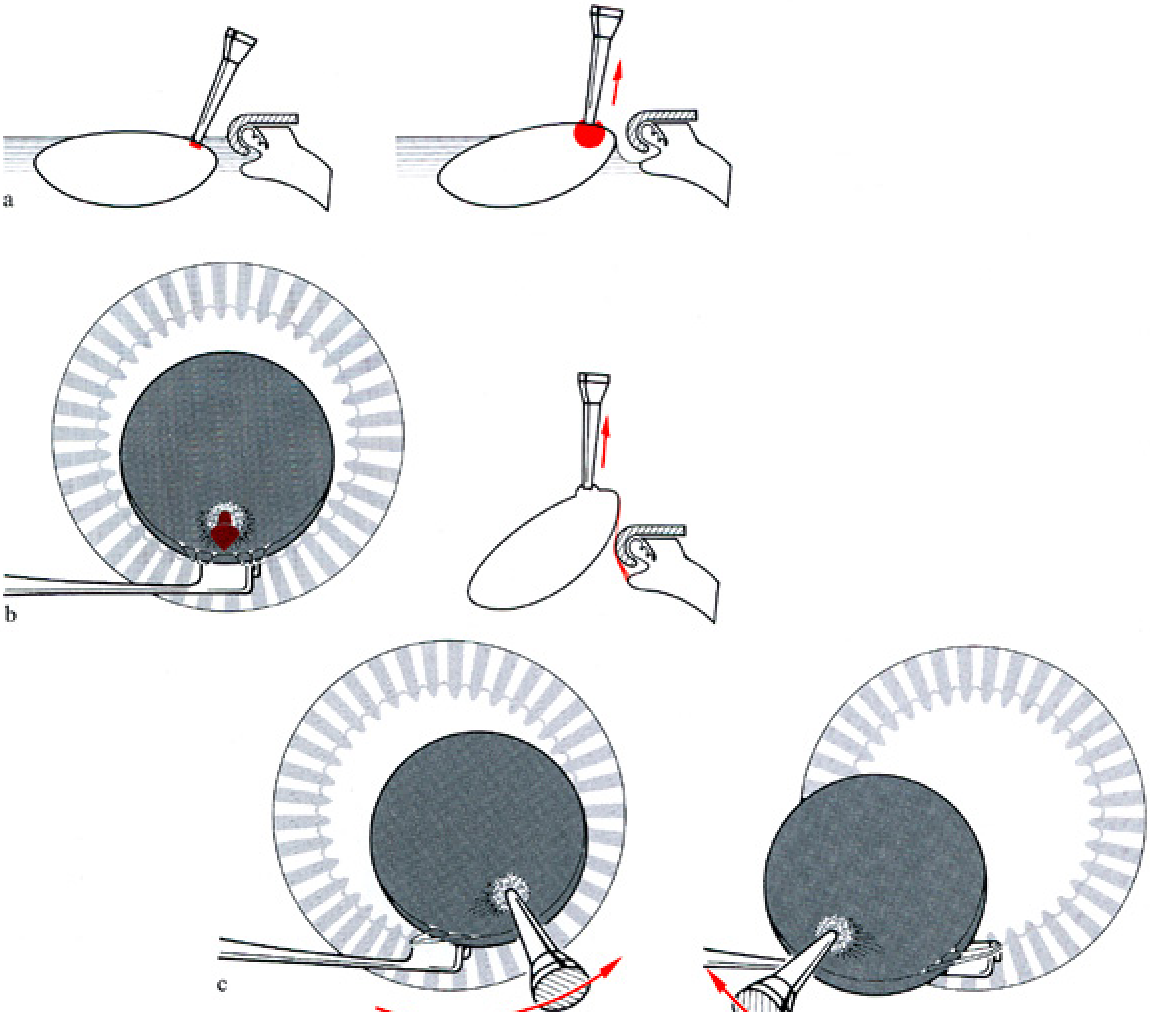
c *Delivery of lens through pupil and incision.* The vitreous pressure is increased to initiate locomotion. The zonule is made tense by zig-zag movements of gradually increasing amplitude (see Fig. 8.3c). Countermovements are made with the expressor to rupture the zonule (parallel to the vitreous face, see Fig. 8.4c, B). Following separation of the zonule inferiorly, the forceps are passed toward the corneal opening for the second phase of the reversing maneuver (*diagram at right*). The expressor is applied with its broadest surface to break the lateral zonule and simultaneously tamponade the enlarging zonular gap.

d *Final phase.* All pressure is released as soon as the largest lens cross-section has passed through the corneal opening. The lens is wheeled out over one edge of the incision. The incision is tamponaded with the expressor









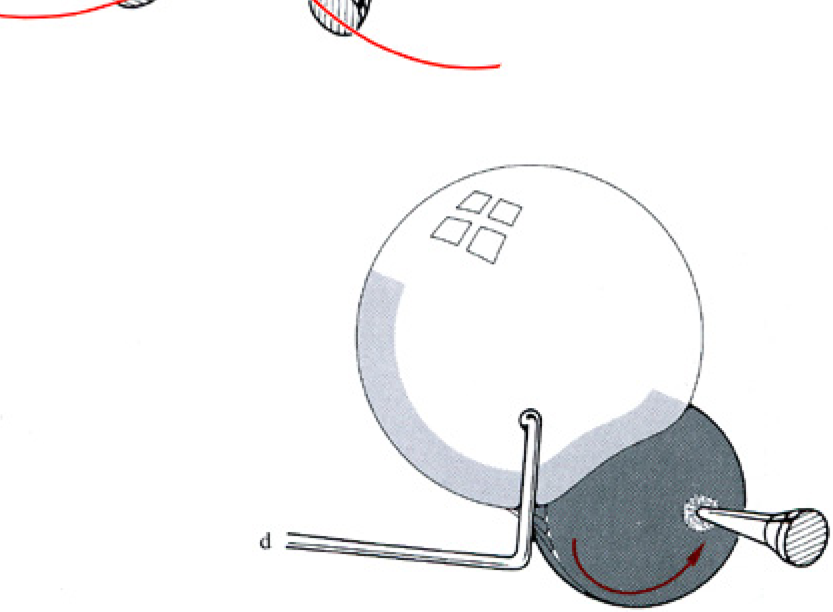


Fig. 8.18. **Extraction with cryoextractor**

a *Placement of instruments.* The superior pole of the lens is exposed with an iris retractor. The cryoextractor is applied uncooled (*left*), is activated, and the lens is immediately raised to remove the application site from the heat-conducting fluid layer (*right*). The definitive ice ball forms in the insulating air.

b *Formation of initial gap.* Upward traction brings the zonule in direct contact with the iris retractor, which acts as a "sharp zonulotome" to rupture the fibers.

c *Passage through pupil and cornea.* Traction is increased to initiate locomotion. Meanwhile the rest of the zonule is separated by pulling the lens past the iris retractor in rotary motions (analogous to Fig. 8.4c, B).

d *Final phase.* The lens is wheeled out over one edge of the incision. Remaining zonule fibers are separated, and the wound is simultaneously closed with a blunt instrument

The precise coordination of forces is easier if the lens can respond to the forces freely. This is facilitated by using a grasping instrument that has a *small contact area.*[14]

In delivery by *tumbling*, only one zonule gap is created and is easily tamponaded; this facilitates expression maneuvers. Delivery by *sliding* involves the creation of multiple gaps, which are difficult to tamponade; this situation favors delivery predominantly by traction.

Combined extraction and expression (Fig. 8.17) is in principle a controlled expression in which pressure serves as the primary motor while traction is used mainly for control.

Extraction

When delivery is effected purely by extraction (Fig. 8.18), all applied forces are exerted on the lens capsule. Hence, the main problem in this technique is to *relieve tension on the capsule* to avoid capsule rupture.

One way to accomplish this is to use an extractor that establishes a *large contact area* with the lens (possibly including the contents of the capsule; see Table 8.1). Another way is to *reduce the force applied in separating the zonule* (enzyme zonulolysis, mechanical zonulotomy). If, despite such measures, there is evidence of impending capsule rupture (traction folds), the direction of the traction is altered in an effort to relieve stress on the capsule by selective fiber tension.

The advantage of delivery by extraction alone is that no pressure is exerted on the vitreous chamber – an important safeguard against undesired vitreous prolapse.

[14] The associated danger of capsule rupture is reduced by switching to expression when warning signs appear (folds in the lens capsule).

8.2.6 Completing the Intracapsular Delivery after Inadvertent Capsule Rupture

If the capsule ruptures accidentally during a planned intracapsular extraction, the surgeon may elect to leave the capsule in the eye (converting to an *extracapsular extraction*), or he may pursue the original plan of a *complete lens removal.*

The *capsule is grasped* by identifying its *free edges* and bringing them between the forceps jaws (Fig. 8.19). If the capsule is ruptured at the **start of the delivery** (Fig. 8.20), the lesion lies at the application site of the grasping instrument. Tags of capsule are recognized by their motion during irrigation of the anterior chamber. If the zonule is still intact, the procedure can be converted to an extracapsular extraction.

If the capsule ruptures in the **final phase** of the delivery (Fig. 8.21), capsule remnants are accessible at the lip of the incision. By that point the zonule is partially separated and offers little resistance; conversion to an extracapsular delivery is no longer possible.

During *extraction of the capsule*, forces are no longer transmitted to the zonule as a whole since the capsular bag is destroyed (see p. 221). Thus, the zonular fibers can be made tense only by applying the forceps *close to their insertion*. Since the distance between the forceps and remaining intact fibers increases as the extraction proceeds, the forceps must be continually reapplied closer to the fibers to be divided (*taking alternate grips with two pairs of forceps*). The applied forces are optimally utilized by employing selective fiber tension (Fig. 8.22).

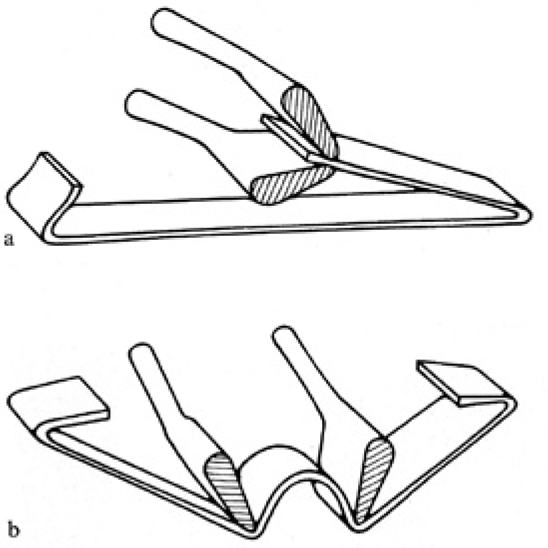


Fig. 8.19. **Grasping the torn capsule (here: With capsule forceps)**
a The free edge of the capsule is grasped at the rupture site. *Note*: The forceps is held horizontally, i.e., parallel to the capsular plane.
b If the forceps were applied vertically, as for grasping an intact lens (see Fig. 8.13), it could grasp only by making a fold. But this could cause rupture of the posterior capsule or incarceration of vitreous

back to index

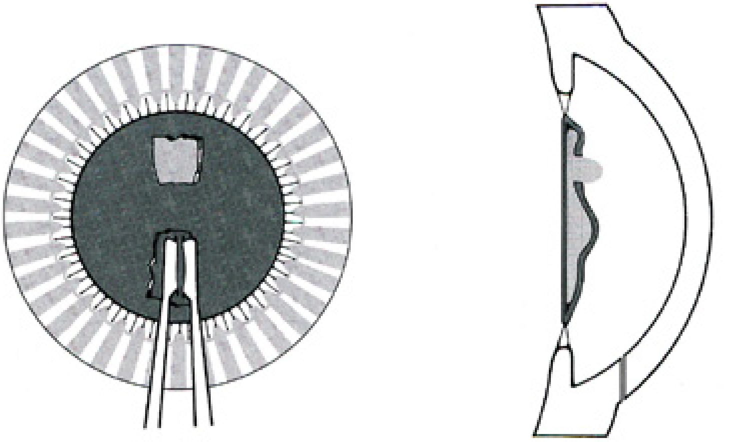


Fig. 8.20. **Rupture of the capsule on grasping the lens.** The rupture occurs at the site where the extractor (here: Forceps) is applied. The capsule remains tense because the zonule is still intact

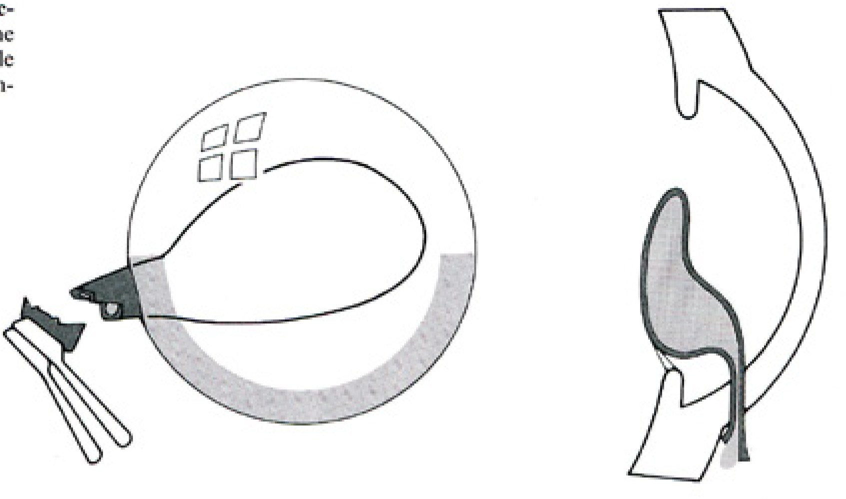


Fig. 8.21. **Rupture of the capsule on extraction.** If the capsule ruptures during the course of extraction, part of the capsule is already within the incision, and the zonule is partially divided

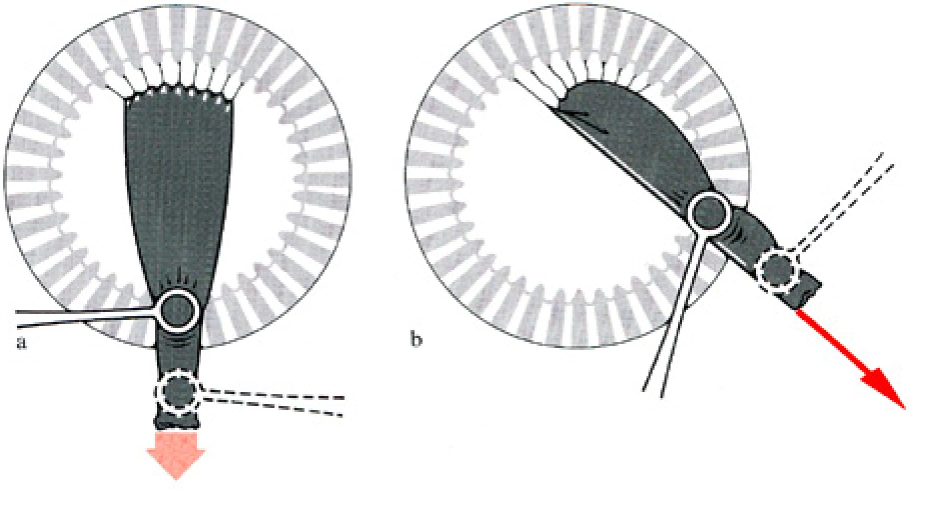


Fig. 8.22. **Extraction of the capsule (here: With ring forceps)**

a If the pull on the capsule is centripetal (i.e., in line with the normal course of the zonule fibers), a diffuse tension is exerted. The tension on each fiber is low compared with the force applied.

b Selective tension (i.e., traction applied at a large angle to the anatomic course of the fibers, see Fig. 2.55) exerts maximum tension on the fibers that are to be separated next, while all others fibers remain lax.
Note: The capsule is extracted by taking alternate grips with two forceps in a "hand-over-hand" fashion

8.3 Extracapsular Cataract Operation

The goal of the extracapsular cataract operation is to remove the contents of the lens bag while preserving the *integrity of the zonulocapsular membrane*. While the intracapsular delivery aims at avoiding the destruction of the anterior hyaloid, all measures in the extracapsular delivery are geared toward preventing lesions of the zonule and the posterior lens capsule.

Each step of the procedure weakens the *diaphragm* separating the anterior chamber from the vitreous chamber, as first the nucleus and then the cortex of the lens are removed, finally leaving only the posterior capsule behind (see Fig. 8.1c). The ability of the open capsular bag to retain its shape depends increasingly on the pressure differential between the bag and its surroundings. A high *intralenticular pressure* can develop if the outflow resistance from the capsular bag is higher than the outflow resistance from the adjacent ocular chamber.

From the standpoint of spatial tactics, we can distinguish between procedures in which the capsule retains its quality as a *separate pressure chamber* and procedures in which the capsule simply forms part of the wall of the anterior chamber or vitreous chamber (Fig. 8.23). This distinction is based on the size of the opening in the lens capsule.

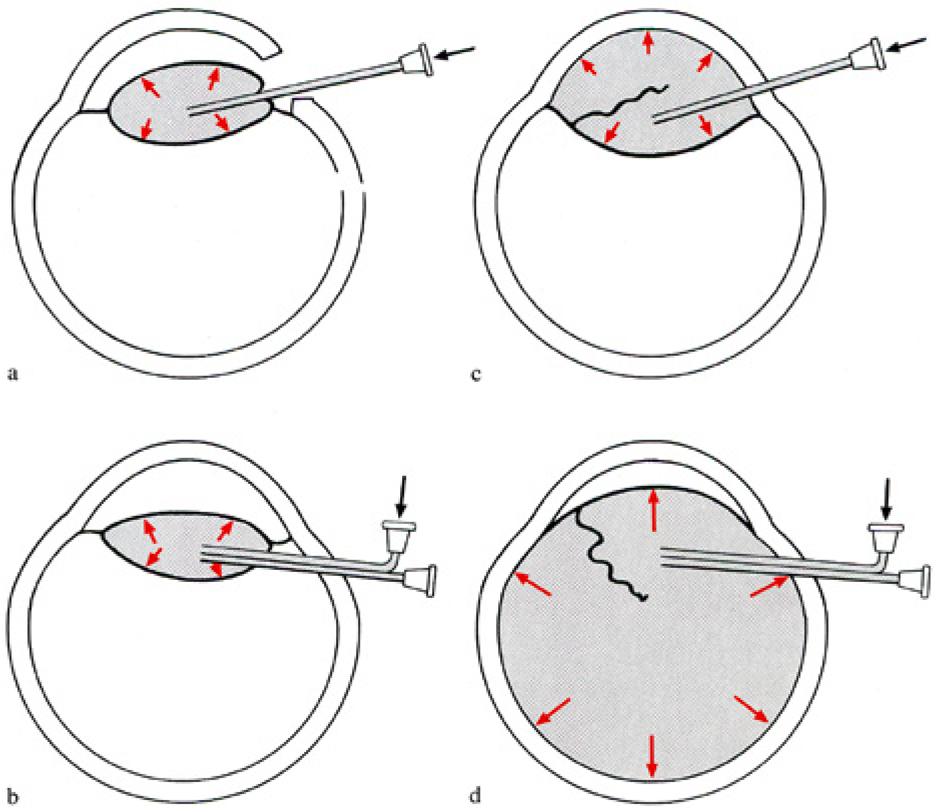


Fig. 8.23. **Space-tactical aspects of extracapsular cataract extraction**

a, b Capsular bag as a separate pressure chamber.
c, d Capsular bag communicating with the adjacent pressure chambers.
a, c Approach through the anterior chamber.
b, d Approach through the vitreous.

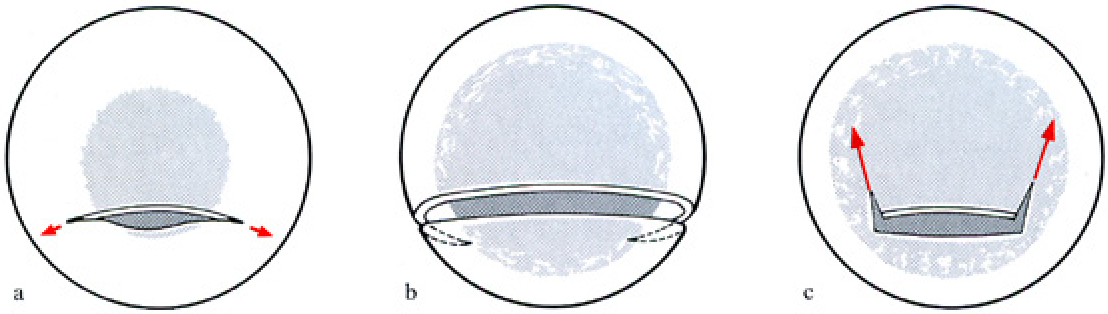
a Capsular pressure chamber with approach through the anterior chamber: The outflow resistance from the capsular bag is higher than the outflow resistance from the anterior chamber. Thus the pressure within the capsule can rise higher than the ambient pressure; the bag can be inflated and will retain its shape (space-tactical condition for endocapsular techniques).

b Capsular pressure chamber with approach through the vitreous (e.g. for lensectomy: The opening in the ocular wall (pars plana) is tamponaded to prevent vitreous prolapse. Thus, the opening in the capsular bag also must be tight if intracapsular pressure is to develop relative to adjacent chambers.

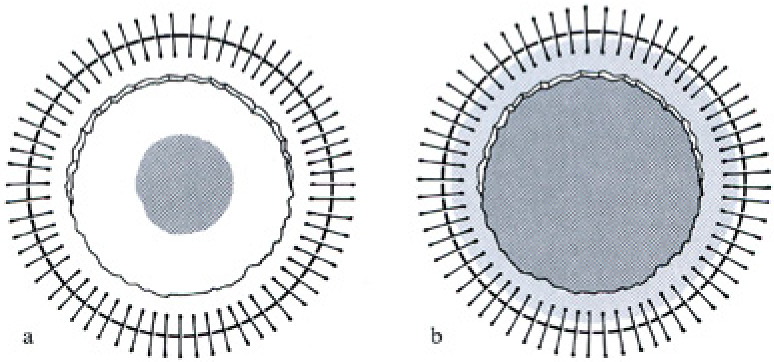
c Capsular bag as part of the anterior chamber: If the outflow resistance from the capsular bag is lower than that from the anterior chamber, the pressures in both chambers will be equal (space-tactical condition for "open capsule" techniques).

d Capsular bag as part of the vitreous chamber: If the opening in the capsule is not watertight, the bag will behave as part of the vitreous pressure system

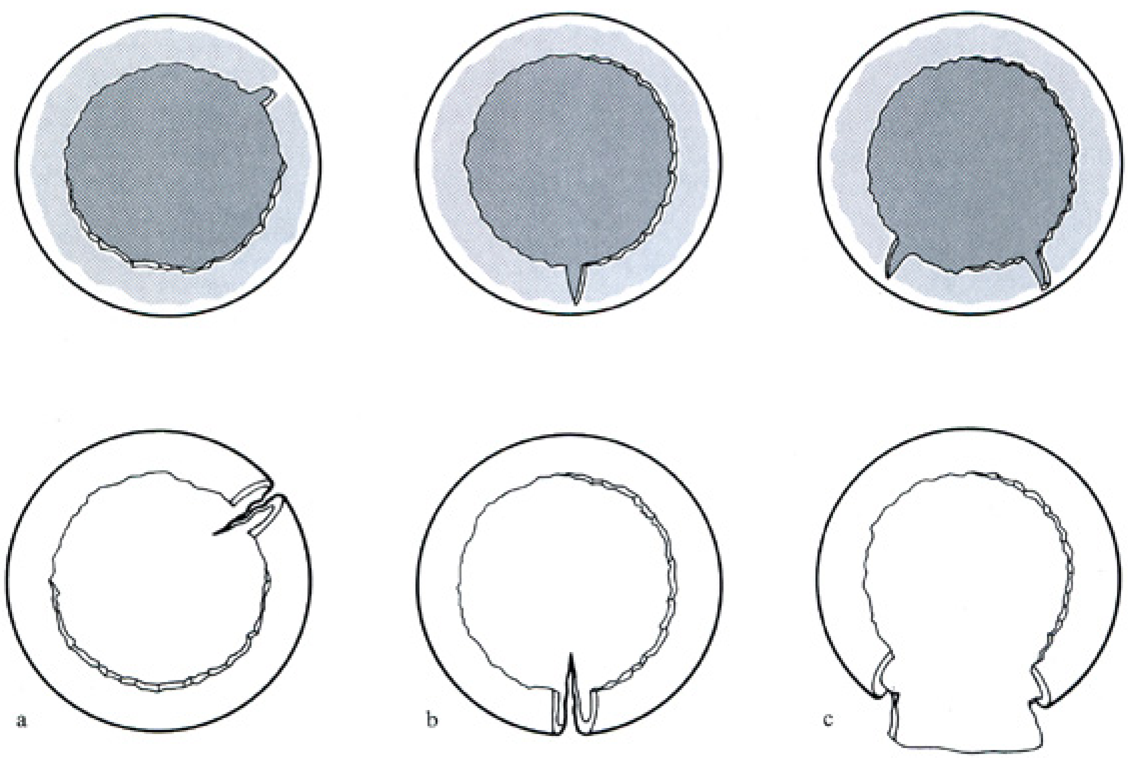
back to index



8.24 a b c



8.25 a b



8.26 a b c

Fig. 8.24. **Slitlike anterior capsulotomies**

a A slitlike opening in the anterior capsule maintains a relatively high outflow resistance from the capsular bag. Capsulotomies of this kind are suitable for endocapsular deliveries provided the opening can accommodate the nucleus (*gray*).

b If the nucleus is too large, the capsulotomy will tear as the nucleus passes through. The tear extends in the original direction of the capsulotomy, spreading into the zonule or even the posterior capsule.

c With a large nucleus, the tear can be redirected from the lens equator (*arrows*) by preplacing small, angled extensions at the ends of the capsulotomy

Fig. 8.25. **Circular anterior capsulectomy**

a The opening in the anterior capsule should spare the zonule attachments to preserve the integrity of the zonulocapsular diaphragm ("maximum allowable opening").

b If the nucleus is too large to fit through an opening of maximum allowable size ("insufficient maximum opening"), it cannot be delivered without endangering the zonulocapsular diaphragm

Fig. 8.26. **Circular capsulectomy: Relaxing incisions to enlarge an "insufficient maximum opening".** *Above*: Appearance of the anterior capsulectomy before delivery of a too-large nucleus; *below*: After delivery of the nucleus.

a Tearing at incidental notches in the margin of the capsulectomy. The deepest notch is the weakest point, and the capsule will tear there when the nucleus is delivered. The random location of this site means that it may be tactically unfavorable.

b Planned relaxing incision at a favorable location (near the entry site into the anterior chamber). The direction of tear expansion is confined to an area easily monitored from the access site by deliberately placing a radial incision there extending from the circular capsulectomy.

c Dual relaxing incisions create a trapdoor-like opening in the border of the anterior capsule. Because the expansion is provided by two incisions instead of one, each of the incisions will undergo less additional tearing during the delivery than a single incision as in **b**

8.3.1 Anterior Capsulotomy

The size and shape of the anterior capsulotomy are planned with the dual objectives of removing the lens contents *and* preserving the integrity of the zonulocapsular diaphragm. Thus, the *maximum size of the capsulotomy* opening is limited by the area of attachment of the zonular fibers on the capsule (Fig. 8.25), while its *minimum size* depends on the size of the noncompliant lens matter that must traverse the opening, i.e., on the size of the lens nucleus. If the nucleus is so large that it would require a minimum capsulotomy larger than the opening permitted by the zonule attachments, the emerging nucleus might cause the capsule to rupture into areas that should remain intact. Thus, the *shape of the capsulotomy* must be such that any further tears accompanying extraction of the nucleus will occur in directions that do not jeopardize the zonule or posterior capsule (Figs. 8.24, 8.26).

In terms of surgical technique, the lens capsule behaves as a *compliant, resilient membrane*. This means that when the tissue is cut with a sharp blade, it manifests the classic forward and lateral shifting tendencies described earlier. When the tissue is divided bluntly (by *tearing*), the shape and direction of the tear depend entirely on the forces applied, since the capsule is structurally homogeneous and contains no anatomic "paths of least resistance."

Cutting the Lens Capsule

In a sharp capsulotomy the blade must first penetrate the lens capsule. Thereafter only the *blade* is moved; the *capsule* should remain stationary to ensure that no forces are transmitted to the zonule.

The *starting point of the incision* is defined by the point of application of the blade. At that site the blade is inserted to the proper depth.[15] Thereafter the section theoretically proceeds in the guidance direction of the blade, although the actual result is influenced by the forward and lateral shifting tendencies of the capsular tissue.

[15] If applied too superficially, the blade will tear the capsule rather than divide it. In this case the starting point of the capsule lesion does not coincide with the point of blade application. If inserted too deeply, the blade will snag the lens contents and, when moved, will cause motion of the nucleus and cortex. Thus, proper blade depth is checked by watching for concomitant movements: In cutting neither the capsule nor lens contents should move with the blade.

back to index

The *forward shifting tendency* causes the incision to become shorter than the path traveled by the blade (Fig. 8.27). Thus, while the starting point of the incision is plainly defined, its end point is not. If precision requires that the incision reach a specific point, this can be done only by starting the cut at that point or by reapplying the blade there.

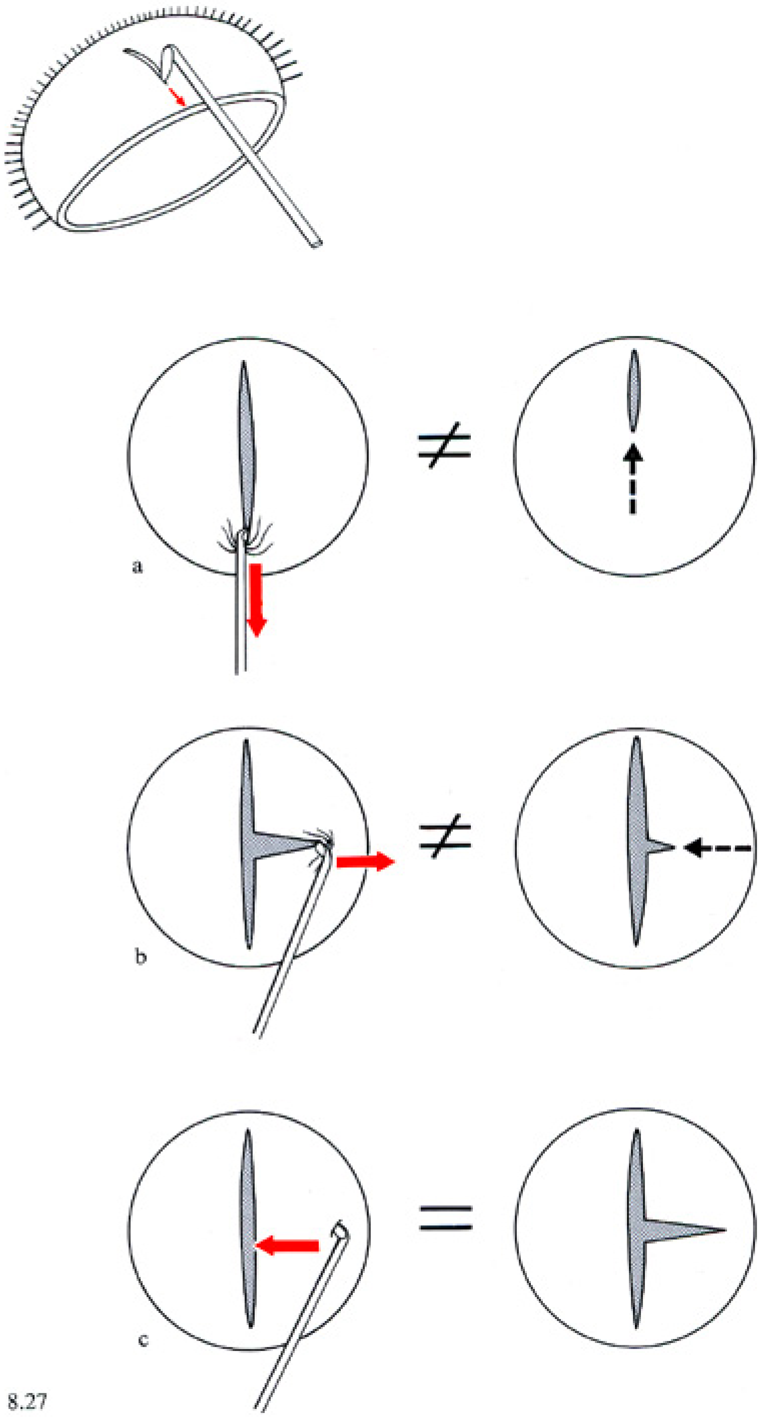
The *lateral shifting tendency* is a factor whenever the guidance path of the blade does not coincide with its preferential path (see Fig. 2.60). Such discrepancies are scarcely avoidable when the blade is introduced through a narrow limbal access opening (Fig. 8.28).

Both shifting tendencies depend on the sectility of the capsule. Because the capsular tension dwindles as the cut proceeds, both tendencies increase with the length of the incision. If the capsule becomes so lax that it can no longer be cut with a blade, the capsulotomy is completed with a scissors or by tearing.

Tearing the Lens Capsule

In this method the function of the capsulotomy instrument is to *grasp* rather than divide the tissue. The division is accomplished by subjecting the capsule to excessive tension. This is the basic feature that distinguishes capsulotomies performed by tearing as opposed to cutting: the cystitome acts as a *blunt instrument* and is *connected* to the capsule in such a way that motion of the instrument elicits *motion of the capsule*.

The main problem in tearing is **control**. Given the absence of predefined rupture lines in the capsule, the cleavage process is influenced by the relative tensions that develop, and these can change constantly as the capsulotomy proceeds. Even the site of the *initial tear* cannot be predicted with accuracy; it occurs



8.27

back to index

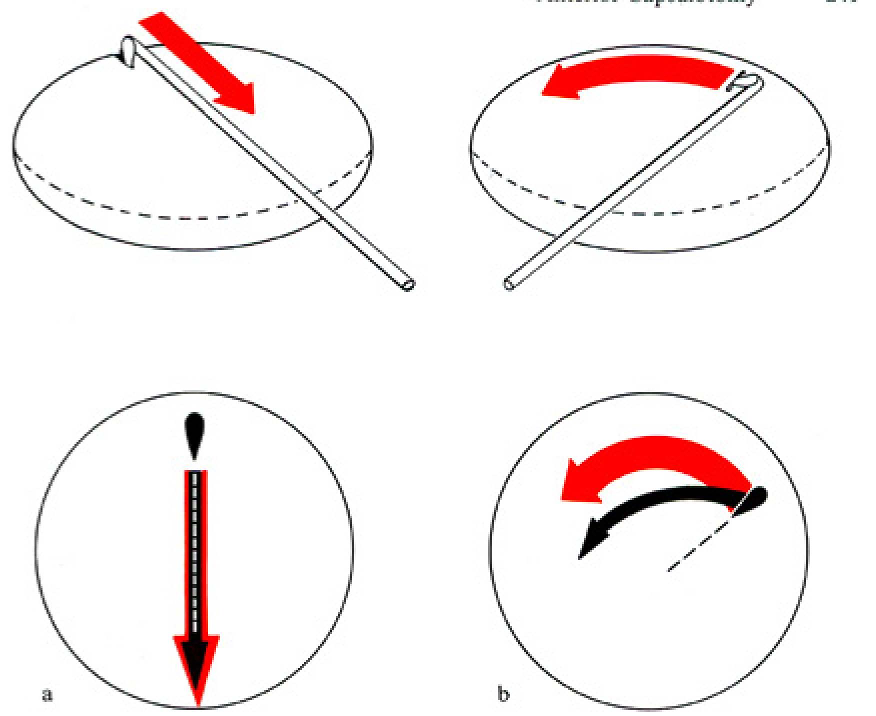


Fig. 8.27. **Capsulotomy by cutting**: Effect of forward shifting tendency on length of cut. *Left*: Motion of the cutting edge; *right*: Result.

a Effect of forward shifting tendency on a straight incision: The resulting cut is shorter than the path traveled by the cutting edge.

b Effect of forward shifting tendency on a lateral extension of the capsulotomy: The lateral extension is considerably shorter than the path traveled by the cutting edge, because the primary incision had made the capsule more lax than in **a**. If the capsule is so lax that it cannot be cut at all, the ends of the primary incision will tear toward the periphery (analogous to Fig. 8.28c).

c Forward shifting is avoided by initiating the extension away from the primary capsulotomy, in tissue that is more tense, and carrying it toward the main incision. The length of the cut then equals the path traveled by the cutting edge

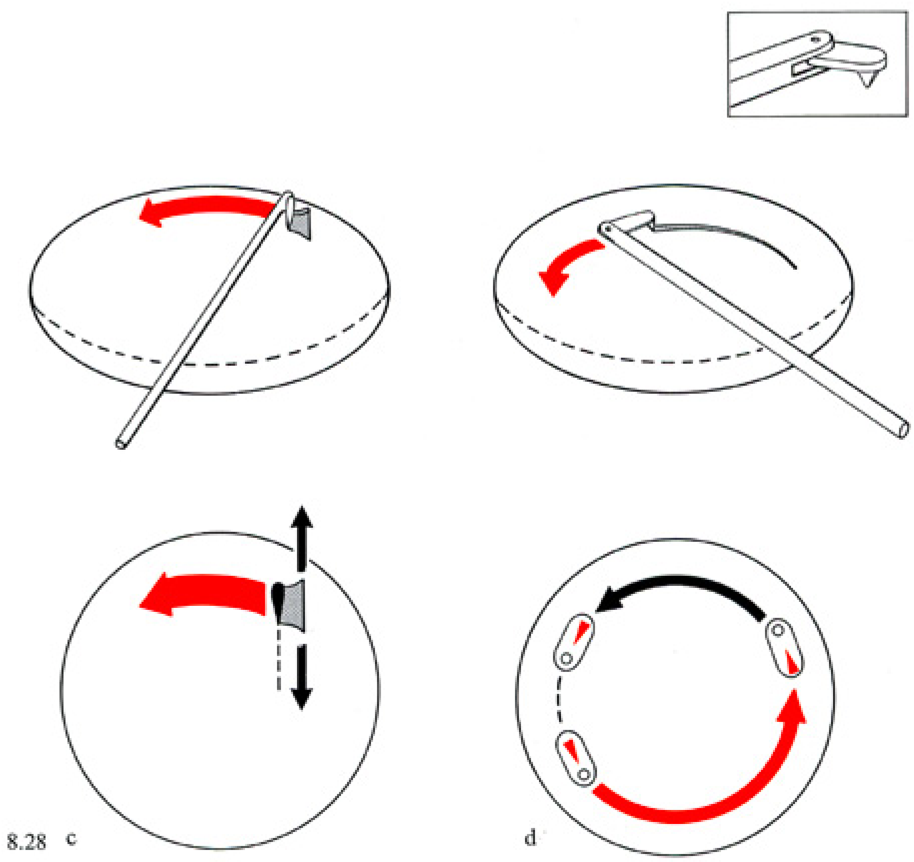


Fig. 8.28. **Capsulotomy by cutting: Effect of lateral shifting tendency on direction of cut.** (Illustrated for a discission knife.) *Red arrow*: Guidance path; *hatched line*: Preferential path; *black arrow*: Direction of resulting cut.

a Cutting the capsule with a straight pulling motion: The incision starts at the point where the blade is applied. The guidance path is congruent with the preferential path, so the direction of the incision follows the path of the cutting edge.

b Lateral sweep with the blade angled: If the knife is swept laterally, the guidance path forms an angle with the preferential path. The asymmetric resistances produce a lateral shifting tendency, and the capsulotomy deviates in the direction of the corneal incision.

c Lateral sweep with the blade upright: In this maneuver the blade behaves as a blunt instrument, so the capsulotomy is made by tearing rather than cutting. The capsule will tear into the zonule at right angles to the direction of blade motion.

d Circular incision made by constantly realigning the preferential path with the guidance path: The stem must rotate through 360° in order to make a circular incision. Given the limited space available, this is possible only if the stem is very short. The capsulotome pictured here (*inset*) has an extremely short stem connected to the handle by a swivel joint. The stem can rotate through a full circle even when the handle has been inserted through a small opening

back to index

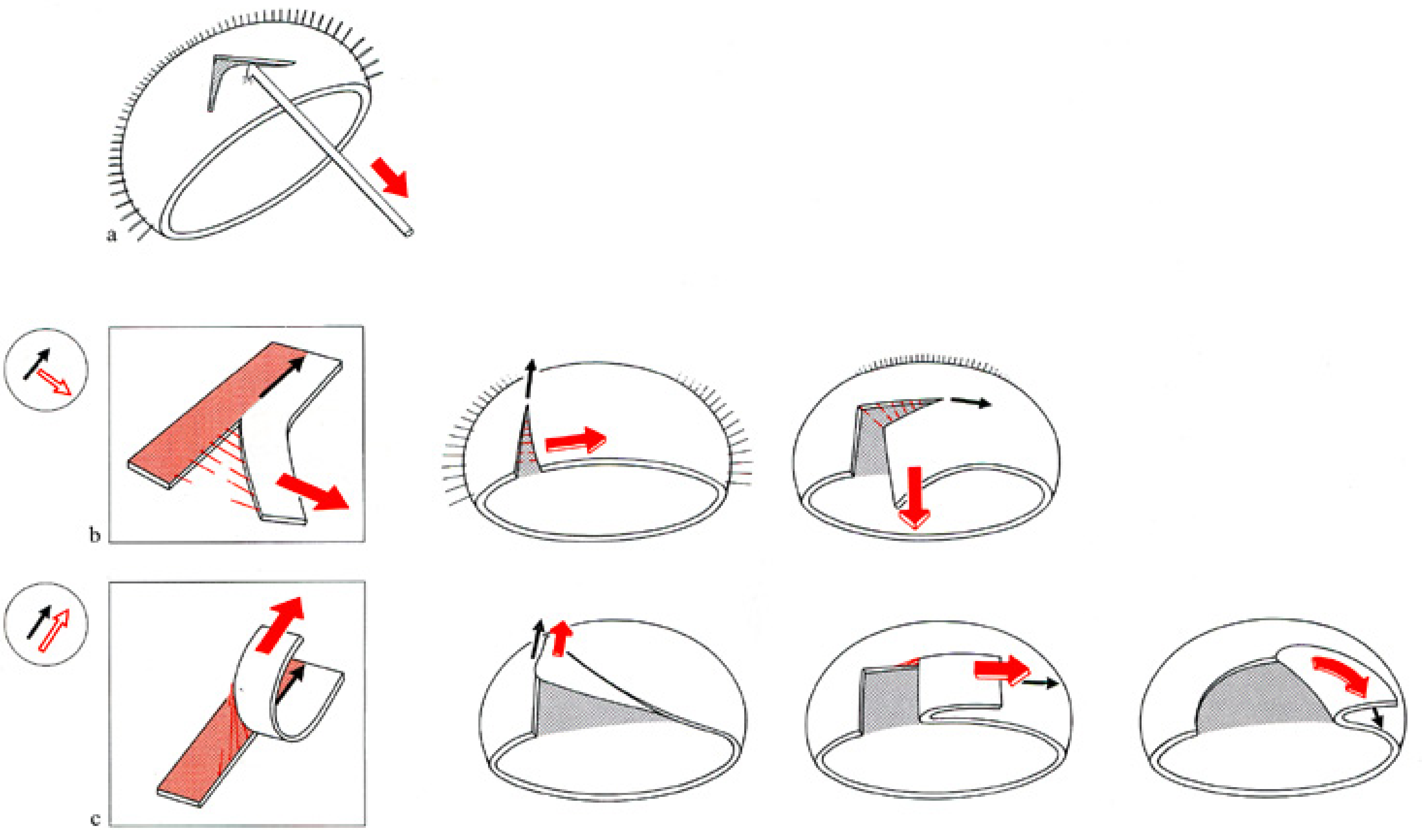


Fig. 8.29. **Capsulotomy by tearing**

a Initial tear. The cystotome is pressed against the capsule, this working motion serving to produce a high frictional resistance between the instrument and capsule (= grasping). Pulling the cystotome (guidance motion) increases the tension of the capsule until it gives way. This tension is transmitted to the zonule; if that is the area of least resistance, the zonule will tear instead of the capsule.
Note: Because the tear can initiate anywhere between the attachment of the zonule and the site of instrument contact, the instrument should be applied farther away from the zonule for tearing than for cutting.

b When tension (*red arrow*) is applied parallel to the capsule surface, the tear will extend (*black arrow*) at right angles to the direction of pull (*inset*). Thus, a tear running parallel to the lens border (*left*) will not turn centripetally when tension is directed toward the center of the capsule, but will extend laterally toward the zonule. The tear is redirected (*right*) by pulling the capsule parallel to the border of the initial tear (i.e., at right angles to the new direction in which the tear is to extend).

c If the capsule is reflected as it is torn free (*inset*), the tear will proceed in the direction in which the reflected flap is pulled (*left*). With this technique it is easier to control abrupt direction changes (*center*), and it is possible to produce a circular capsulectomy (*right*)

somewhere between the point of application of the instrument and the line of attachment of the zonule (Fig. 8.29a).[16] The *direction of extension* of the tear is also difficult to predict, for it does not follow the guidance motions of the instrument. The fibers rupture in the direction of the highest tension, so the tear extends at right angles to the direction in which the capsular tissue is pulled (Fig. 8.29b). Once a tear starts to extend in a particular direction, it tends to maintain that course.[17] When a tear must be abruptly redirected, the best precision is achieved by reflecting the mobilized part of the capsule as the tear proceeds (Fig. 8.29c).

Thus, it is not possible to control precisely the starting point, end point, or direction of the "blunt" capsulotomy (Figs. 8.30 and 8.31). None of these quantities correlate closely with the position or motion of the capsulotomy instrument, so none can be estimated from the behavior of the instrument.[18] Close

[16] The site of the initial tear depends in part on the speed of the tearing motion. The faster the instrument is pulled back, the greater the likelihood that the tear will initiate close to the point where the instrument is applied.

[17] Enlargement of a tear in the initial direction must be anticipated when the capsular tension is diffusely increased, as during delivery of the nucleus or a sudden elevation of the vitreous pressure (see Figs. 8.24 and 8.26).

[18] It is especially dangerous to attempt to grasp and tear off tags of capsule with an aspirating cannula. Neither the direction nor the force of the traction can be controlled, for the traction is produced not just by guidance motions (which can be controlled by the operator) but also by the suction in the cannula.

back to index

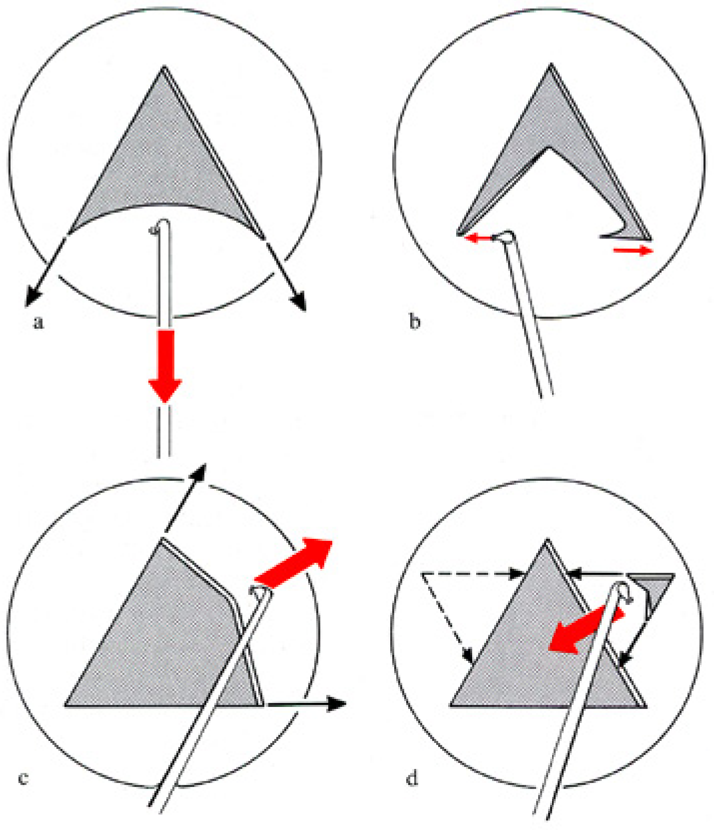


Fig. 8.30. **Triangular capsulectomy by tearing**

a Pulling the cystotome back from the initial gap creates a tear extending in two directions (see Fig. 8.29a), and a triangular defect is formed. With continued traction, there is a great danger of extension into the zonule (*arrows*).

b This is avoided by redirecting the tears at the proper point. As this is difficult to accomplish by tearing alone, it is safer to cut the corners of the triangle with a scissors or a small, sharp knife (a knife is moved toward the preexisting tear as shown in Fig. 8.27c). With the corners thus redirected, the triangular flap can be pulled toward the center of the pupil.

c To enlarge a triangular capsulectomy, it is not advisable to tear from the existing opening toward the periphery, as this would risk extension of the tears into the zonule.

d Instead the cystotome is reapplied outside the capsulectomy and pulled centripetally toward the existing capsular defect

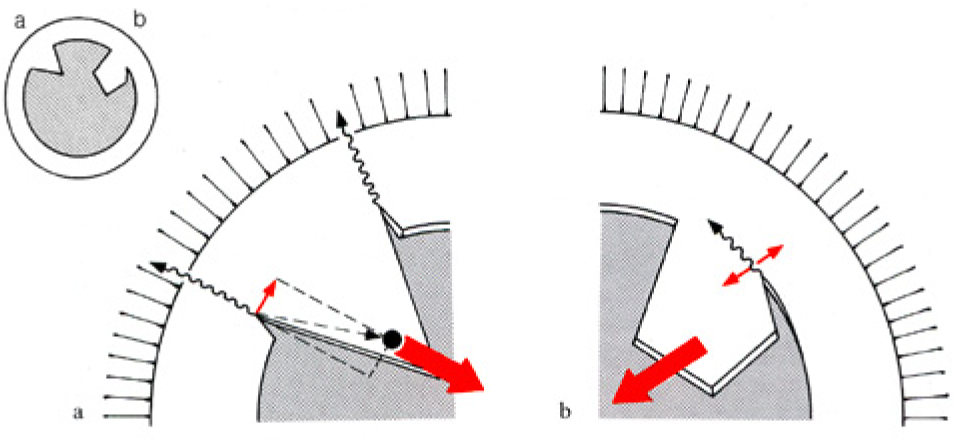


Fig. 8.31. **Removal of capsule tags by tearing**

a If the small tears flanking the tag are both oriented radially, traction in any direction, even centripetally (*inset*), has components that would extend the tears toward the lens equator. Triangular tags of this kind are better not be removed by tearing.[19]

b If the end of the tear at the flap is angled parallel to the lens equator, the tag is easily removed by centripetal traction (see Fig. 8.29b)

[19] A sudden tug toward the center of the lens would offer the best chance of success but is dangerous in this situation because of the peripheral location of the tag. A sudden tug with forceps, if not successful at first attempt, would tear the capsule into the zonule.

back to index

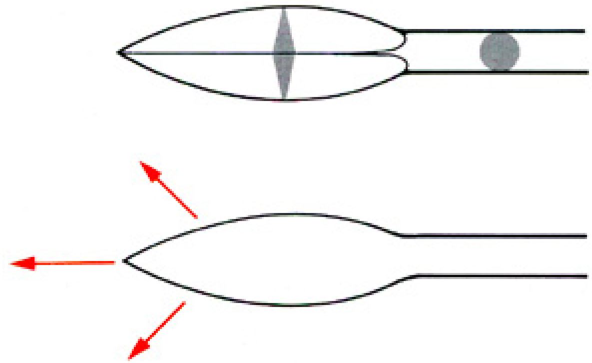


Fig. 8.32. **Straight discission knife.** Straight discission knives behave as sharp instruments when moved forward as well as laterally. They do not divide tissues when pulled backward (*below*). *Note*: If the cross-sections of the blade and stem (*gray*) are of equal surface, the knife is suitable for use in a no-flow system, since it can be advanced and withdrawn without causing aqueous loss. (see Fig. 2.4b)

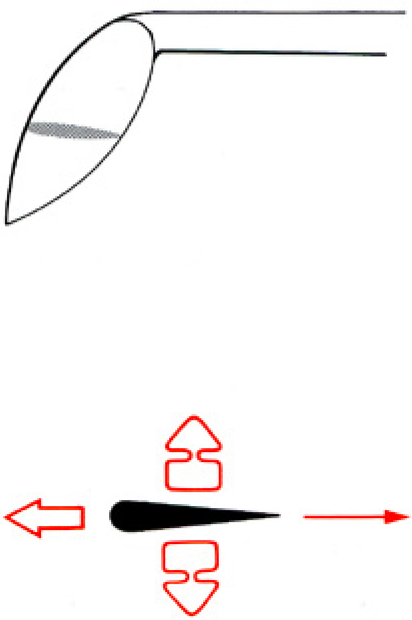


Fig. 8.33. **Angled discission knives.** Angulated discission knives behave as sharp instruments only when pulled backward, as the cross-section of the blade indicates (*below*). They are blunt when moved forward or laterally

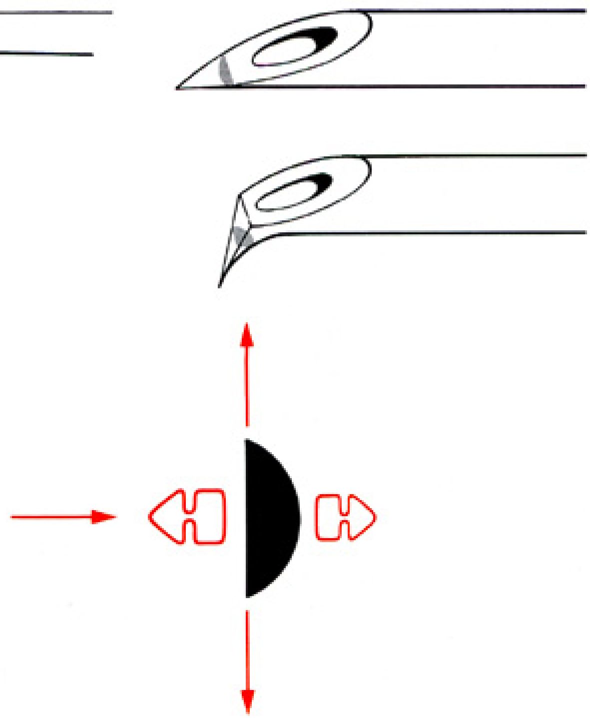


Fig. 8.34. **Injection cannula as a cystotome.** A cannula bent sharply at the tip makes an excellent cystotome. A cross-section through the tip (*below*) shows that it behaves as a sharp instrument when moved laterally and as a blunt instrument when advanced or withdrawn

visual monitoring, then, is essential when tearing is employed.[20] The surgeon should not only focus his attention on the tear and its extension but should also observe the rim of capsule that is left adjacent to the zonule. Motion of this area signifies an interference with the cleavage process which, if neglected, may cause damage to the zonule.

Methods of Capsulotomy

The difficulties of controlling a capsulotomy performed by cutting or tearing are compounded by the fact that it is often difficult to predict whether the capsulotomy instrument will cut or tear the capsule in a given situation.

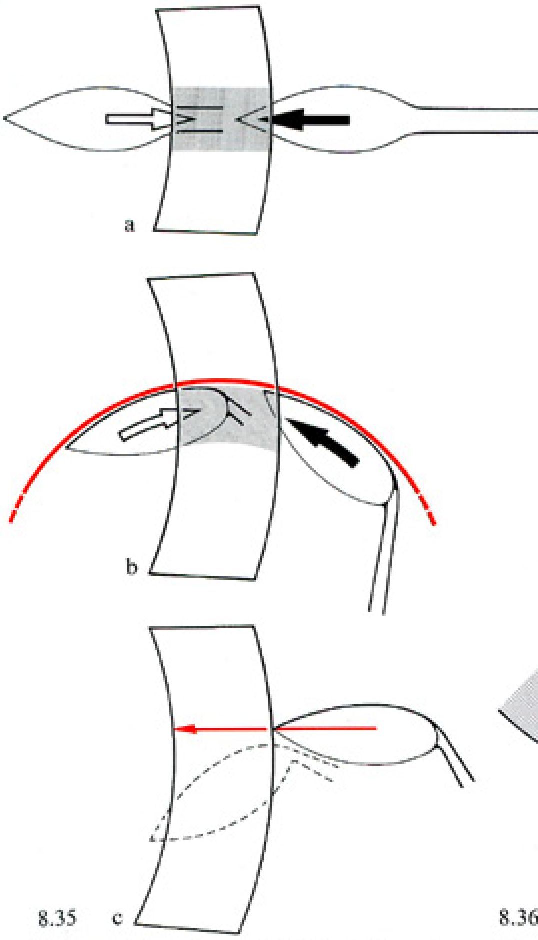
One factor is the *instrument design*. Any blade will exert a sharp, cutting action only in certain directions while producing a blunt, tearing action in all other directions (Figs. 8.32–8.34).

Another factor is the loss of sectility that occurs with *diminishing capsular tension*. It is important, therefore, to maintain a high capsule tension for as long as possible. On the one hand, this means maintaining the tension of the diaphragm as a whole and preventing a general fall of intraocular pressure by using the capsulotomy instruments in a no-outflow system (Figs. 8.35, 8.36b) or a controlled outflow system (Fig. 8.36c). On the other hand following the initial incision, capsule tension is maintained by preventing the premature discharge of lens matter. This is achieved by occluding the capsulotomy opening with air or viscoelastic material (Fig. 8.37). Despite these measures, the capsule will still tend to become increasingly lax and less sectile as the capsulotomy proceeds. That is why a perfect circular excision is difficult to achieve even

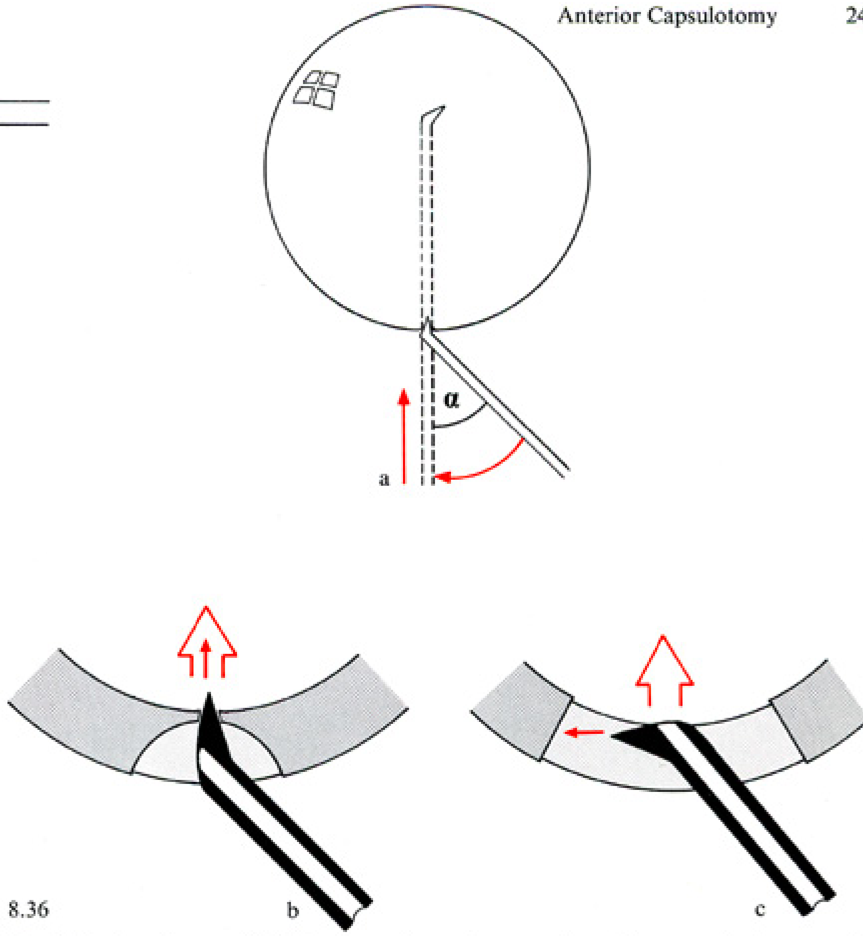
[20] Note: Optical phenomena in the underlying cortex may interfere with visual monitoring of the capsule. They are much more conspicuous under coaxial illumination than the subtle changes in the thin, transparent capsule and may hamper recognition of the capsular border. The latter is most easily identified by injecting air into the anterior chamber, as this brings out reflexes that help define the slightest irregularities on the lens surface.

back to index

‹ ›



8.35



8.36

Fig. 8.35. **Insertion of discission knives in a no-flow system.** Instruments used in a no-flow system must be inserted so that the cross-section of the opening in the anterior chamber precisely matches the cross-section of the instrument shaft. It is not sufficient for the blade to have the appropriate dimensions (see diagram in Fig. 8.32, *top*); additionally the blade must be guided so that it does not enlarge the opening.

a Discission knives with two cutting edges are advanced precisely along their axis.

b Discission knives with one cutting edge are guided along the blunt back of the blade, so they are inserted on a curved path. Note the different angle of application (compared with **a**): The point is directed obliquely toward the back of the blade.

c If the blade were inserted in line with its own axis, it would be deflected by its blunt back (*dashed line*). Any countermaneuvers intended to keep the knife on the desired path (*arrow*) would produce a high resistance and deform the wound area

Fig. 8.36. **Inserting an injection cannula with an angled tip**

a The cannula is applied obliquely for insertion and is not straightened until the tip is inside the anterior chamber.

b Insertion in a no-flow system. The tip cuts its own path, so it must behave as a sharp instrument. The tip is applied perpendicularly and is thrust into the chamber. Thus, the obliquity of the stem on insertion (i.e., the angle α between the stem and a perpendicular to the tissue surface) is determined by the degree of angulation of the tip. *Note*: To reduce the resistance on insertion a preliminary partial thickness incision may be prepared.

c For insertion through a wide incision, the cannula is held in a "blunt" position: The blunt face is leading, and the tip points away from the chamber. The orifice is directed toward the anterior chamber so that fluid can be infused through the cannula immediately after entry.

Large arrow: Guidance direction of cannula.

Small arrow: Direction of tip (=preferential path)

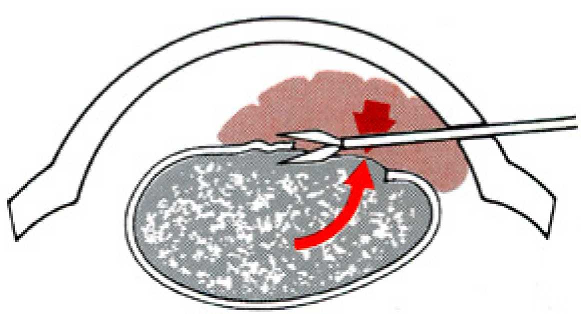


Fig. 8.37. **Preservation of capsule tension by using viscoblockade to maintain pressure in the capsular bag.** Viscoelastic material is placed over the capsulotomy to keep the liquefied lens contents from escaping. This maintains the sectility of the capsule and facilitates visual monitoring for continuing the capsulotomy

back to index

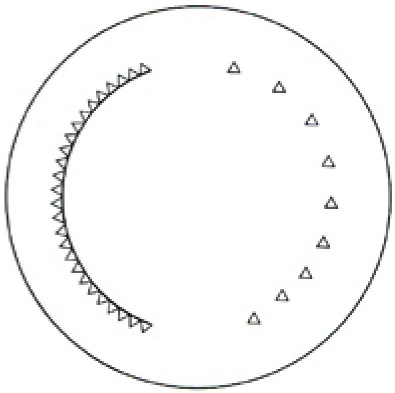


Fig. 8.38. **Performing the capsulotomy in mini-steps.** Multiple, separate capsulotomies of minimal length eliminate the problems associated with a long travel path of discission instruments. The excision can be made circular or any shape desired using the mini-step technique. The perforations can be placed so close together that a continuous capsulotomy is obtained (*left*). Alternatively, intact tissue bridges may initially be left between the perforations so that capsule tension is maintained along the whole circumference (*right*)

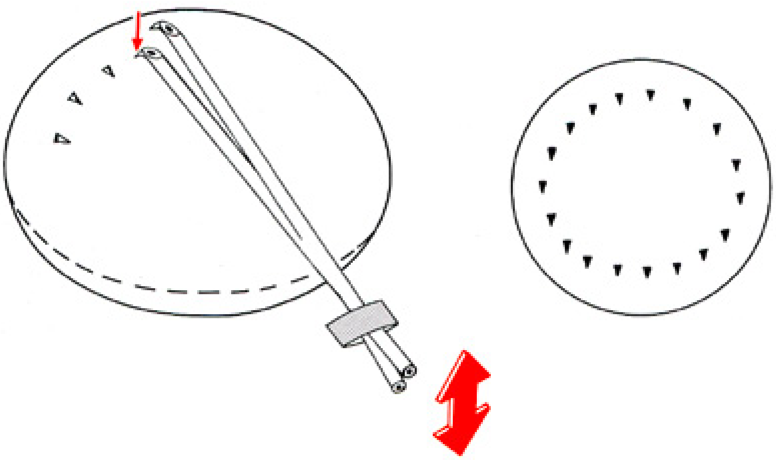


Fig. 8.39. **Mini-step capsulotomy with an up-and-down action of an angled cannula tip.** The cannula cystitome is bent as shown in Fig. 8.34. The amplitude of the downstroke is necessarily small due to space limitations. Whether this is adequate to perforate the capsule depends on "sharpness," i.e., on the cutting ability of the instrument and the sectility of the capsule (capsular tension). The resistance to perforation of the capsule also depends on the condition of the cortex. If the surgeon attempts to compensate for poor sharpness by increasing the amplitude of the up-and-down motion, tension will be exerted on the zonule

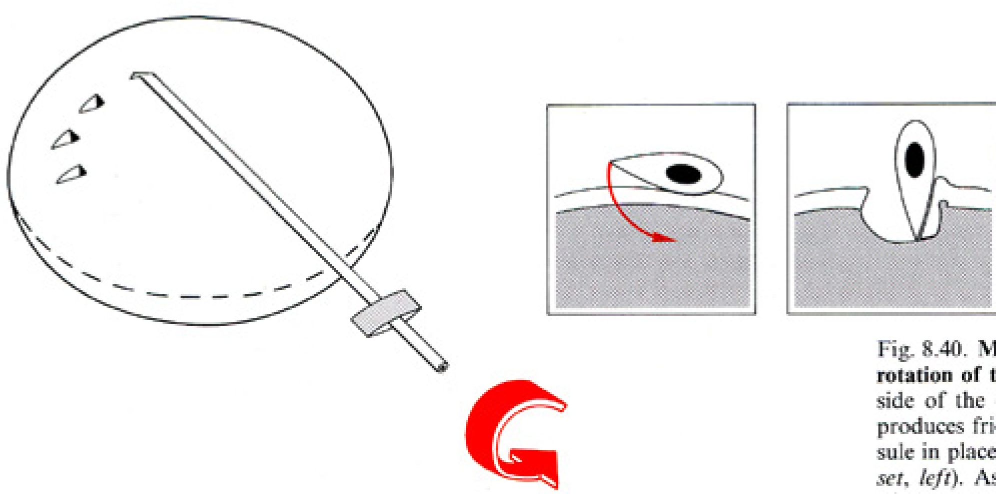


Fig. 8.40. **Mini-step capsulotomy by axial rotation of the cannula.** Placing the blunt side of the cannula tip onto the capsule produces friction that helps hold the capsule in place and improves its sectility (*inset, left*). As long as just the pointed tip of the cannula penetrates the capsule, a cutting effect is achieved. But if the cannula is rotated further, the capsule is acted upon by the blunter sides of the bent tip, and a tearing action may result (*inset, right*)

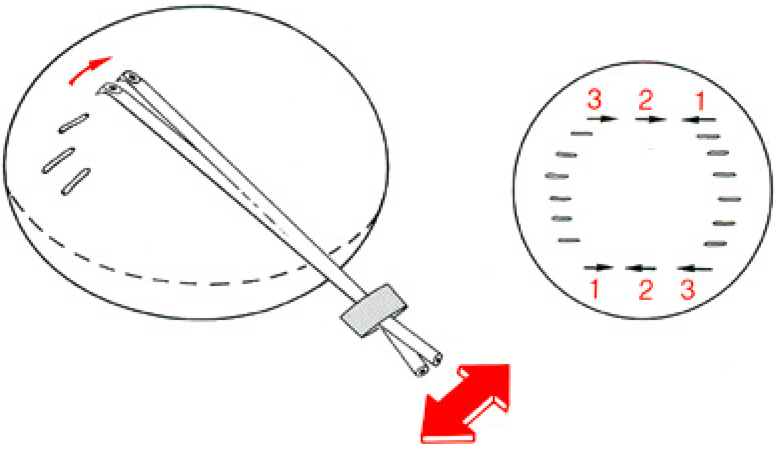


Fig. 8.41. **Mini-step capsulotomy with a lateral sweeping motion of the cannula tip.** The tip behaves as a sharp instrument when moved laterally, so small incisions are produced. Cutting *toward* the center of the capsule (*1*, *3*) places stress on the zonule, but if the zonule is sufficiently resistant, tension adequate for the capsulotomy exists around the whole circumference of the lens. Cutting *away from* the center of the capsule (*2*) relieves stress on the zonule, but the tension for the cutting action dwindles as the capsulotomy proceeds. This places greater demands on the cutting ability of the instrument.
Note: Long incisions usually cannot be made because of diminishing capsule tension. That is why multiple small incisions are preferred even along the upper and lower circumference of the capsulotomy, where theoretically longer incisions could be made. Note the sequence of the mini-cuts in the diagram on the right!

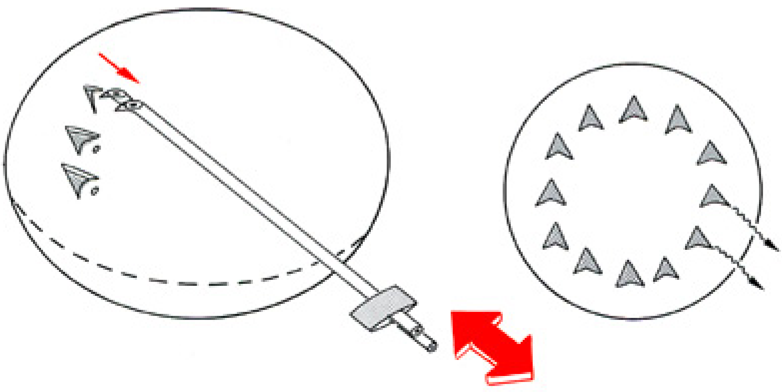


Fig. 8.42. **Mini-step capsulotomy with forward and backward motions of the cannula.** The cannula tip behaves as a blunt instrument, producing triangular perforations.
Note: In the lateral perforations, there is a danger of tearing into the zonule (*arrows* in the diagram on the right)

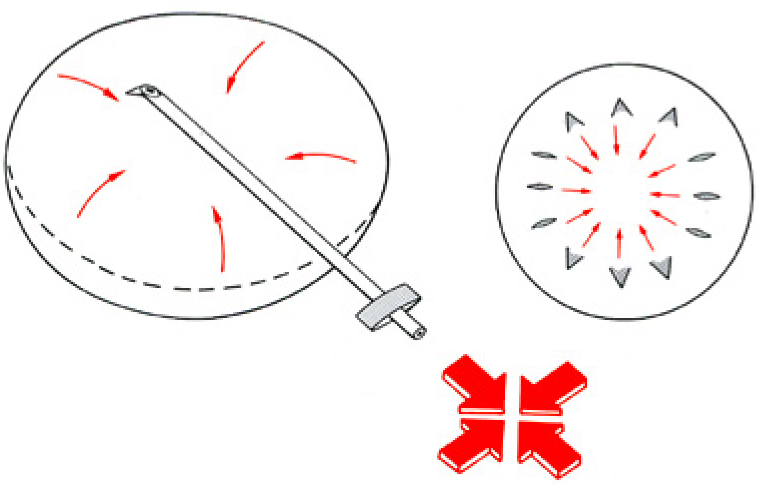


Fig. 8.43. **Mini-step capsulotomy with radial perforations of the capsule.** When radial guidance motions are used, the cannula cuts the lateral portions of the capsule while tearing the upper and lower portions

when an extremely sharp cystotome is used.

Since the difficulties of the procedure correlate with the length of the capsulotomy, they can be reduced by subdividing the procedure into **multiple mini-steps**. The smaller each individual step, the less it matters whether the tissue is cut or torn (Fig. 8.38). The "mini-step" capsulotomy can solve the problem of diminishing capsule tension by leaving intact tissue bridges between the perforations that outline the piece of capsule to be removed. The individual cuts are then joined together by a tearing procedure in a second step. Mini-step capsulotomies are illustrated in Figs. 8.39–8.43.

Low sectility can be compensated for by using fast, jabbing motions of the cystitome. Control problems are managed by keeping the amplitude of the motions very small. This

back to index

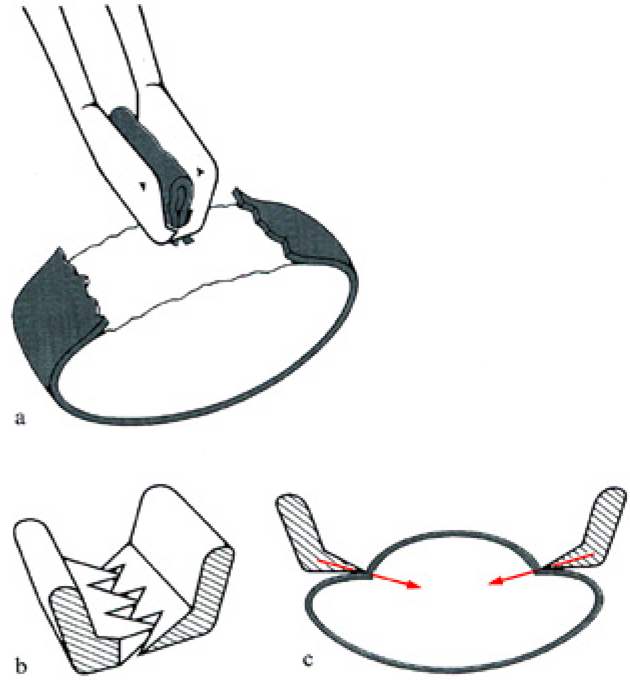


Fig. 8.44. **Anterior capsulectomy with forceps**

a The forceps jaws tear out the tissue that is gripped between them.

b When closed, the jaws are smooth externally and can be moved about safely within the anterior chamber.

c For grasping, the sharp teeth are pressed into the lens so that their preferential paths (*arrows*) are nearly perpendicular to the capsule surface

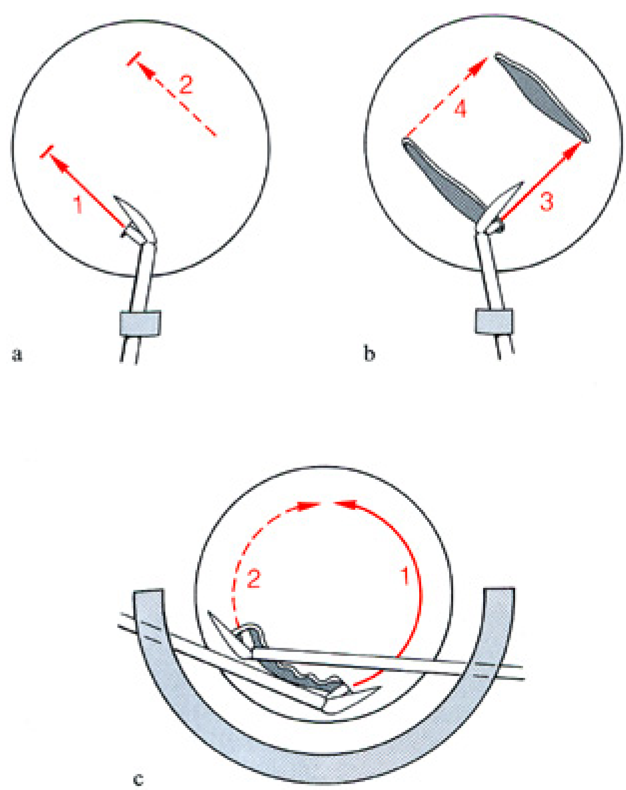


Fig. 8.45. **Anterior capsulectomy with microscissors**

a, b When introduced through a small access opening, one microscissors with a 45° angulation can make a diamond-shaped capsulectomy. Two parallel incisions are made with the scissors held one way (**a**), then the instrument is turned over to make the two remaining incisions (**b**).

c When greater access is available, a circular capsulectomy can be made by cutting half the circle (*solid line*), turning the scissors over, and cutting the remaining half (*broken line*)

back to index

can be done, for example, by rotating the cystitome about its own axis (Fig. 8.40). A more technically elaborate solution is the ultrasound cystitome.

Toothed capsule forceps automatically tense the capsule upon closure (Fig. 8.44). Control is difficult, however, because the area of jaw contact and thus the pressure on the capsule are difficult to define. Therefore one cannot predict whether the forceps will exert a cutting or tearing action in a given situation, and whether the capsule or the zonule is more likely to give way.

A very precise instrument for capsulotomies is the **microscissors** (Fig. 8.45). Because each blade meets an opposing surface, scissors can always cut without tearing, regardless of the capsule tension. Microscissors are especially indicated when tearing must be avoided, e.g., when the resistance of the zonule is presumed to be low[21] or an abrupt change of direction is required.[22]

8.3.2 Delivery of the Nucleus

The maneuvers for delivering the nucleus, like those for removing the entire lens, consist of *mobilization* (nucleolysis), *alignment*, and *locomotion*. However, many more technical variations are possible in delivery of the nucleus due to the great variability in the size, compactness, and surface characteristics of the nucleus and the stress tolerance of the diaphragm. Basically the nucleus is more difficult to grasp than the intact lens, and its surface is rougher. On the one hand, this means that the *external resistances* (friction) are higher, so greater forces may be needed to effect the delivery; on the other, the *internal resistances* (compactness) are lower, so the direct application of forces to the nucleus is less efficient. Locally applied forces (e.g., hooks, forceps, or cryoprobes) act upon the whole nucleus only if its internal resistance to dissociation is greater than the external, frictional resistance to motion of the nucleus. This means that control of the delivery not only involves controlling the *force applied to the nucleus* but is especially concerned with *reducing frictional resistance* at the surface of the nucleus.[23]

Nucleolysis

The nucleus and cortex do not form discrete anatomic structures, and (in contrast to the zonule in the intracapsular delivery) there is no definite cleavage plane separating the part to be removed from structures that are to be left behind. The boundary, rather, lies somewhere in a zone of gradually increasing compactness, and the *location of the cleavage plane* for a given tissue structure will vary according to the nature of the applied forces (i.e., site of application, magnitude, direction, and velocity).

Delivery of the nucleus is influenced not only by the properties of the nucleus but also by the *properties of the cortex*. If motion of the nucleus exerts *pressure* on the cortex, the cortex will act as a cushion over the lens capsule. A thin or noncompliant cortex increases the danger of capsular damage when the nucleus is moved. A thick, compressible cortex enhances the safety of the nucleolysis, but all motions must be performed slowly enough to allow sufficient time for any compression or yielding of the cortex to occur.

If motion of the nucleus exerts *traction* on the cortex, remaining tissue attachments may transmit the forces to surrounding structures (capsule, zonule). The inherent dangers decrease as the nucleolysis proceeds. The surgeon confirms completion of the nucleolysis by noting that motion of the nucleus no longer elicits motion of the cortex or capsule.[24]

The *force* needed to mobilize the nucleus depends on the ease with which the attachments between the nucleus and cortex can be divided. This in turn depends on the difference in consistency between the part to be removed and the part that is to remain. If the consistency difference is large, applied forces will act locally at the plane of separation. But if the nucleus has a soft consistency similar to the cortex, the effects will be distributed evenly over a large tissue volume, and substantial force must be used to obtain a local separation (Fig. 8.46).

The *direction* of motion of the nucleus can be precisely controlled by the direct, **localized application** of forces. Using *lateral motions* to effect nucleolysis alters the volume distribution inside the capsular bag. Because some parts of the cortex are stretched and others are compressed, the amplitude of the lateral motion is limited by the compliance of the cortex (Fig. 8.47a). By contrast, *rotation* of the nucleus does not affect the cortical topography. An "infinite" excursion is possible.

---

[21] After a prior vitrectomy or when there is risk of subluxation (e.g., in pseudoexfoliation syndrome or after trauma).

[22] Abrupt direction changes must be made when a tear threatens to spread into danger zones and a sharp-angle course correction is required. Examples are triangular flaps that tear into the zonule (see Fig. 8.30b) and partially divided tags of capsule (see Fig. 8.31b).

[23] E.g., by enlarging the capsulotomy, enlarging the pupil (see Figs. 7.36–7.38), extending the corneal incision, using glides to avoid entanglement with obstructions, or by reducing friction with viscoelastic lubricants.

[24] Thus, the safety of the nucleolysis is monitored by watching the capsule border. Any concomitant motion signifies possible force transfer to the zonule.

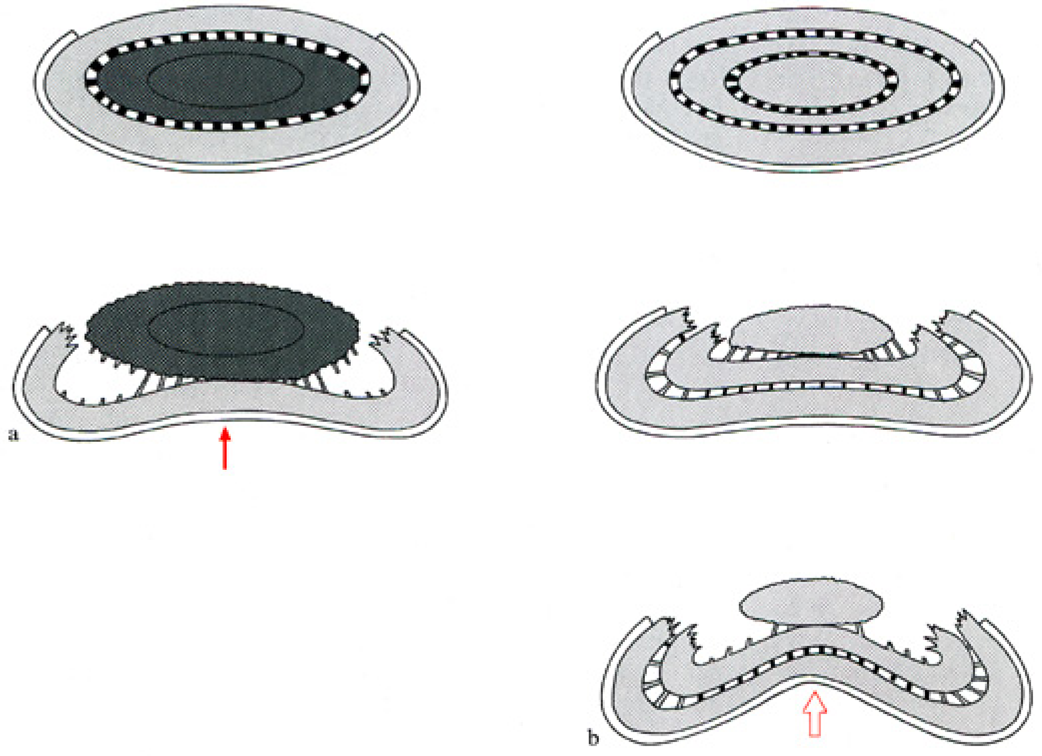


Fig. 8.46. **Nucleolysis by the indirect application of forces**

a Expression of a well-demarcated nucleus with a much harder consistency than the cortex (*top*). If the posterior capsule is driven forward and deformed by a rise of pressure in the vitreous, it will produce a similar deformation of the cortex. The hard nucleus is not deformed, however, and the geometric discrepancy between the nucleus and cortex leads to rupture of the connections (*bottom*).

b Expression of a soft nucleus having a consistency similar to that of the cortex (*top*). The nucleus also deforms in response to deformation of the cortex. As a result, tension on the connections is spread over multiple layers, and the tension in any one layer is insufficient to effect fiber rupture (*center*). The deformation must be markedly increased (i.e., the vitreous pressure must be further increased) to produce the critical tension necessary for rupture of the connections (*bottom*)

The resistance to the rotation is very high, however, because all the attachments are stretched simultaneously. The resulting danger of force transfer to the zonule can be reduced by starting the rotating maneuver at a small amplitude and gradually increasing the amplitude as the nucleus becomes loose (Fig. 8.47).

When forces are **applied diffusely**, the nucleus is mobilized by *pressure*. The pressure may be produced ambiently in the vitreous chamber (nucleolysis by expression), or the pressure within the capsular bag alone may be increased by injecting fluid between the nucleus and cortex (nucleolysis by *hydrodissection*).

Nucleolysis by expression is always combined with *locomotion*. The cortex is simultaneously loosened, facilitating subsequent corticolysis. The maneuver always affects a large ambient tissue volume due to the general pressure rise in the vitreous chamber (see Fig. 1.42). The maximum attainable *pressure level* depends on the resistance of the zonulocapsular diaphragm, whose integrity is an essential prerequisite for nucleolysis by expression.[25]

[25] This method is contraindicated if the zonule has been weakened as a result of trauma, pseudoexfoliation, or previous vitrectomy close to the zonule.

back to index

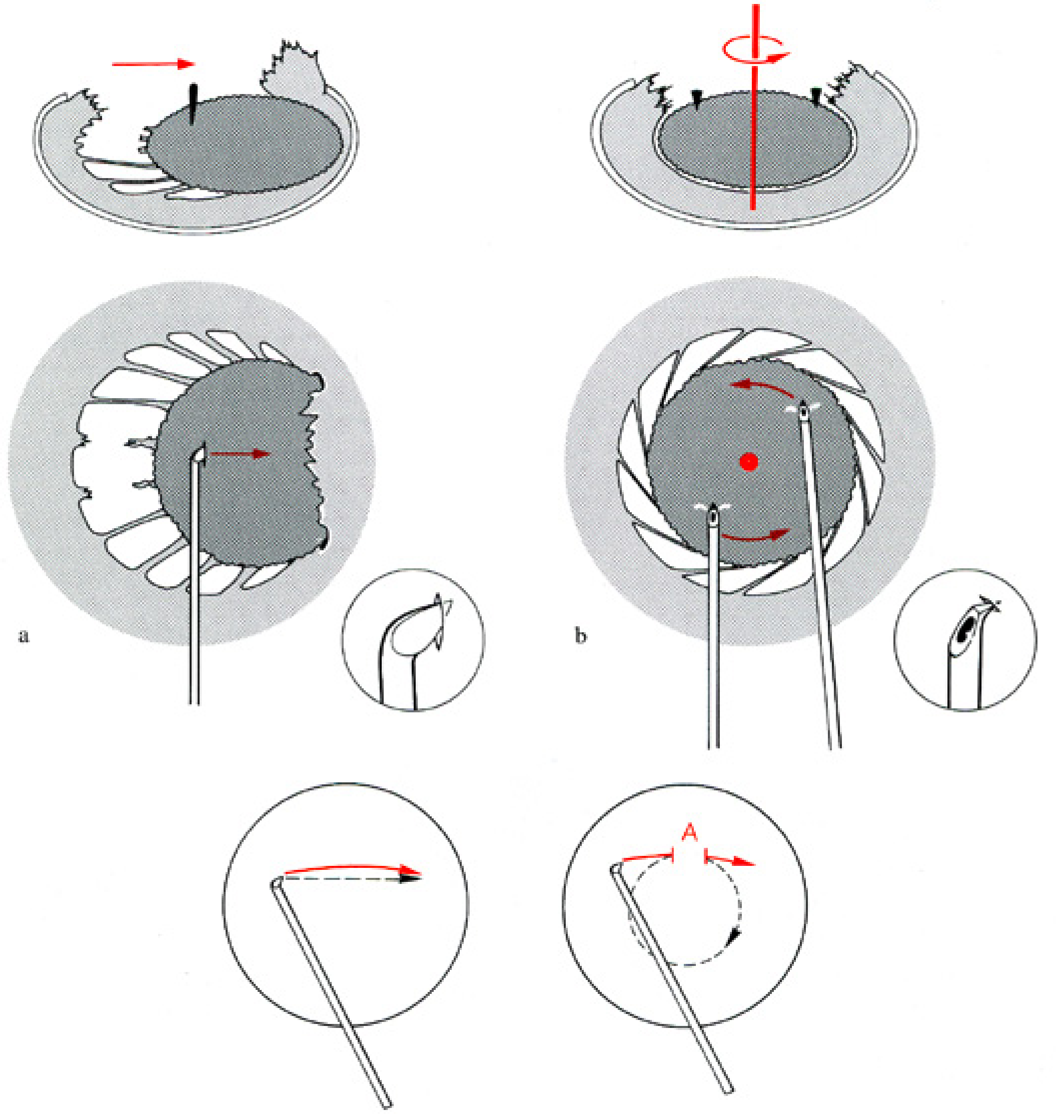
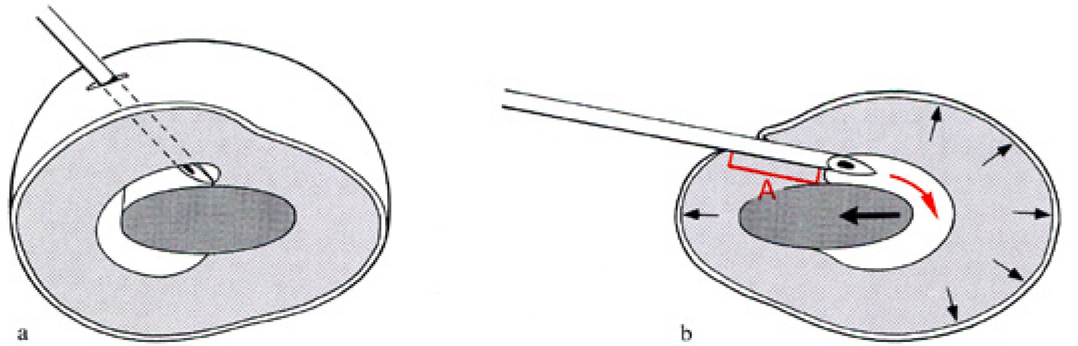


Fig. 8.47. **Nucleolysis by the direct application of forces**. *Top*: Cross-section through the nucleus; *center*: Top view of the nucleus; *bottom*: Diagram of motion.

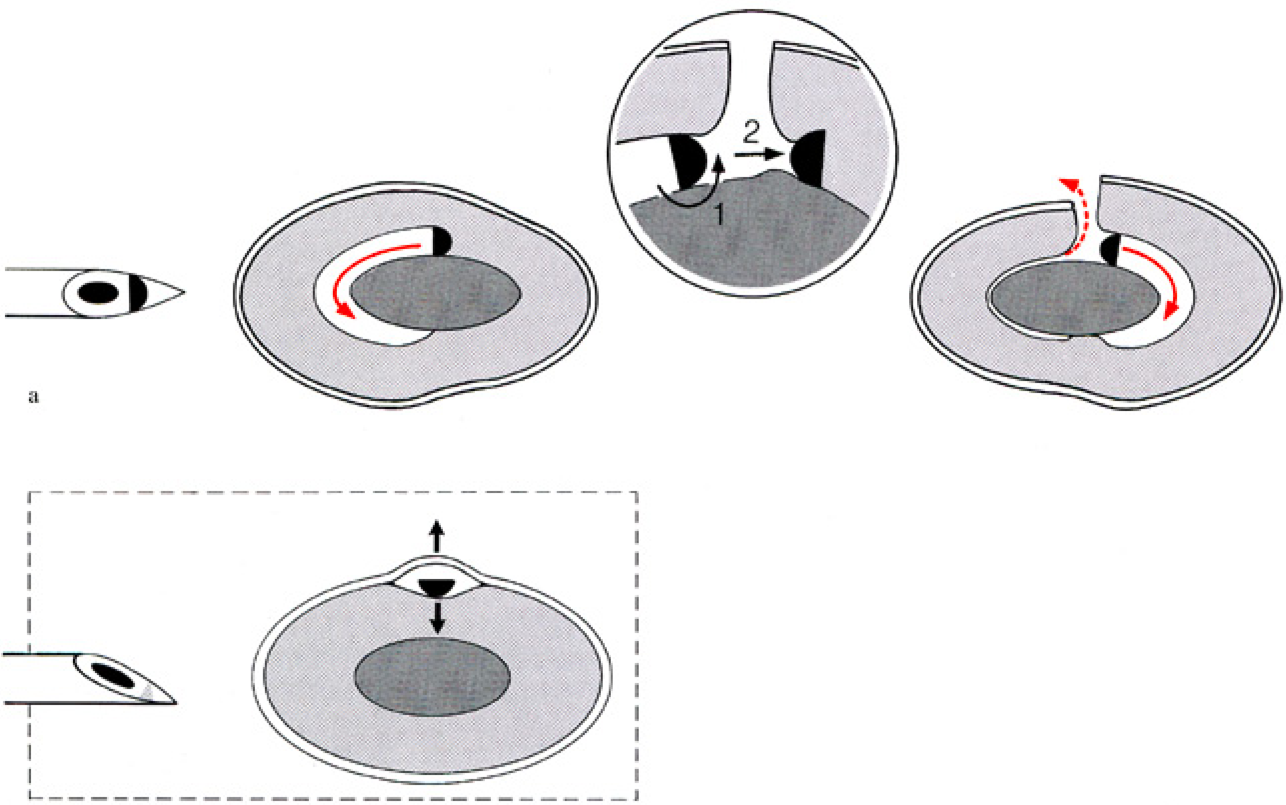
a *Lateral motion*: The nucleus is engaged with a cystitome whose blade offers the highest resistance when moved *laterally* (i.e., whose *lateral* surfaces are blunt, see *inset*). The lateral motion of the nucleus ruptures the connections between the nucleus and cortex on one side; on the opposite side pressure is exerted on the cortex, which is either compressed or pushed aside. *Bottom*: The arc of a swiveling motion about a pivot at the entry site (*red arrow*) is nearly congruent with the direction of the lateral shift of the nucleus it should produce.

b *Rotation*: The nucleus is engaged with the bent tips of infusion cannulas that act as blunt instruments when *advanced* or *withdrawn* (see *inset*), and the nucleus is rotated to rupture its cortical attachments. Tension is exerted all over the cortex, but no pressure. The volume distribution within the capsular bag remains unchanged. *Bottom*: A swiveling motion of the cystitome produces a rotational movement about the entry site, but the true goal of the maneuver is rotation about the center of the nucleus (which has a much smaller radius). The arcs of both movements coincide for only a short distance (*A*). Therefore, rotation with only one cystitome should be done in very short increments, since larger movements would place undue stress on the zonule. Maintaining the axis of rotation at the center of the nucleus is made easier by the simultaneous use of two cystitomes

back to index



8.48 a b



a

b

8.49

back to index

Fig. 8.48. **Nucleolysis by hydrodissection,** basic technique.

a A cannula is passed through the capsulotomy into the interior of the lens. Fluid injection creates a pressure chamber in the potential space entered by the cannula opening.

b Longitudinal section. The pressure that can be produced in the pressure chamber is limited by the quality of the seal around the cannula. This depends largely on the size of the capsule opening, the ability of the cortical substance to form a seal around the cannula, and the length of cortex traversed by the cannula (*A*). As pressure builds up in the newly created intralenticular pressure chamber, it compresses the cortex and presses it against the capsule

Fig. 8.49. **Nucleolysis by hydrodissection,** practical application.

a Cross-section. *Left*: The cannula opening faces laterally in the target layer so that the fluid can spread along the lens fibers. *Inset*: For injection toward the opposite side, the cannula is turned (*1*) and pressed tightly against the fibers on that side (*2*). *Right*: This allows fluid to drain from the previously injected chamber. Meanwhile a new seal is established around the cannula for the second injection, increasing the outflow resistance so that a new pressure chamber can form.

b If, in contrast to **a**, the cannula were inserted superficially with its opening facing the capsule, hydrodissection would effect a corticolysis instead of nucleolysis[27]

The effects of **hydrodissection**, by contrast, are confined to the capsular bag. The injected fluid creates an artificial *pressure chamber* between the nucleus and cortex, which ruptures the connections through its expansion (Fig. 8.48a). The *maximum attainable pressure level* is limited by the resistance of the capsule alone.[26] This factor also limits the volume of fluid that can be injected. It may be necessary to remove fluid from spaces already created before more fluid can be injected into new regions (Fig. 8.49). The *pressure level attainable in practice* depends on the outflow resistance, i.e., on the quality of the seal around the injection cannula (Fig. 8.48b). The injection of *watery fluid* for hydrodissection expands the interspaces among the lens fibers and merely loosens the nucleus, requiring that other means be used to complete the nucleolysis.[28] A complete and continuous corticonuclear interspace can be formed by the injection of *viscoelastic material.*[29]

A major difference between nucleolysis by hydrodissection and the other methods is that hydrodissection does not loosen the *cortex*, but presses it firmly against the capsule. As a result, the cortex can pose an additional obstacle to subsequent delivery of the nucleus unless a preliminary "corticotomy" is carried out.

Aligning the Nucleus for Delivery

Whereas the proper lens alignment for an intracapsular delivery is determined by the location of gaps in the zonule, the optimum alignment of the nucleus in an extracapsular delivery is determined largely by the *frictional resistances* between the rough nucleus, the adjacent tissue surfaces, the pupil margin, and the incision. The rationale for minimizing these resistances is to increase the mobility of the nucleus, thereby reducing the force needed for its delivery.

[26] The condition of the zonule is irrelevant in this method. Hydrodissection is appropriate for the foregoing cases where expression would be contraindicated.

[27] This achieves the opposite of the planned nucleolysis, which aims at separating the nucleus from the cortex to facilitate the delivery. Instead, it is likely that the cortex will come away with the nucleus when the delivery is attempted, and the larger volume will compound the difficulty of negotiating the capsulotomy, pupil, and corneal incision.

[28] Nucleolysis by hydrodissection is most efficient if combined with simultaneous locomotion so that the nucleus can move forward while being loosened. If this is impossible, as in endocapsular procedures, hydrodissection is less effective.

[29] The reflux resistance of viscoelastic material being very high, there is a danger of excessive capsular tension and rupture during injection. This can be reduced by initiating the hydrodissection with watery fluid, allowing the fluid to drain, and then separating the remaining fiber attachments with viscoelastic material.

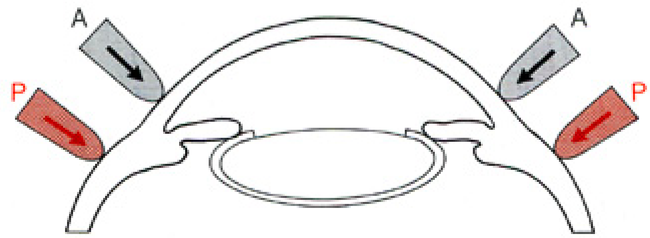


Fig. 8.50. **Locomotive and aligning function of expressors.** Depressors applied to the limbocorneal area serve mainly to align (*A*) the emerging nucleus, while depressors applied more posteriorly to the sclera (*P*) exert pressure on the vitreous chamber (see Fig. 1.42c) and mainly support locomotion of the nucleus

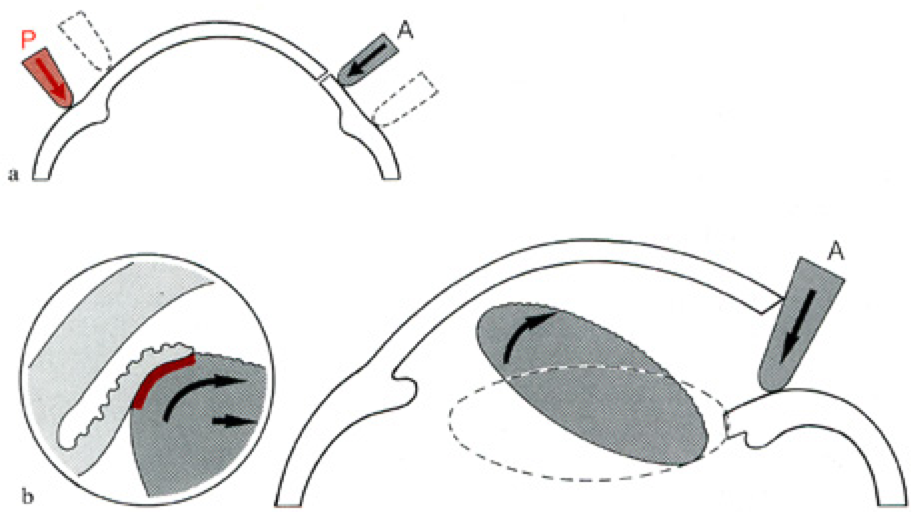


Fig. 8.51. **Tumbling the nucleus for delivery by expression**

a The locomotor depressor *P* is placed inferiorly on the sclera so that it does not hinder the tumbling maneuver. Superiorly the aligning depressor *A* is applied to the limbocorneal zone to restrict upward movement of the superior pole of the nucleus.

b While gliding with its smooth posterior surface past the undersurfaces of the iris and cornea, the nucleus moves away from the iris and cornea (*inset*)

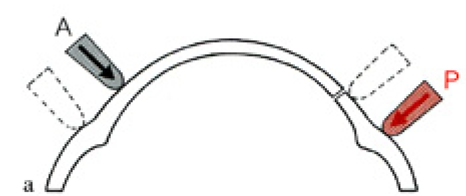
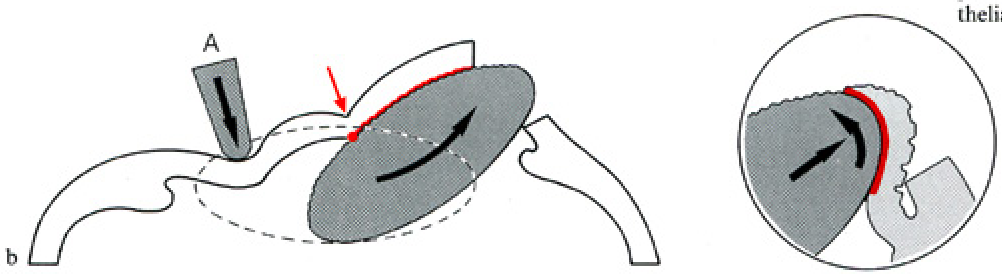


Fig. 8.52. **Delivery of the nucleus by sliding with elevation of the corneal lip**

a The lower expressor (*A*) performs an aligning function by restricting upward motion of the inferior pole of the nucleus. The upper depressor (*P*) is applied to the sclera and raises the vitreous pressure.

b While the superior pole of the nucleus is upraised, it glides tangentially past the undersurface of the iris; but in contrast to Fig. 8.51, it is directed toward the iris. The rough upper surface of the nucleus faces the corneal hinge fold. The longer the nucleus glides past this fold (i.e., the smaller the corneosceral incision and hence the closer the hinge fold is to the superior limbus), the greater the risk of endothelial injury (see also Fig. 5.20 and 5.21)



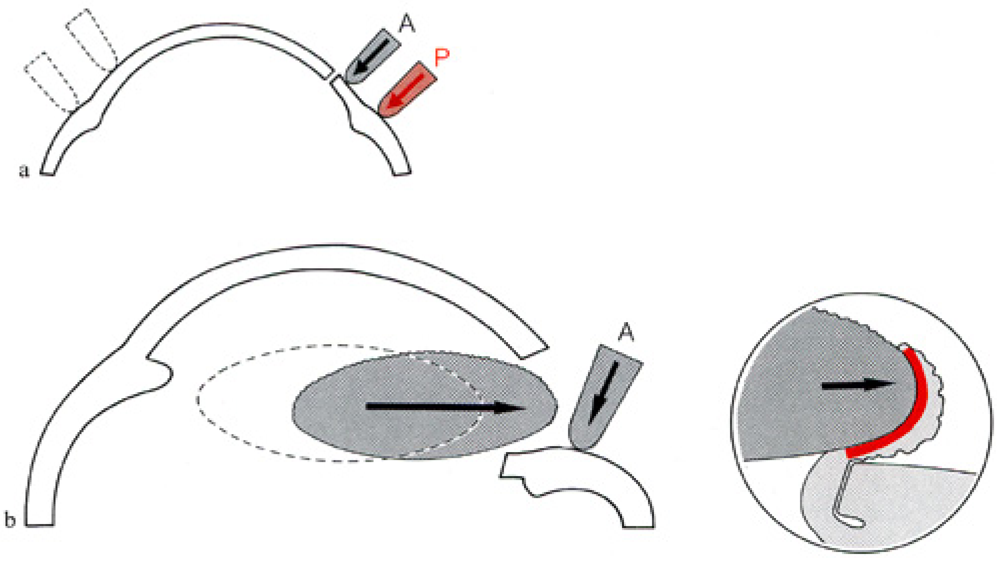


Fig. 8.53. **Delivery of the nucleus by sliding with depression of the lower lip of the corneal wound**

a Both depressors are applied at the lower wound lip. One depressor (*A*) is applied close to the limbus and depresses the lower corneal wound lip to align the nucleus. A second depressor applied to the sclera (*P*) serves to regulate the pressure.

b The nucleus is expelled horizontally. If the pupil is not wide enough it engages directly against the posterior surface of the iris (*inset*). The resistance there is overcome either by retracting the iris with a small hook or by switching momentarily to the technique in Fig. 8.52, i.e., depressing the inferior pole of the nucleus to raise the superior pole (see also Fig. 8.59d)

In delivery by **tumbling**, the *opposite pole* of the nucleus presents first. As the nucleus is tumbled toward the incision, it slides tangentially along the iris and posterior corneal surface. There is relatively little friction, however, because the nucleus moves away from those tissue surfaces and because it presents its smooth posterior face to them (Fig. 8.51).[30]

The pathway for a **sliding delivery** is cleared either by lifting the upper corneal wound lip or by depressing the lower lip. **Raising** the corneal wound margin involves less rotation of the nucleus than tumbling (Fig. 8.52). Significant iris friction can occur in this maneuver, because the nucleus moves *toward* the iris as it glides along its posterior surface. Friction with the posterior corneal surface is a risk if the cornea buckles into a stiff *hinge fold* that scrapes against the rough surface of the nucleus.

In sliding delivery by **depression** of the lower lip of the incision, the nucleus is not rotated from its anatomic level, and it does not touch the posterior corneal surface (Fig. 8.53). If the pupil is *large*, resistance to the delivery is very low. But if the pupil is *small*, the nucleus may move directly toward the posterior iris surface and become entangled there.

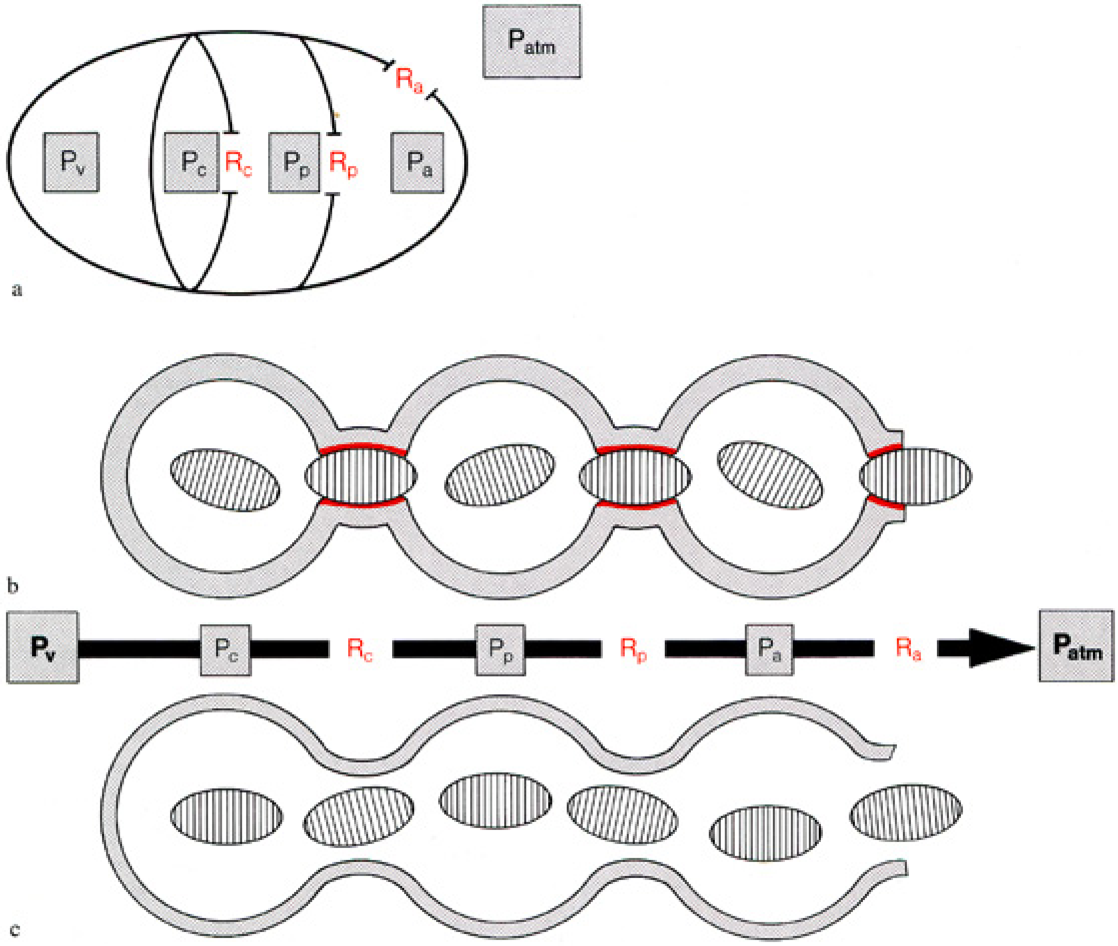
The alignment of the nucleus can be controlled directly in *extraction*. In *expression* it is controlled indirectly by increasing or decreasing the resistance along specific paths. Thus, the instruments used in the expression serve two functions: to supply the forces necessary for locomotion, and to control the direction of lens motion. Which effect is predominant depends on the site of instrument application (Fig. 8.50).

With regard to the **choice of alignment** in a given case, the *tumbling* maneuver is facilitated by a nucleus that is approximately spherical. Tumbling may be considered if the incision is placed well corneally, for in this situation tumbling will produce less friction than a sliding delivery with elevation of the corneal flap. The sliding delivery with *depression of the lower wound lip* creates the least friction, provided the pupil is large.

Viscous or viscoelastic materials can be applied as *surface coatings* to reduce friction. Viscoelastic material can also be used as a permanent *spatula* to retain the nucleus in a given alignment even while the expressors are being removed.

[30] The anterior side of the nucleus may be rough from the previous manipulations. But the posterior side has just been detached from the cortex and has a smoother surface.

back to index



Locomotion

Locomotion consists of two phases: passage through open spaces and passage through narrow openings. As each phase involves different resistances, each requires the application of different locomotive forces.

When the nucleus passes through **open spaces** in the eye, the resistances to locomotion are negligibly small, so minimal force is required. By contrast, the delivery encounters high resistance at **narrow openings**, so much larger locomotive forces are required. The major difference, however, is that the nucleus behaves as an independent loose body while in *open spaces* and moves only when the forces are applied to the nucleus itself. But in *narrow openings* the nucleus effectively becomes part of the wall of the compartment, so movements raise space-tactical problems that require the proper coordination of pressure and resistance. Forces no longer act just on the nucleus, but in all portions of the compartment. Both phases may occur in a sequential, alternating fashion (Fig. 8.54).

In locomotion by **extraction**, the nucleus is grasped with *locally applied instruments* such as hooks, forceps, suction cups, or cryoprobes. Extraction is easily accomplished through open spaces even with a nucleus of low compactness. But extraction through narrow openings may produce a *negative pressure* in the chamber from which the nucleus emerges. This vacuum increases the resistance to locomotion through the narrowing, in which

Fig. 8.54. **Sequence of pressure phases during locomotion**

a Schematic representation of the delivery path from the pressure chamber of the capsular bag (P_c) through the capsulotomy (R_c) into the retropupillary pressure chamber (P_p), through the pupil (R_p) into the anterior pressure chamber (P_a), and through the incision (R_a) to the outside into the "atmospheric pressure chamber" ($P_{atm}=0$).

b When there are narrow openings along the path of the delivery, phases of low pressure will alternate with phases of higher pressure. Locomotion through narrow passages is driven by the pressure gradients between the vitreous space, anterior chamber, and the outside environment. For locomotion through open spaces, other forces (i.e., extractors) must act on the nucleus to move it forward.

c When the openings along the delivery path are large, all locomotion involves a "pressureless" passage through open spaces

❮ ❯

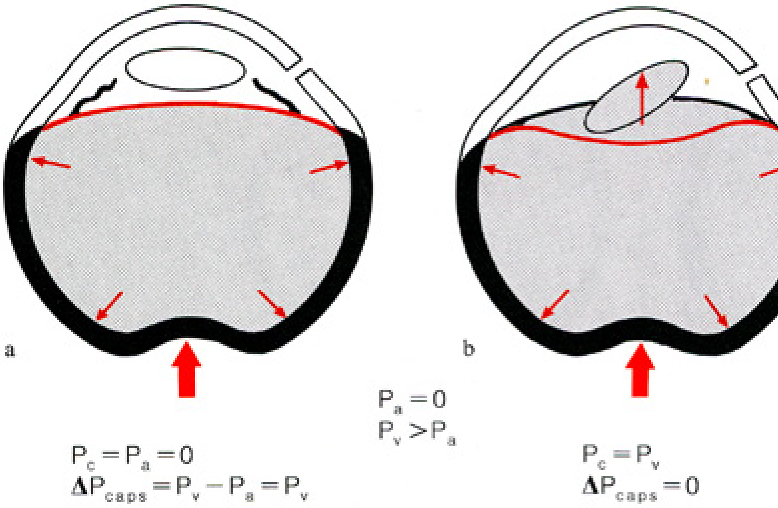


Fig. 8.55. **Space-tactical aspects of delivery by expression.** The pressure in the vitreous chamber (P_v) is higher than the pressure in the anterior chamber (P_a).

a If the capsulotomy or capsulectomy is large, the outflow resistance from the capsular bag (which behaves here as a precapsular chamber) is zero, and the pressure in the precapsular chamber (P_c) equals the pressure in the anterior chamber P_a (when the anterior chamber is open, it equals the outside pressure $P_a = 0$). Thus, the pressure in the space in front of the posterior lens capsule is P_a, and P_v behind it; the posterior capsule is exposed to the full effect of the pressure differential.

b With a small capsulotomy, the emerging nucleus can occlude the opening. Since the pressure in the precapsular chamber can equal the vitreous pressure up to the moment at which the largest cross-section of the nucleus emerges through the capsulotomy, the posterior capsule is not exposed to a pressure differential until that moment

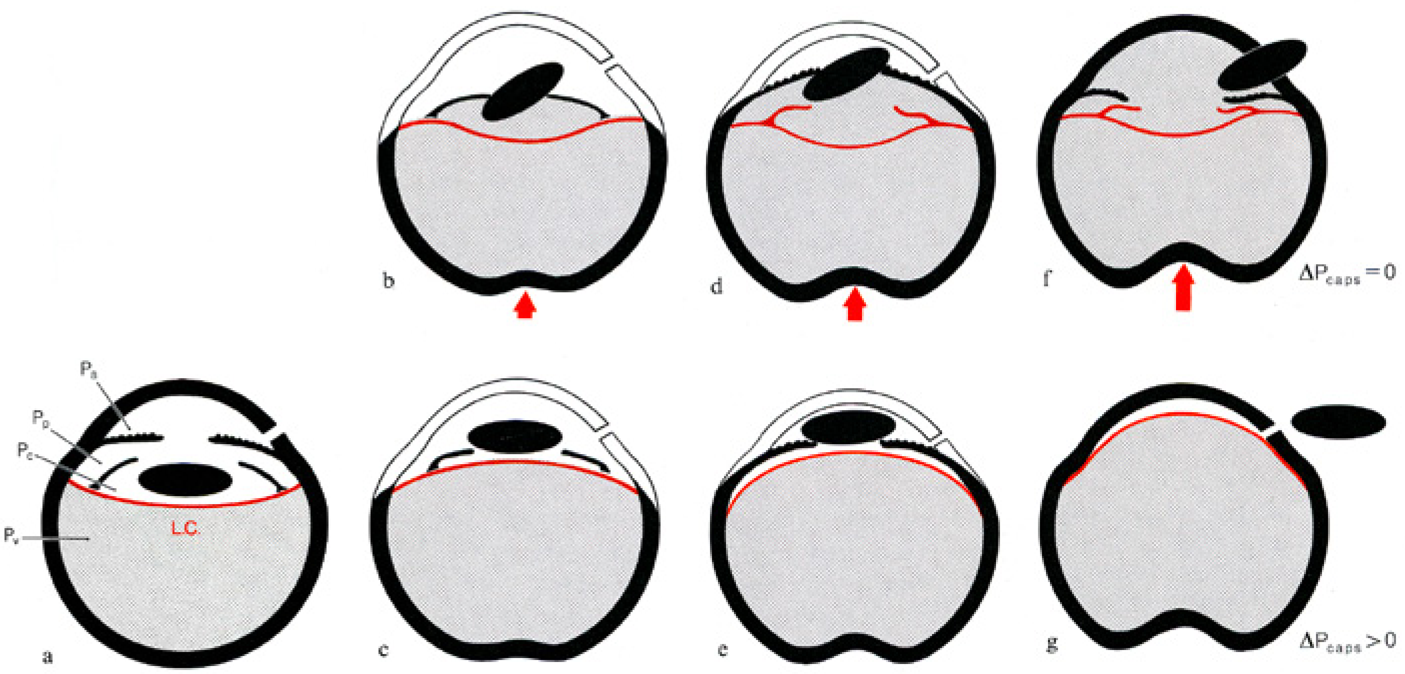


Fig. 8.56. **Stresses on the posterior lens capsule in the various phases of expression.** *Top row*: High-pressure phases through narrow openings; the posterior capsule (L. C.) is not exposed to a pressure differential. *Bottom row*: Low-pressure phases through open spaces; the posterior capsule is exposed to a large pressure differential.

a Nucleus in the capsular bag.

b Passage of the nucleus through the capsulotomy.

c Nucleus in the retropupillary chamber.

d Passage through the pupil.

e Nucleus in the anterior chamber.

f Passage through the corneal incision.

g Completion of locomotion. The nucleus is now outside the eye

back to index

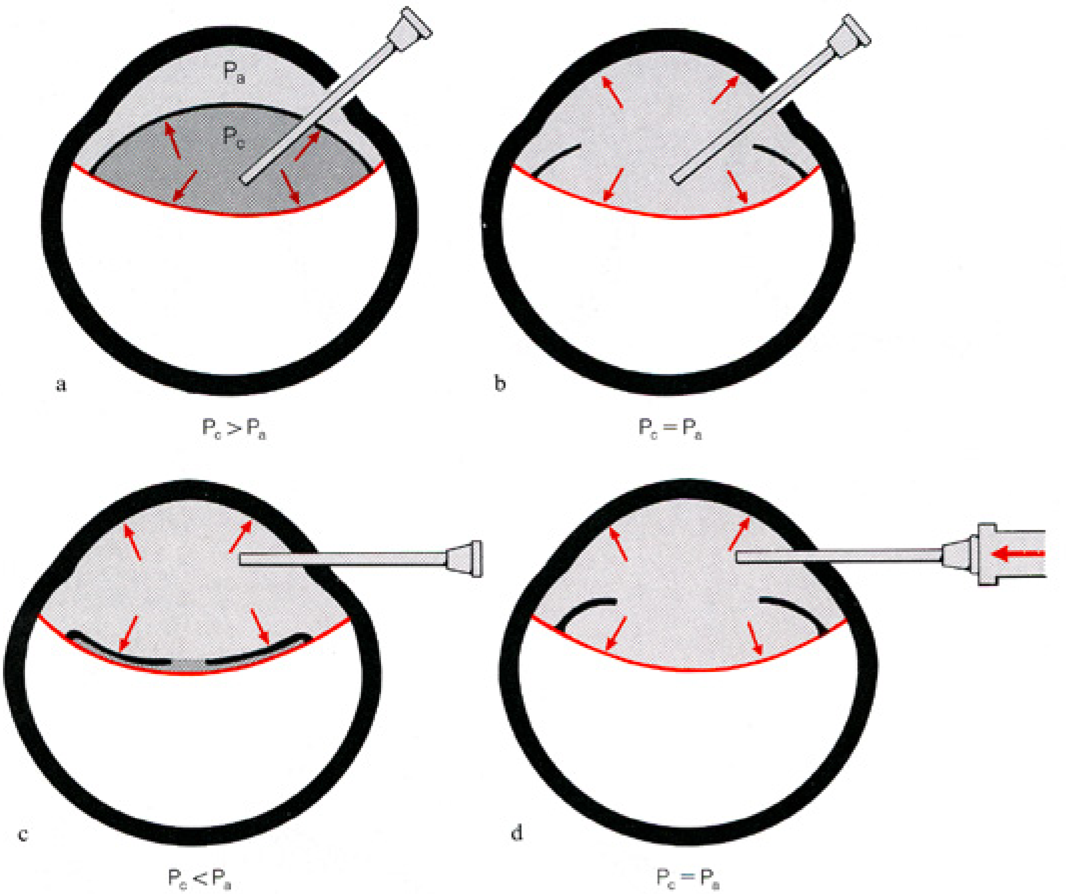


Fig. 8.57. **Space-tactical aspects of irrigation for expulsion of the nucleus.** The pressure in the anterior chamber (P_a) during irrigation is greater than that in the environment and greater than or equal to that in the vitreous chamber (P_v).

a, b Injection into the capsular bag.
c, d Injection into the anterior chamber.

a Injection into the capsular bag through a small capsulotomy: The pressure in the capsular bag (P_c) can exceed that in the anterior chamber (P_a).

b Injection into the capsular bag through a large capsulotomy: P_c equals P_a.

c Injection into the anterior chamber with a small capsulotomy: P_a exceeds P_c, and the capsular bag collapses.

d Injection into the anterior chamber with a large capsulotomy: P_c equals P_a

case the nucleus must be very compact for an extraction to succeed.

Locomotion by **expression** involves a rise of *pressure* in *the vitreous chamber*. In the phases where resistance is low, the elevated pressure serves merely to raise the diaphragm, thereby reducing the space available for the nucleus and forcing it to move along paths of least resistance; a small pressure increase will be sufficient. But in the high-resistance phases where the nucleus must traverse sites of narrowing, it is necessary to raise the pressure in the chamber until it becomes high enough to forcibly expel the nucleus.[31]

The danger posed to the *posterior lens capsule* by this maneuver depends on the pressure difference between the space in front of the posterior lens capsule ("precapsular chamber system")[32] and the space behind. This pressure difference in turn depends on whether the precapsular chamber is part of the vitreous pressure system or part of the anterior-chamber pressure system

[31] This is analogous to spitting out a cherry pit. In the low-resistance phase the pit is carried through the open oral cavity to the lips with the tongue; it may then be released with slight force if the lips are separated (i.e., if the diameter of the aperture is larger than the pit). Conversely, a high-resistance phase is produced by pressing the lips tightly together. Now the tongue plays no role in expulsion of the pit, which is effected by a high pressure within the oral cavity.

[32] The entire pressure system governing the pressure in front of the posterior capsule is termed the "precapsular chamber." Depending on the resistances at the capsulotomy, the pupil, and the corneoscleral incision, the precapsular chamber may comprise the capsular bag, the retropupillary chamber, the anterior chamber, or the extraocular atmosphere.

back to index

(Fig. 8.55). The two locomotive phases differ in this regard: The precapsular chamber belongs to the pressure system of the *anterior chamber* while the nucleus is passing through *open spaces*, but it belongs to the *vitreous* pressure system while the nucleus passes through *narrow openings*.

This fact has several implications. As long as the nucleus can *occlude the narrow opening*, the pressures in the vitreous chamber and precapsular chamber are equal, so the lens capsule is not exposed to a pressure differential. But once the nucleus has *passed through* the narrow opening, the pressure in the precapsular chamber falls precipitously, and the posterior capsule is suddenly exposed to the full effects of the pressure differential (Fig. 8.56). Thus, there is no danger to the capsule before the largest diameter of the nucleus has traversed the narrow opening, regardless of the degree of pressure applied. But as soon as the largest nuclear diameter emerges, the capsule comes under tension abruptly and may rupture.

This principle is reflected in the **safety rule for expression of the nucleus**: The impending *danger* of capsule rupture is signified by an increase in the force needed for locomotion. The *moment* of rupture occurs just when this force ceases to be necessary.

The surgeon can anticipate this danger whenever he tries to compel locomotion by applying greater pressure.[33] He can reduce the risk of capsule rupture by discontinuing the application of force at the proper time, i.e., just *before* the largest cross-section of the nucleus traverses the narrow opening. He may then enlarge the opening to provide a path of lower resistance.[34]

In **expulsion**, locomotion of the nucleus is accomplished by *fluid injection* (Fig. 8.57). When the nucleus moves through an open space, the motivating force is produced by the fluid stream and thus obeys hydrodynamic laws. But in narrow openings a pressure chamber forms behind the nucleus, and this pressure, which derives from the increased resistance, supports the movement of the nucleus against this very resistance. The pressures do not attain the values that develop in an expression, because the irrigation cannula that has been introduced prevents watertight occlusion of the opening. Accordingly, expulsion carries less danger of posterior capsule rupture. The main complication in fluid expulsion is *entanglement* of the nucleus on surface irregularities along the passageways. Whereas the volume of the anterior chamber is reduced in expression, in expulsion it is increased. This allows much room for uncontrolled movements of the nucleus, a tendency that may be aggravated by the eddy currents that form in the forcibly injected fluid.[35] *Control* of the expulsion is geared toward producing a uniform stream (i.e., avoiding eddy flow by using a large-gauge cannula) and preventing entanglement by using a glide to direct the nucleus toward the incision.

The general **safety strategy** in locomotion is to minimize the *pressure differential* at the posterior lens capsule. Basically this means establishing at the outset a path of low resistance for delivery of the nucleus – a sufficiently large capsulotomy, pupil, and incision – so that virtually all phases of the locomotion can occur through open spaces (see Fig. 8.54c). If that is not possible, the surgeon must be prepared to take appropriate measures *before the largest cross-section* of the nucleus slips through a narrow opening; he must respond quickly by releasing pressure on the vitreous in time.

Examples of Techniques for Delivering the Nucleus

In contrast to intracapsular deliveries, *expression* is less hazardous than extraction in an extracapsular delivery because the diaphragm is less vulnerable. *Extraction*, on the other hand, is more difficult because grasping instruments cannot grip the nucleus as securely as they can an intact lens capsule.

The selection of expression or extraction in a given case will depend on the stress tolerance of the diaphragm and also on the compactness of the nucleus. It may be appropriate to use *separate techniques* for negotiating the capsulotomy, pupil, and incision, because the size (resistance to delivery) and direction (alignment for delivery) may be different for each of these apertures.

The examples in Figs. 8.58–8.60 illustrate extracapsular delivery by *pure expression*, *pure extraction*, and *mixed techniques*.

[33] The "pressure test" is an important monitoring aid for the instructing surgeon assisting a novice. By applying a palpating instrument to the sclera, the surgeon can detect the pressure rise, recognize that danger exists, and give appropriate instruction.

[34] E.g., by extending the capsulotomy, enlarging the pupil (see Figs. 7.36–7.38), or enlarging the corneal incision.

[35] Eddy currents are most apt to form when a narrow-gauge cannula is used. A high inflow rate is then needed to develop a sufficient pressure, and this implies high flow velocities.

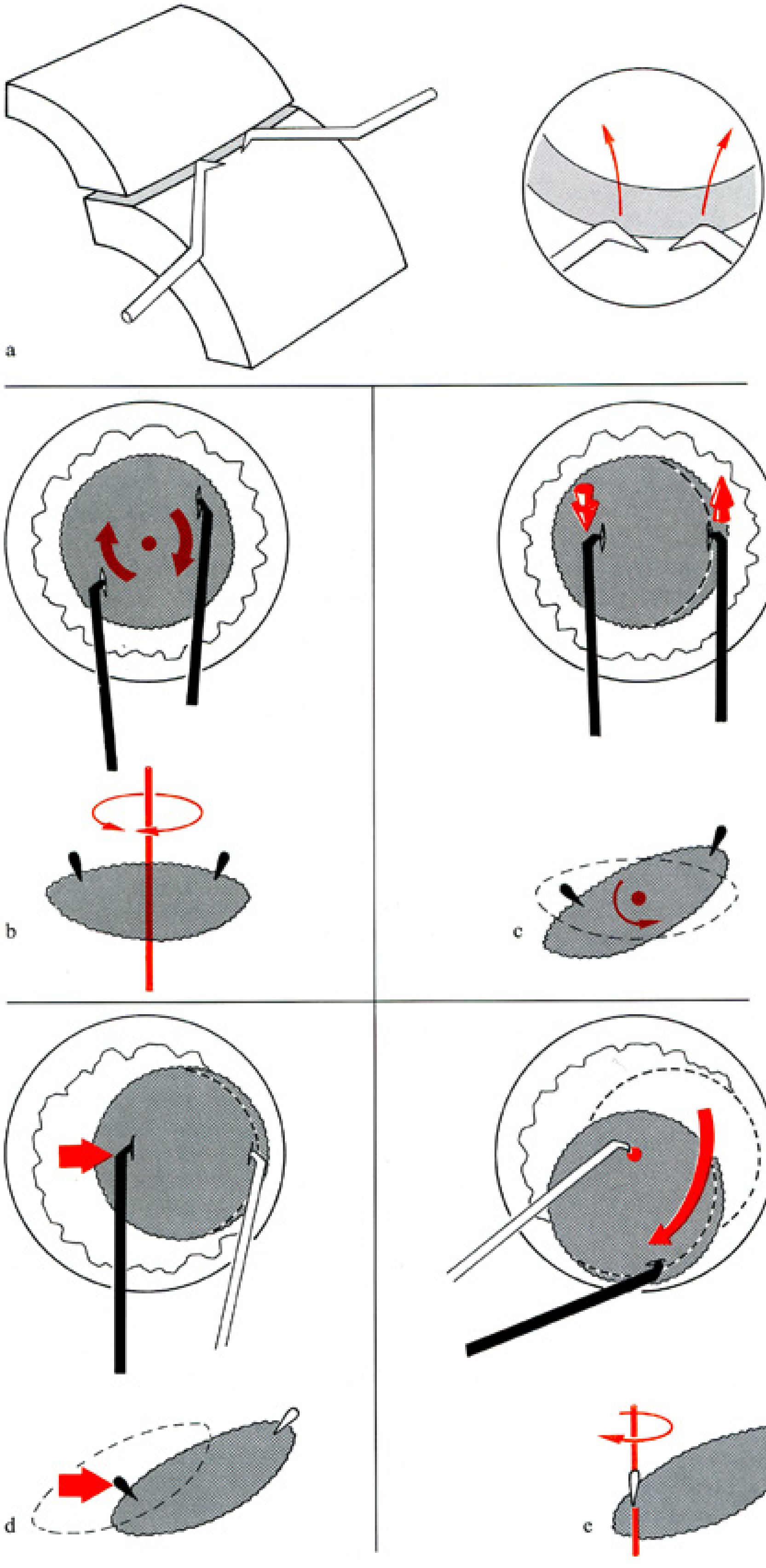


Fig. 8.58. **Extraction of the nucleus using two infusion cannulas with angled tips**

a Introduction of the instruments: The cannulas are passed into the anterior chamber at the center of the incision and are guided from there in divergent directions. The tips face laterally with the blunt ends leading until the nucleus is reached (see also Fig. 8.36c). There the tips are turned downward.

b The sharp tips are hooked into the midperiphery of the nucleus, which is mobilized by rotation about its vertical axis (see Fig. 8.2d).

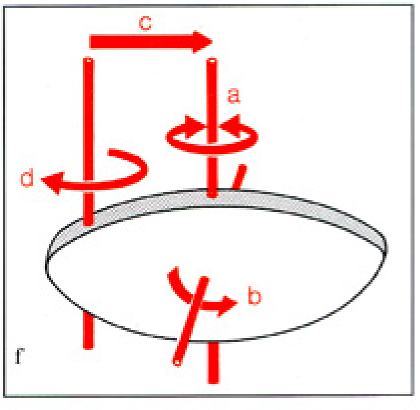
c The right pole is delivered into the anterior chamber by tipping the nucleus about a transverse axis. For this the left hook is pressed downward slightly, while the right hook moves upward with the opposite pole.

d Once the right pole has crossed the iris plane, the nucleus is shifted to the right until the left hook is at the center of the pupil.

e At this point the left hook functions passively as an eccentric pivot for wheeling the nucleus out of the eye with the right hook.

f Review of the extraction maneuvers. The letters correspond to the figure labels and designate the rotational axes and lateral shifts of the various phases.

Hooks in black: Active force transmitters
Hooks in white: Passive hooks



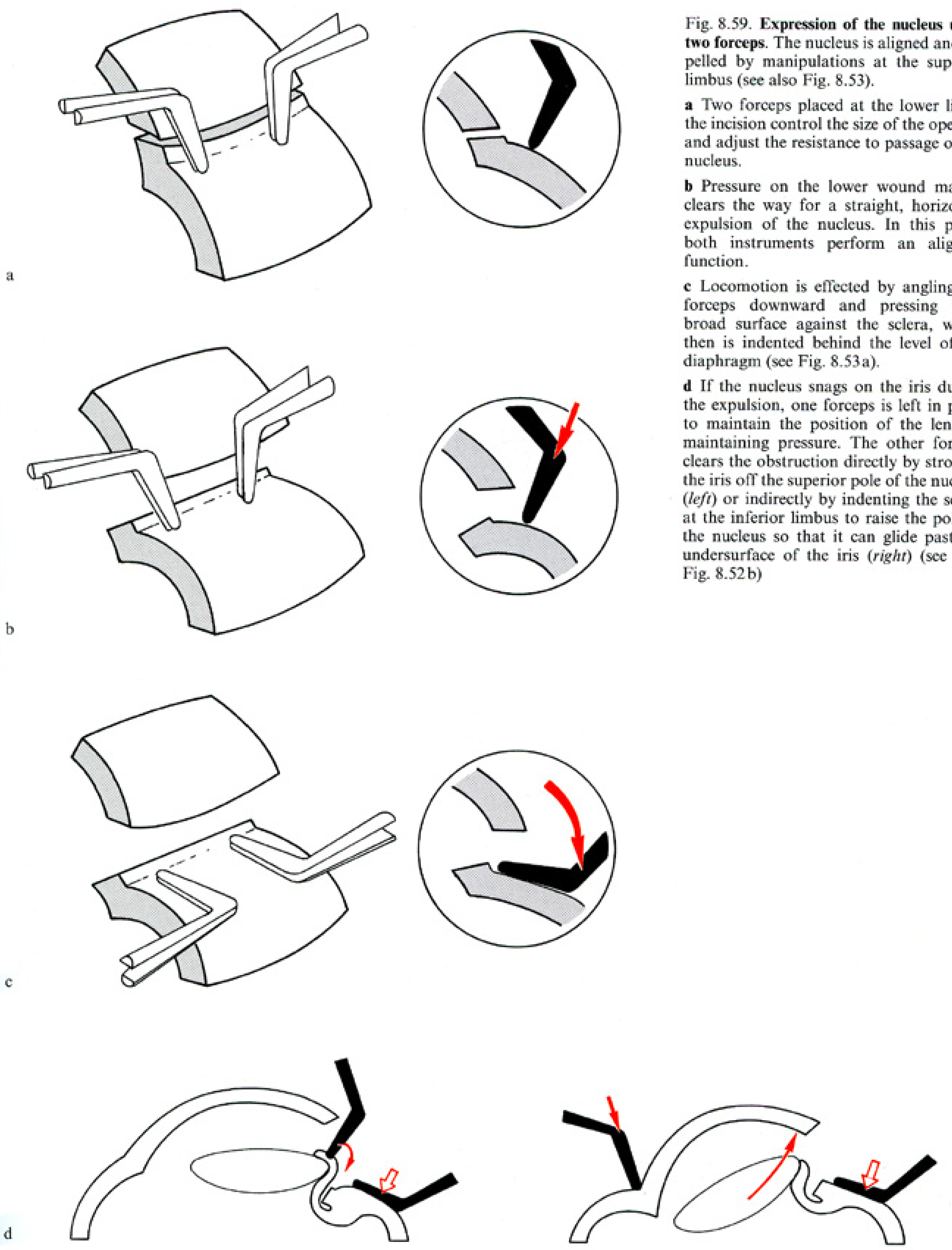


Fig. 8.59. **Expression of the nucleus using two forceps.** The nucleus is aligned and expelled by manipulations at the superior limbus (see also Fig. 8.53).

a Two forceps placed at the lower lip of the incision control the size of the opening and adjust the resistance to passage of the nucleus.

b Pressure on the lower wound margin clears the way for a straight, horizontal expulsion of the nucleus. In this phase both instruments perform an aligning function.

c Locomotion is effected by angling the forceps downward and pressing their broad surface against the sclera, which then is indented behind the level of the diaphragm (see Fig. 8.53a).

d If the nucleus snags on the iris during the expulsion, one forceps is left in place to maintain the position of the lens by maintaining pressure. The other forceps clears the obstruction directly by stroking the iris off the superior pole of the nucleus (*left*) or indirectly by indenting the sclera at the inferior limbus to raise the pole of the nucleus so that it can glide past the undersurface of the iris (*right*) (see also Fig. 8.52b)

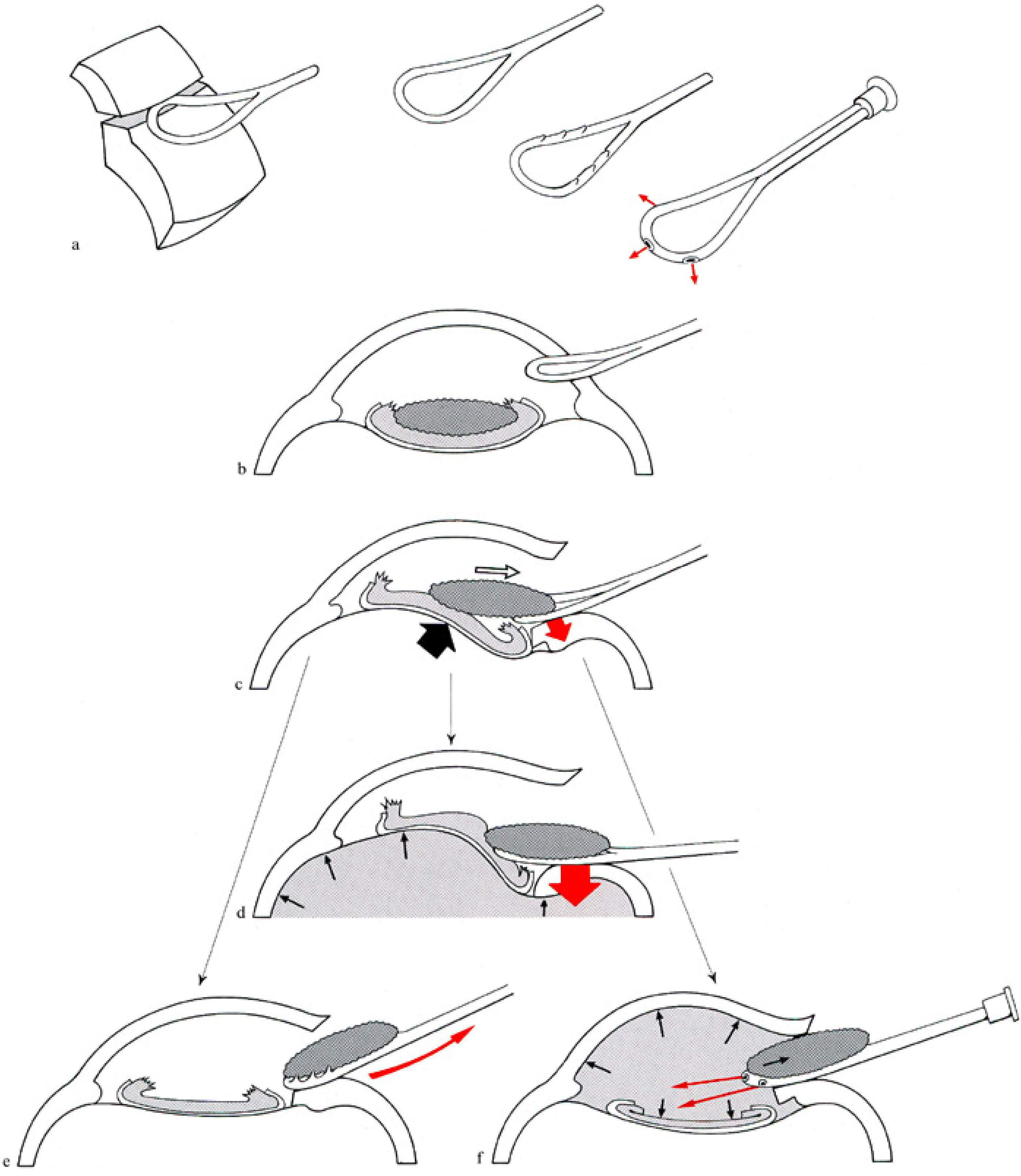

a
b
c
d
e
f

Fig. 8.60. **Combined expression and extraction techniques (with a lens loop)**

a Different types of loop serve different functions: *Left*: Smooth loop as a glide for a nucleus delivered by expression; *Center*: Serrated loop with back-angled teeth for extraction; *Right*: Irrigating loop for expulsion.

b, c The initial phase of the maneuver is the same for all three instruments: The nucleus is expressed until its upper pole engages against the loop.

b Insertion of the loop into the eye. The front end of the loop is inserted so that it does not block upward motion of the superior pole of the nucleus.

c The lower lip of the incision is depressed with the loop to initiate the expression. The superior pole of the nucleus glides onto the loop, which serves both an aligning and a locomotive function (analogous to the forceps in Fig. 8.59c).

d–f Further locomotion differs for each type of loop.

d Pure expression. Further depression of the smooth loop elevates the diaphragm and expels the nucleus onto the loop, which acts as a glide to prevent entanglement of the nucleus in the iris and corneal ledge.

e Extraction. The nucleus is expressed until the teeth of the serrated loop can engage its posterior surface. The loop is then withdrawn, extracting the nucleus.

f Expulsion. The irrigating loop is immobile and maintains depression of the wound margin, while fluid is injected to raise the pressure in the anterior chamber and expel the nucleus. *Note*: If expulsion is done through a small capsulotomy (as in Fig. 8.57a), the capsular bag will function as the expelling pressure chamber. Because the volume of the bag is small and the resistance at the capsulotomy is relatively high, the volume and pressure of the injection required for expulsion are smaller than with a large capsule opening (as in Fig. 8.57b)

8.3.3 Phacoemulsification

In phacoemulsification the substance of the lens nucleus is broken up into very small particles and removed by aspiration. A phacoemulsifying instrument must perform three functions (Fig. 8.61a): fragmentation of the material (*ultrasonic vibration*), removal of the material (*aspiration*), and replacement of the aspirated volume (*infusion*).

Because of the heat generated by the ultrasonic vibrator, the instrument tip is cooled by a fluid stream. This **cooling stream** must continue to flow even when the aspiration port is obstructed and outflow through the aspirating system stops.[36] An uninterrupted flow therefore requires a reliable *outlet* that is independent of the aspiration. A deliberate "leak" formed at the site of insertion of the phacoemulsifier may serve this purpose. Such a communication with the outside may depressurize the anterior chamber (see Fig. 1.5c) and there is a danger of chamber collapse unless the cross-section of the outlet is precisely matched to the available infusion capacity. Spacetactical *safety control* requires close monitoring of the position of the emulsifier at this opening in order to keep its cross-section constant during all maneuvers (see Fig. 1.14).

Cooling requirements at the site of action demand that the fluid be infused as *close* to the ultrasonic tip as possible. Consequently the cross-section of the emulsifier is enlarged just behind the tip by the extra cross-section of the infusion line. The trailing part of the instrument is correspondingly thicker than the channel cut into the substance of the nucleus, and the depth of penetration is limited by the distance of the infusion sleeve from the tip (Fig. 8.61).

If the nuclear material is to be emulsified effectively, it must not be pushed aside by the vibrating tip, i.e., it must be affixed to the tip. There are **two basic methods** of accomplishing this fixation: by inertia of the nucleus (with *aspiration in flow*) and by suction (with *aspiration by occlusion*) (see Fig. 2.26).

[36] In a controlled-flow system, infusion ceases when the aspirating port is obstructed. Unplanned occlusion during aspiration means the loss of cooling capacity. The danger of tissue overheating during ultrasonic vibration, and thus the cooling requirements, depend on the power of the vibrations.

back to index

Emulsification by Aspiration in Flow

In this method the aspiration port remains open throughout the emulsification (Fig. 8.63). The vibrating tip is moved along the nucleus, the direction of this movement determining the direction in which the emulsification proceeds (Fig. 8.65b). The nucleus remains stationary.

The *immobility of the nucleus* is an inertial effect based on the mass of the nuclear material (Fig. 8.65a). But this mass dwindles as the emulsification proceeds. To maintain effective emulsification during the entire procedure, the immobility of the nucleus must be reinforced by friction. This friction either may be produced by the anatomic connections between the nucleus and cortex, which should be left intact for as long as possible (avoiding preliminary nucleolysis), or it may be provided by fixation instruments (e.g., spatulas holding the nucleus in place).

Immobility of the lens nucleus is *the criterion for the control* of phacoemulsification in flow. The **power of the vibrations** should be high enough to provide efficient emulsification but low enough to avoid shaking the entire nucleus. Due to concomitant movements of the nucleus, excessive vibration will not improve efficacy and may cause undesired transmission of motion to surrounding tissues. Therefore as the *mass of the nucleus decreases*, the power of the vibrations should be reduced.

The immobility criterion also influences the **speed of the guidance motion**. Moving the tip too rapidly will merely displace the nucleus without improving the efficacy of the emulsification.

The **shape of the instrument tip** for aspiration in flow is not a critical factor during application of the tip to the nucleus. For the subsequent emulsification phase, however, a pointed tip has the advantage of aiding visual monitoring and preventing unintentional occlusion (Fig. 8.62). Additionally, a pointed tip can conform geometrically to narrow spaces and poses less danger when used close to adjacent tissues.

The **position of the sleeve,** i.e., its distance from the vibrator tip, limits the application angle of the instrument to the nucleus. If the tip is directed at too flat an angle, the sleeve will engage against the nucleus and push it away from the vibrating tip (Fig. 8.66c).

In terms of **spatial tactics**, a fluid stream must flow throughout the emulsification in flow. The *pressure level* in the anterior chamber, as determined by the flowthrough parameters (see Fig. 2.26b), lies between the initial and terminal pressures. The *pressure difference* between the chamber and aspiration port is very small (Fig. 8.66d). Since the fluid flow is continuous, adequate tip cooling does not rely on a special outflow path for the cooling fluid (Fig. 8.66e, Fig. 8.67).

The use of an *open aspiration port* involves risks: emulsified particles may be projected at high velocity toward adjacent tissue surfaces (Fig. 8.65c),[37] and mobile surrounding tissues may be inadvertently aspirated (Fig. 8.65d). Thus, successful emulsification by aspiration in flow requires that a *safe distance* be maintained with respect to neighboring tissues.

Emulsification by Occlusion

In emulsification by occlusion, the instrument tip is applied to the nucleus in a way that occludes the aspiration port. *Control* aims at maintaining this occlusion throughout the emulsification (Fig. 8.64). The **shape of the tip** is critical, for it should conform to the surface of the nucleus to be emulsified (see Fig. 8.66a). Otherwise there will either be no occlusion if the nucleus is immobile, or a mobile nucleus will abruptly change its orientation in an unpredictable way and damage adjacent tissues. However, if the nuclear geometry is unfavorable, the ultrasonic vibrator can be used to create **occludability**, i.e., to cut the site of application (in an initial burst of aspiration in flow) to a suitable shape that will permit occlusion without reorientation of the nucleus (Fig. 8.64b).

Once occlusion has been established, suction plays the predominant role. The procedure of emulsification by occlusion is basically an aspiration in which ultrasonic vibration merely serves the adjunctive purpose of creating or maintaining the occlusion. The *tip* can be held *stationary* and the emulsification allowed to proceed by *motion of the nucleus*. This is an important safety factor, for it avoids any motion vectors directed toward surrounding tissues (Fig. 8.65b). *Occlusion of the tip opening* also prevents inadvertent aspiration of adjacent tissues and the projection of emulsified lens particles toward delicate structures (Fig. 8.65c, d).

In terms of **spatial tactics**, the situation is stable due to the absence of an aspirating stream

[37] Delicate tissues like the corneal endothelium can be protected from particle bombardment by surface-tactical measures (e.g., protective coating of viscous or viscoelastic material).

back to index

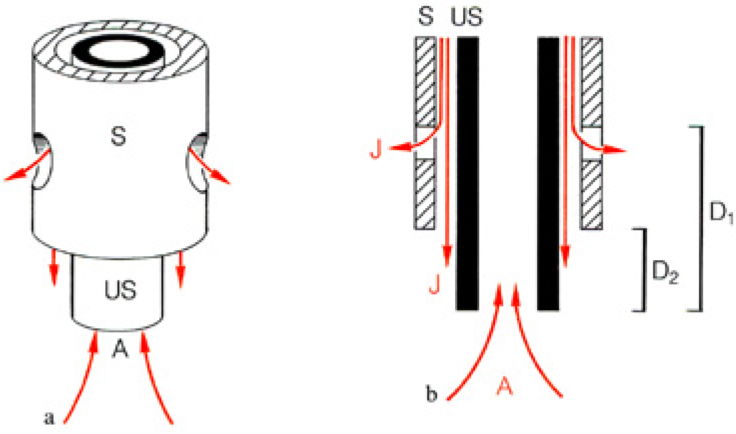


Fig. 8.61. **Design of a phacoemulsifier with infusion and aspiration**

a The central tube serves as the aspiration channel (*A*) and as the ultrasonic tip (*US*). It is surrounded by a sleeve (*S*) through which fluid is infused. Its front opening serves mainly to cool the vibrating tip, while the side openings add volume for space-tactical stabilization. If one of the openings becomes obstructed by tissue, the other will ensure maintenance of the infusion.

b The distance of the infusion ports (*J*) from the vibrating tip (D_1) determines how far the instrument can be withdrawn from the chamber without compromising its spatial stabilization (i.e., the minimum distance from the access opening at which emulsification can still be performed). The distance D_2 between the end of the infusion sleeve and the tip determines how far the instrument can penetrate into the hole cut by the tip (i.e., the maximum penetration depth into the tissue)

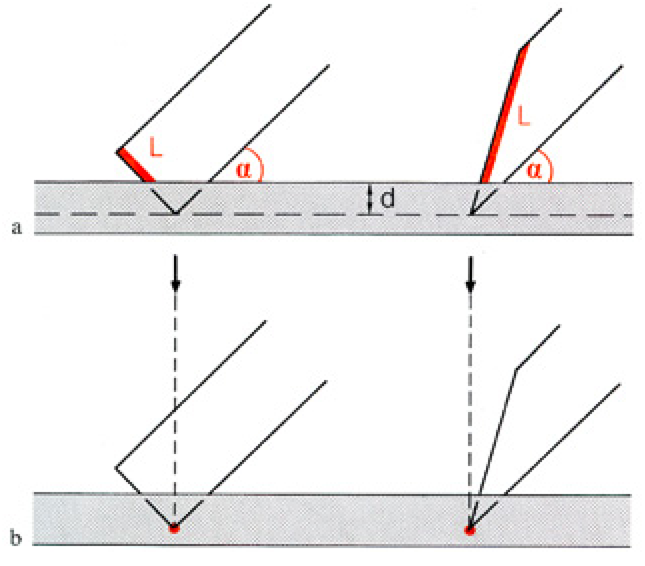


Fig. 8.62. **Shape of the instrument tip**

a A blunt tip applied at a given angle (α) and given depth of penetration (*d*) experiences greater luminal obstruction (*L*) than a sharply beveled tip. Thus, it is easier to establish occlusion with a blunt tip (*left*), and easier to keep the aspiration port clear with a beveled tip (*right*).

b Visual monitoring of the working area: A blunt tip obscures vision of the tip opening and base of the tissue groove when viewed from above (*arrow*). A beveled tip facilitates visual observation

back to index

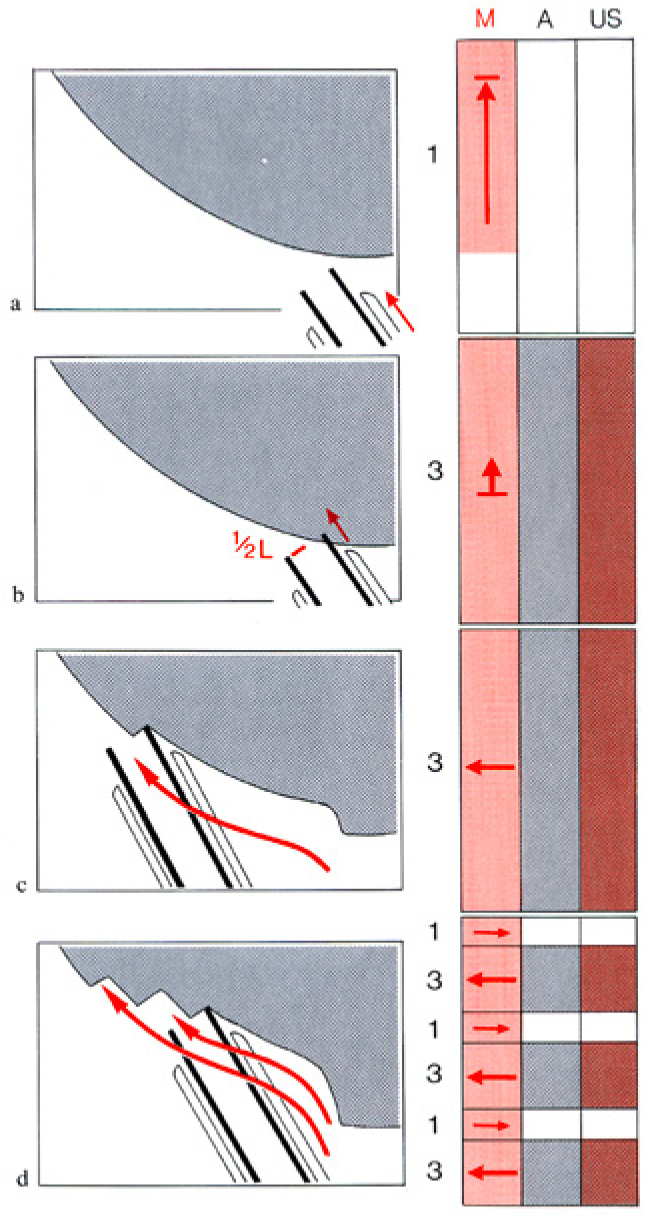


Fig. 8.63. **Phacoemulsification by aspiration in flow.**
Left: Sequence of steps in procedure; *right*: Instrument motions and switch positions during procedure; *M*: Guidance motions; *A*: Aspiration; *US*: Ultrasonic vibration; *numbers*: Positions of footswitch.[38]

a *Seeking the site of application*: The instrument tip is brought close to the site of election for beginning the emulsification but does not yet touch the nucleus. Monitoring at this stage aims at space-tactical stabilization and thus involves regulation of the infusion and the size of the outflow opening from the anterior chamber (see Fig. 1.4). Aspiration and vibration are not activated. The site of contact with the nucleus is chosen so that the tip can be applied without becoming occluded.

b *Engagement*. The tip is applied to the nucleus while *A* and *US* are simultaneously activated. The tip begins to cut a groove into the substance of the nucleus. *Note*: At least half the lumen (*1/2 L*) should remain clear to avoid occlusion.

c *Peeling*. The tip is guided over the nucleus, moving parallel to its surface (i.e., at a constant tissue depth). The progress of the emulsification is determined entirely by the direction in which the tip is moved. The direction in which the opening faces is of no significance, aside from the stipulation that approximately half the lumen remains clear. *Note*: *A* and *US* must always be activated while the moving tip is in contact with the nucleus; otherwise the tip will displace the nucleus without cutting it. Conversely, *A* and *US* should not be activated unless the tip is moving, since this will have no peeling effect and will increase the risk of unplanned occlusion.

d *Deepening the emulsification*. The tip is lifted away from the nucleus (*A* and *US* turned off!) and moved back before repeating the scaling maneuver. The end of the excavation is "terraced" to reduce the risk of unintended occlusion.

Note: In phacoemulsification in flow only footswitch positions *1* and *3* are used

[38] In most current systems position 1 is infusion only, position 2 is infusion plus aspiration, and position 3 is infusion, aspiration, and ultrasonic vibration.

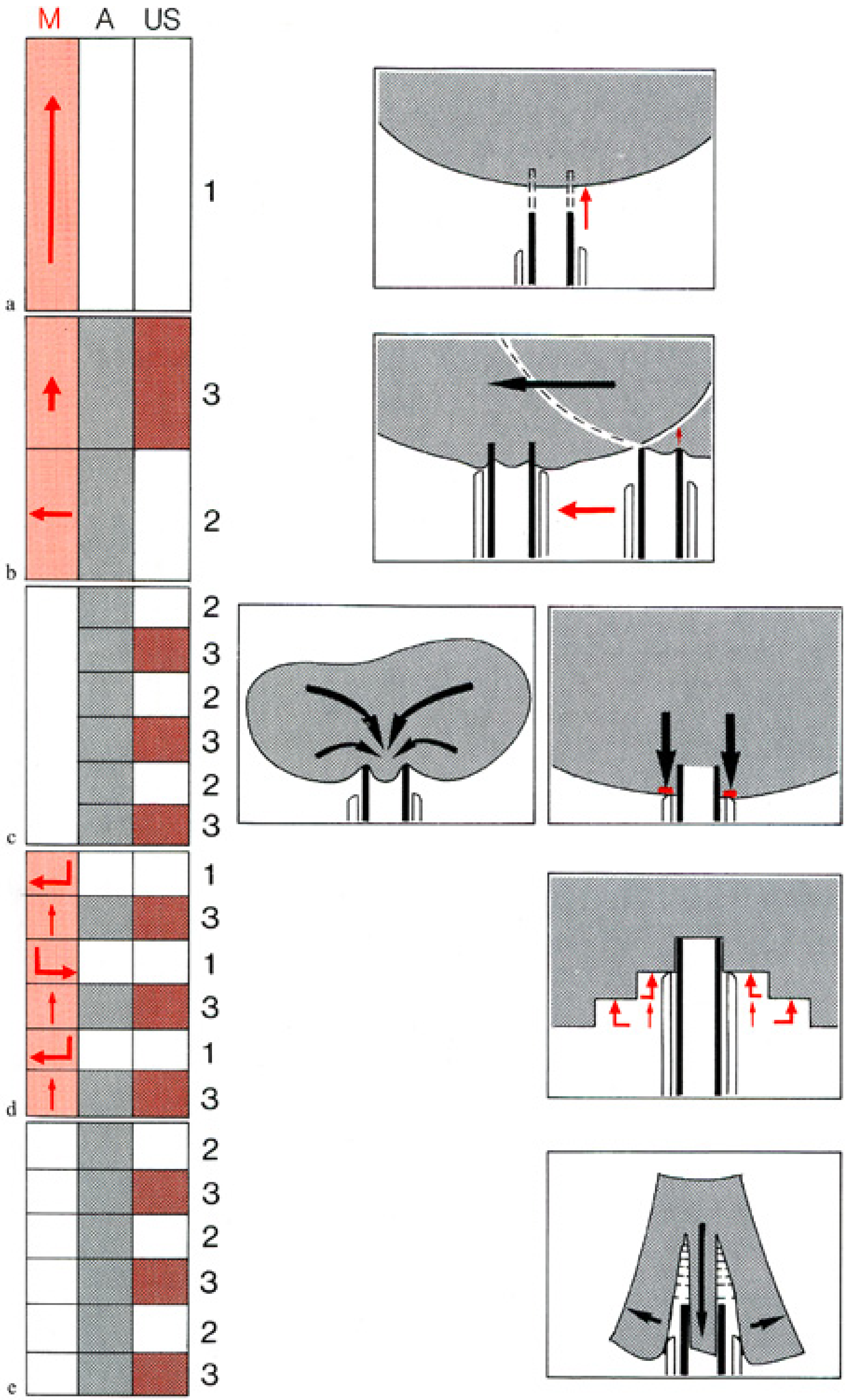


Fig. 8.64. **Phacoemulsification with aspiration by occlusion**. *Left*: Instrument motions and switch positions. *Right*: Sequence of steps in procedure.

a *Seeking occlusion*: The instrument tip is moved into position with *A* and *US* switched off (footswitch position *1*). A site is selected on the nuclear surface where occlusion can be established as soon as the tip is applied.

b *Engagement*. If the nucleus cannot be engaged right away, occludability must be established by a short burst of emulsification in flow. The instrument with the affixed nucleus is then shifted into a region where there is adequate clearance to proceed with emulsification by occlusion (*left*). Only aspiration is switched on during this maneuver to keep the nucleus adherent to the tip (footswitch position *2*).

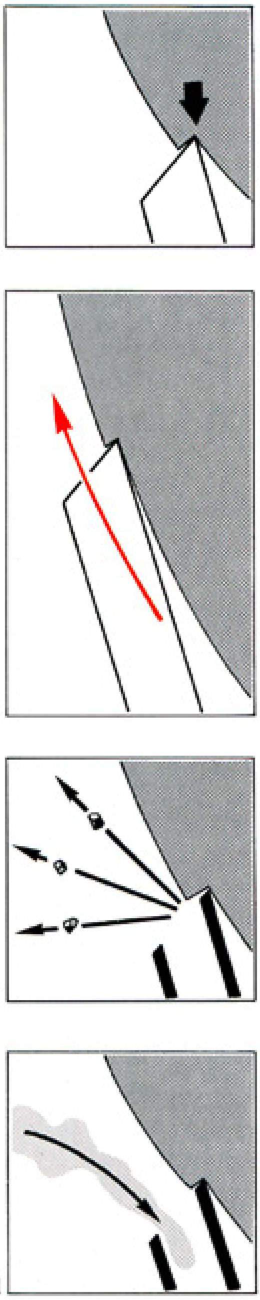
c *Emulsification*. The instrument is held stationary while aspiration is activated and assisted by short bursts of vibration. If its substance is deformable, the entire nucleus can be emulsified in this way (*left*). If the material is nondeformable, motion of the nucleus toward the tip opening will be checked by the sleeve (*right*).

d *Continuing the emulsification* of nondeformable material. The tip is moved back (with *A* and *US* switched off) and reapplied at an adjacent site so that the excavation is progressively deepened.

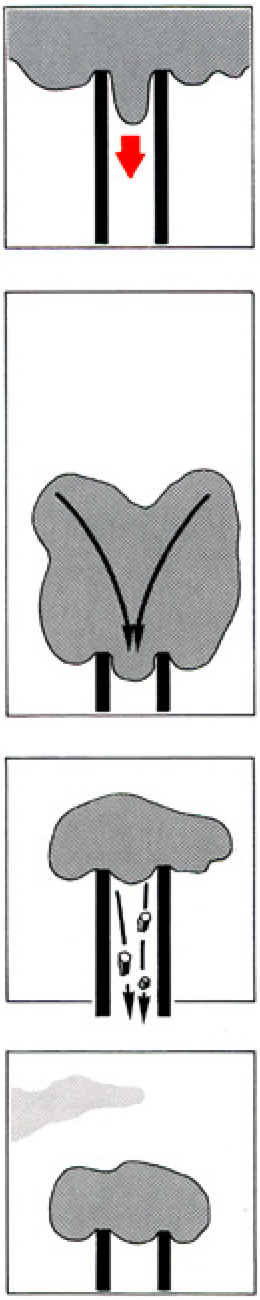
e *End of the emulsification*. When the particle has become so small that its sides begin to separate ahead of the sleeve, the emulsification can be completed using the technique for deformable material (**c**, *left*).

Note: In phacoemulsification by occlusion footswitch position *2* plays an important role

back to index



a b c d

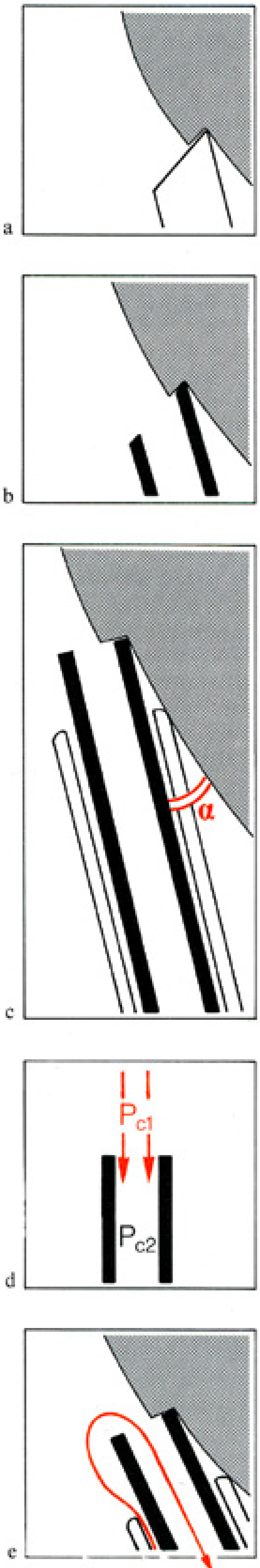


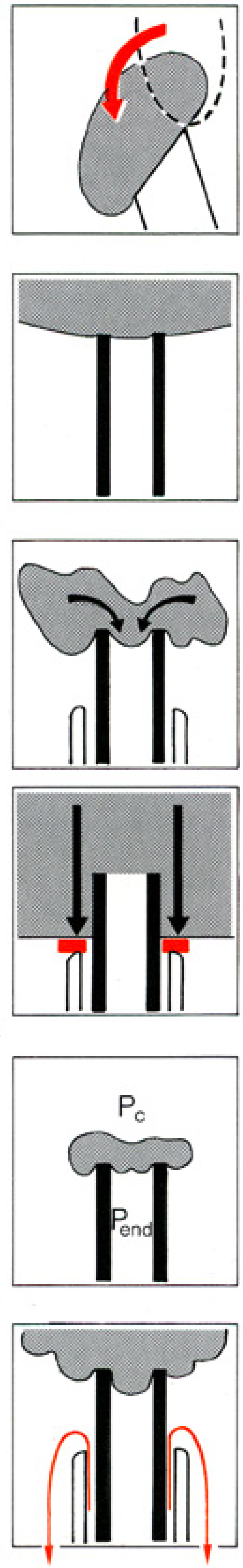
Aspiration in flow		Aspiration of occlusion
by the inertia of the material	*Fixation* of the material before the cutting edge	by suction
by movement of the tip (nucleus immobile)	*Force vectors of motions* Progression of the emulsification process	by movement of the nucleus (tip immobile)
toward environment	Direction of motion vectors	toward tip
yes	Danger of transmitting motion to environment?	no
yes	*Side-effects* Danger of damage from projected particles?	no
yes	Danger of inadvertent aspiration of adjacent tissue?	no

Fig. 8.65. **Comparison of the two basic methods of phacoemulsification**: Mode of operation

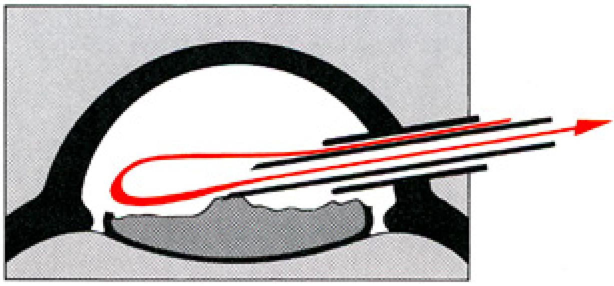
Fig. 8.66. **Comparison of the two basic methods of phacoemulsification**: Aspects of instrument design

Aspiration in flow		Aspiration by occlusion
	Shape of tip	
not critical	On engagement of the nucleus	critical: reorientation of nucleus on occlusion (see Fig. 2.28)
beveled: favors nonocclusion	Tendency to become occluded (see Fig. 8.62)	blunt favors occlusion
	Position of sleeve	
limits angle of instrument application		with deformable nucleus: not critical with nondeformable nucleus: critical (limits depth of penetration)
	Chamber pressure	
P_c between P_{start} and P_{end}	Pressure level in chamber (P_c)	P_a between P_{start} and P_{atm} (depends on size of outlet for cooling stream)
minimal	Pressure difference between chamber and aspiration lumen	maximal
	Cooling stream	
through aspiration port	outflow	through separate outlet from the chamber

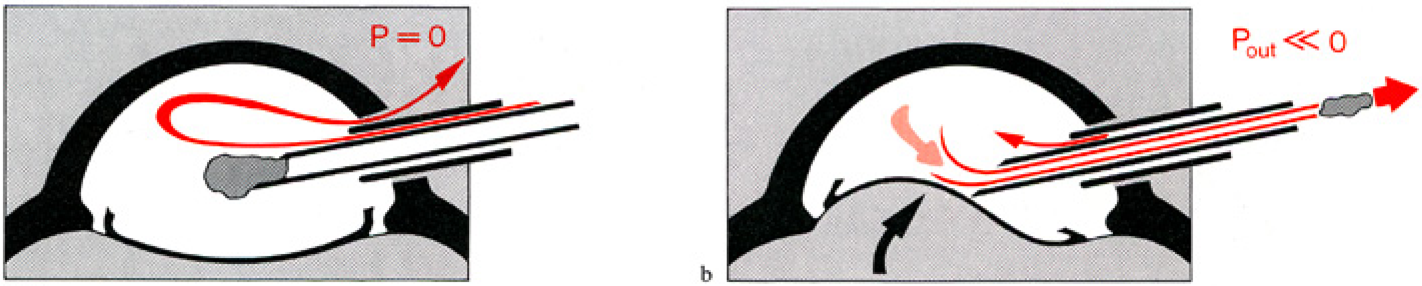




8.66

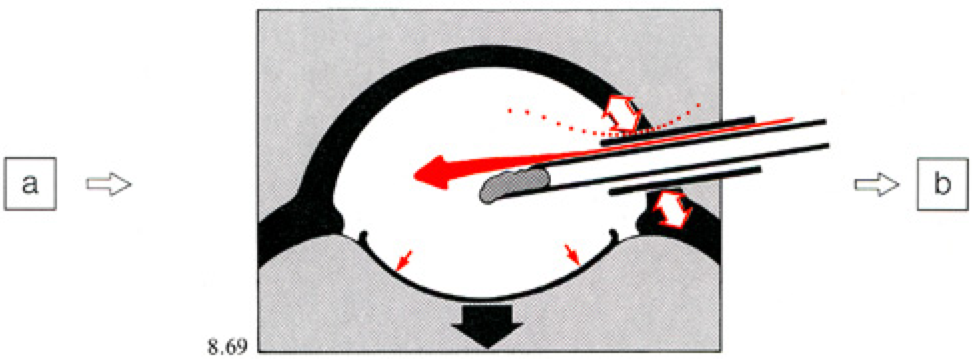


8.67



a b

8.68



8.69

Fig. 8.67. **Spatial tactics for phacoemulsification in flow:** A continuous stream of the cooling fluid is maintained through the open aspiration cannula. There is no need for an accessory outlet. Therefore, the access opening can remain watertight during emulsification.

Fig. 8.68. **Spatial tactics in phacoemulsification by occlusion**

a During occlusion the cooling flow is maintained through an accessory outlet, (e.g., a leaking access opening).

b As the occluding particle has passed through the aspiration cannula, the occlusion ceases. The chamber is suddenly exposed to the strong suction (outflow pressure below zero), and a large fluid volume will abruptly escape. As the chamber collapses, tissue from the vicinity may move into the range of the emulsifying tip

Fig. 8.69. **Space tactical safety precautions prior to cessation of the occlusion**

At the transition from stage **a** to stage **b** (in Fig. 8.68) a "control stop" is interposed to secure maximal chamber volume: Emulsification and aspiration are interrupted but infusion is maintained. The outflow through the auxiliary outlet is minimized by correcting movements of the emulsifier at the entrance opening (*red arrow*; see Fig. 1.14). Only when the chamber has attained maximum depth (i.e., the position of the lens capsule has been brought back as far as possible) emulsification is activated again for the final removal of the occluding particle

back to index

(Fig. 8.66d). The *pressure* in the chamber depends on the size of the additional cooling fluid outlet. If the outlet is sealed off, the chamber pressure equals the initial pressure (see Figs. 1.4a and 2.26a); if it is widely open, the pressure equals atmospheric (see Fig. 1.6a). But in contrast to aspiration in flow, the pressure cannot fall below atmospheric, so there is less danger of chamber collapse (Fig. 8.68a).[39]

The characteristics of both emulsification techniques are summarized in Figs. 8.63 and 8.64. It is apparent that the *control criteria* for each of the techniques are different and are even opposite in many respects. This accounts for the difficulties to be anticipated when emulsification in flow inadvertently changes to emulsification by occlusion; or vice-versa, during the operation.

Thus, the most essential control aspect of phacoemulsification is to maintain the technique that has been selected. If a *change to the other technique* is indicated, the change must be carefully planned; it is imperative that unplanned changes be avoided.

Problems in Changing the Emulsifying Technique

What are the risks associated with an unplanned change from **aspiration in flow to aspiration by occlusion**? First, the nucleus may abruptly change its orientation the moment *occlusion* is established (see Fig. 8.66a), posing a threat to surrounding tissues.[40] Second, the nucleus as a whole may be displaced if the surgeon continues to *move* the instrument (i.e., perform guidance motions) after occlusion has been established. Finally, there is a danger of *overheating* if the additional coolant outlet (which need not be open during aspiration in flow) is not functioning properly once occlusion is established.[41] If unplanned occlusion should occur despite precautions, the surgeon must discontinue any guidance motions at once and switch off the vibration until the situation is again under control.

Unplanned occlusion must be anticipated when the nucleus has become increasingly mobile during emulsification in flow so that it may be drawn abruptly against the aspiration port. Thus, *immobility of the nucleus* must be ensured during emulsification in flow until the surgeon elects a *planned* change to aspiration by occlusion.

The reverse process, an unplanned change from **aspiration by occlusion to aspiration in flow**, has even more serious consequences. The sudden release of the aspiration port creates a massive pressure differential (see Fig. 2.26a) leading to a precipitous pressure drop in the anterior chamber. Chamber collapse may ensue (Fig. 8.68b), and adjacent tissues may be inadvertently aspirated and damaged if the instrument tip is still vibrating at that moment.

But change to aspiration in flow is an inevitable part of any ordinary emulsification by occlusion, representing the *final phase* after the material in front of the tip has vanished.

During the emulsification, loss of occlusion occurs if the vibrating frequency is too high, for then the occluding portion of the nucleus will be abruptly excised and aspirated. If at this point other nuclear material is within reach of the suction, emulsification may proceed. But if adjoining tissue is within the range of the tip, it becomes exposed to the effect of the powerful suction.

[39] Note: This is true only while the occlusion is intact. Loss of occlusion constitutes aspiration in flow!

[40] Special care must be taken to prevent unintended reorientation of the nucleus when emulsification has sculpted a sharp edge into hard nuclear material.

[41] E.g., if the instrument is held obliquely (as in Fig. 1.14e).

back to index

The basic **safety strategy** for aspiration by occlusion, then, is to allow for the *possibility of a sudden loss of occlusion* in each phase of the procedure and forestall its consequences. On the one hand this implies reducing the pressure differential upon loss of occlusion; on the other, providing an adequate safety zone in front of the tip. A low *pressure differential* is obtained with the **short-burst technique**. Maintaining aspiration by occlusion for just a few seconds prevents buildup of high negative pressures. Thus, when occlusion is lost after a short emulsification burst, only a fraction of the force set at the suction pump will become active at the tip. Providing a *safety zone* means maintaining **ample clearance** from adjacent tissues. In this respect aspiration by occlusion requires larger clearances than aspiration in flow. This may seem paradoxical, because occlusion actually protects surrounding structures. However, the safety clearances must provide for an abrupt loss of occlusion, at which point the pressure differential is greater than in aspiration in flow.

Special safety precautions are taken in the final phase of the emulsification, just before occlusion is terminated: Vibration and aspiration are switched off while the infusion is continued. The space-tactical context is checked and optimized, and a *maximum anterior chamber depth* is established by adjusting the position of the instrument at the access opening in order to improve the seal (see Fig. 8.69). Only then the emulsification is completed using short bursts so that both the aspiration and vibration can be switched off immediately upon termination of the occlusion.

Criteria for Selection of the Emulsification Technique

The **indication for emulsification in flow versus emulsification by occlusion** depends on the quality of the lens nucleus and its mobility.

With regard to *emulsifiability*, we can distinguish between compliant nuclear matter that is easily penetrated by the instrument and firm, noncompliant nuclear matter that blocks entry of the sleeve (Fig. 8.64c). Basically, emulsification by occlusion is more appropriate for *deformable* matter, while emulsification in flow is better suited for *nondeformable* matter.

A no less important criterion is the *mobility of the nuclear material.* Only immobile material, whether deformable or nondeformable, can be emulsified in flow, whereas mobile material inevitably will appose to the suction tip and therefore is emulsified by occlusion. This means that both an ideal and an unfavorable emulsification condition exists for deformable and nondeformable nuclei. These conditions cannot be freely chosen but depend on the *anatomic setting* in which the emulsification is carried out: When the phacoemulsification is performed in the anterior chamber, the nucleus has been dislocated from its original position and hence is freely movable within the chamber. When the nucleus is emulsified in situ ("in the posterior chamber"), the anatomic connections between the nucleus and cortex may have remained intact, and the nucleus is immobile. It follows, then, that optimum conditions prevail when deformable matter is emulsified in the anterior chamber, and nondeformable matter is emulsified in the posterior chamber (Fig. 8.70, *red arrows*).

These optimum conditions cannot always be achieved in practice. It can be difficult to mobilize a deformable nucleus and dislocate it into the anterior chamber, because the soft matter is difficult to separate from the cortex. Conversely, a nondeformable nucleus cannot always be kept immobile in the posterior chamber, because it must be mobilized and displaced as the emulsification proceeds in order to present it optimally to the tip. Hence there is no way to avoid working at least temporarily under *suboptimal conditions.*

One suboptimal condition, for example, is the emulsification of *deformable material by aspiration in flow* (e.g., emulsification of a soft nucleus in the posterior chamber). Here occlusion can be prevented by extremely superficial peeling so that only the wall of the tube attacks the nucleus while the lumen remains entirely clear. The nucleus may be held immobile with a spatula.

Another suboptimal condition is the *emulsification by occlusion of nondeformable matter* (e.g., the emulsification of hard nuclear matter in the anterior chamber). Here the technique must allow for the blocking action of the sleeve (Fig. 8.64c), so the emulsification is carried out in small steps that progressively deepen the excavation (Fig. 8.64d). If the noncompliant matter becomes incarcerated at the tip, there are two ways to loosen it again: Short, high-frequency bursts of the vibrator can repel it effectively, but they are safe only if the incarcerated material has sufficient mass to check the recoil. With a small particle it is better to use short bursts of low-frequency vibration to loosen the material and to push it back with a spatula.

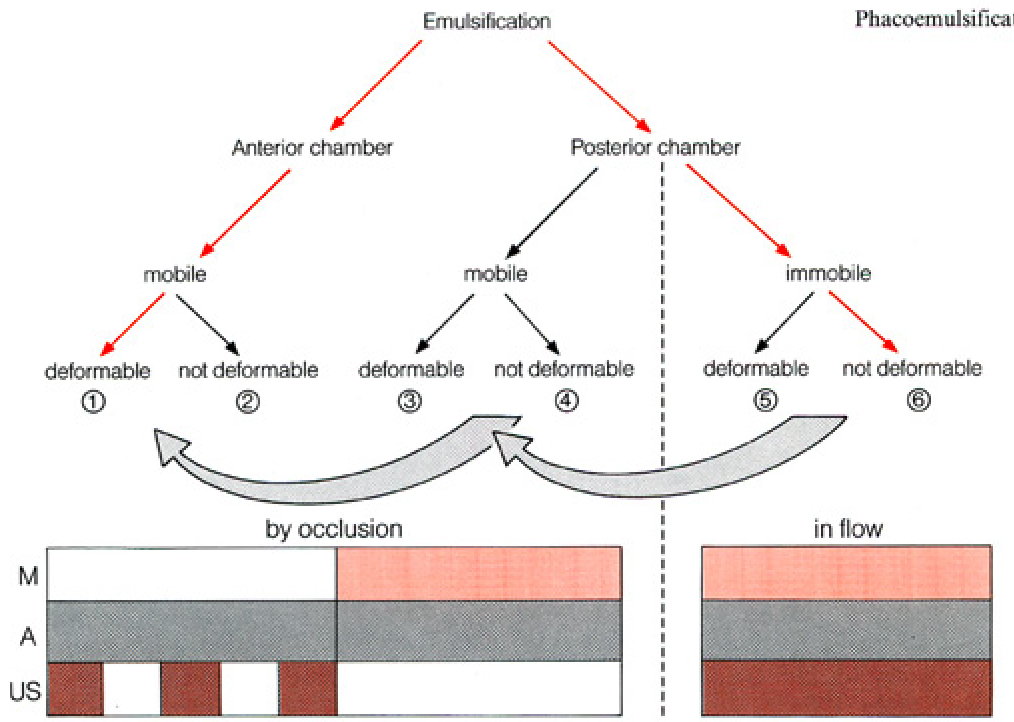


Fig. 8.70. **Decision-making criteria for selecting the emulsification technique**. When emulsification is performed in the posterior chamber, the nucleus is immobile, at least initially. Therefore it is emulsified in flow. This procedure is accomplished most successfully in nondeformable material (*6*), while with deformable matter (*5*) there is a danger of unintended occlusion. If the nucleus has become mobile while in the posterior chamber (*3*, *4*), it may either be immobilized there with a spatula, or it may be dislocated forward into the anterior chamber (using aspiration only). Once inside the anterior chamber, the nucleus is mobile. Since it is emulsified there by occlusion, emulsification in the anterior chamber is ideal for deformable nuclei (*1*) but is suboptimal for nondeformable nuclei (*2*). The *red arrows* indicate the optimum emulsification conditions. The *gray arrows* indicate the sequence of steps for a nucleus in the posterior chamber: an immobile nucleus is mobilized and then dislocated into the anterior chamber. First the nucleus is emulsified in flow, and once mobilized it is emulsified by occlusion

Table 8.2. **Comparison between planned and unplanned transitions from emulsification in flow (E.i.F.) to emulsification by occlusion (E.b.O.), resp. from E.b.O. to E.i.F.**

E.i.F. → E.b.O.		E.b.O. → E.i.F.	
planned start of E.b.O.	unplanned transition	planned end of E.b.O.	unplanned transition
1. *Establish foldability* – remove all hard material ↓	Wrong *moment*: hard material still present	1. *Provide large reserve space* – deepen anterior chamber (see Fig. 8.69) ↓	Wrong *moment*: without sufficient chamber volume
2. *Establish occludability* – align bevel of tip to contour of nucleus (see Fig. 2.28a+d) – cut material into occluding shape (see Fig. 8.64b) ↓	Wrong *way*: bevel not properly aligned (see Fig. 2.28b+c)	2. *Keep bevel away from vulnerable tissue* – stay in safety zone for E.b.O. ↓	Wrong *place*: beyond safety zone for E.b.O.
3. *Proceed to E.b.O.* – transfer material to safety zone for E.b.O. (see Fig. 8.73b) – stay put and cut	Wrong *place*: orifice of tip beyond safety zone	3. *Avoid high pressure difference* – use short burst technique	Wrong *way*: long bursts of ultrasound

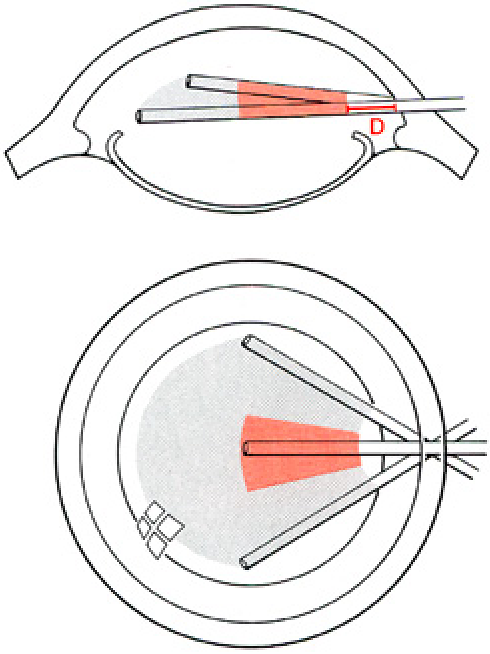


Fig. 8.71. **Topographic criteria for the use of phacoemulsification: Safety zones in the anterior chamber.** *Gray zone*: Safety zone for aspiration alone; *pink zone*: Safety zone for vibration and aspiration combined.
The nucleus is mobile in the anterior chamber and is emulsified by occlusion. The safety margins must be large enough to ensure that a sudden loss of occlusion will not damage nearby tissues. Aspiration alone poses relatively little risk of damage, so the safety zone is large. Ultrasonic vibration, on the other hand, requires large clearances: The safety zone does not extend past the center of the pupil. Very little deviation upward or downward from the horizontal can be tolerated due to the respective dangers posed to the corneal endothelium and iris. Lateral mobility during vibration is limited to ensure that the outlet for the cooling fluid is not obstructed (see Fig. 1.14e). The minimum distance from the access opening (*D*) at which emulsification can be performed depends on the position of the openings in the sleeve (see Fig. 8.61)

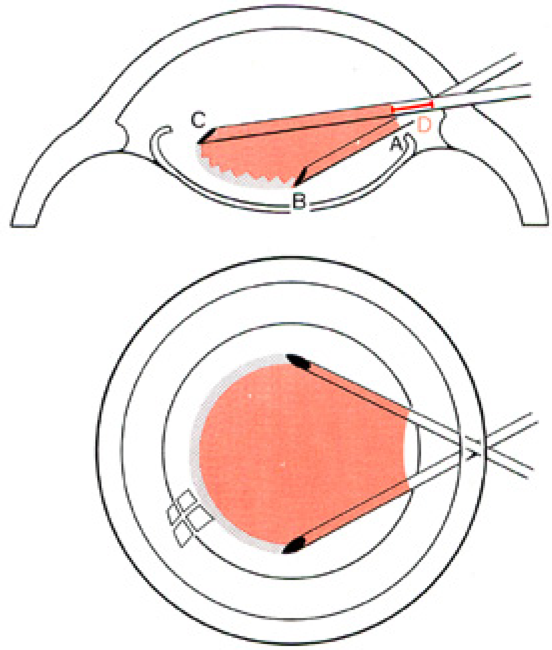


Fig. 8.72. **Topographic criteria for the use of phacoemulsification: Safety zone in the posterior chamber.** If the nucleus is immobile while in the posterior chamber, it is emulsified in flow. Since this method is not associated with abrupt pressure changes, the necessary clearances are small. Thus the safety zone is large and is practically the same for emulsification (*pink*) as for simple aspiration (*gray*). The start of the safety zone (*A*) and its deep boundary (*B*) are influenced by the location of the corneal incision, the end of the zone (*C*) by the pupil size. (*D*) as in Fig. 8.71

Basic Techniques of Phacoemulsification

In both the anterior and posterior chamber there is a **safety zone** whose boundaries are determined by the clearances that must be maintained with respect to surrounding tissues. As noted earlier, these *clearances* depend on the phacoemulsification technique, emulsification by occlusion requiring greater safety clearances than emulsification in flow. Thus, the safety zone for emulsification in the anterior chamber is quite small (Fig. 8.71). It is larger for emulsification in the posterior chamber, as long as the nucleus is sufficiently immobile for emulsification in flow (Fig. 8.72).

The basic rule is that phacoemulsification is performed *strictly within the safety zone* of the respective chamber (Fig. 8.73b). Nuclear material already within the safety zones is removed first, and then the remaining material is transposed into the safety zones before it is emulsified (Fig. 8.73c, d). Topographically, then, the procedure consists of four phases:

- emulsification within the safety zone for emulsification by aspiration in flow
- nucleolysis
- locomotion
- emulsification within the safety zone for emulsification by occlusion.

There are three basic techniques for phacoemulsification according to the way in which these steps are sequenced and combined:

1. Phacoemulsification in the anterior chamber (Fig. 8.74).
2. Phacoemulsification in both chambers (Fig. 8.75).
3. Phacoemulsification in the capsular bag (Fig. 8.76).

a

b

c

d

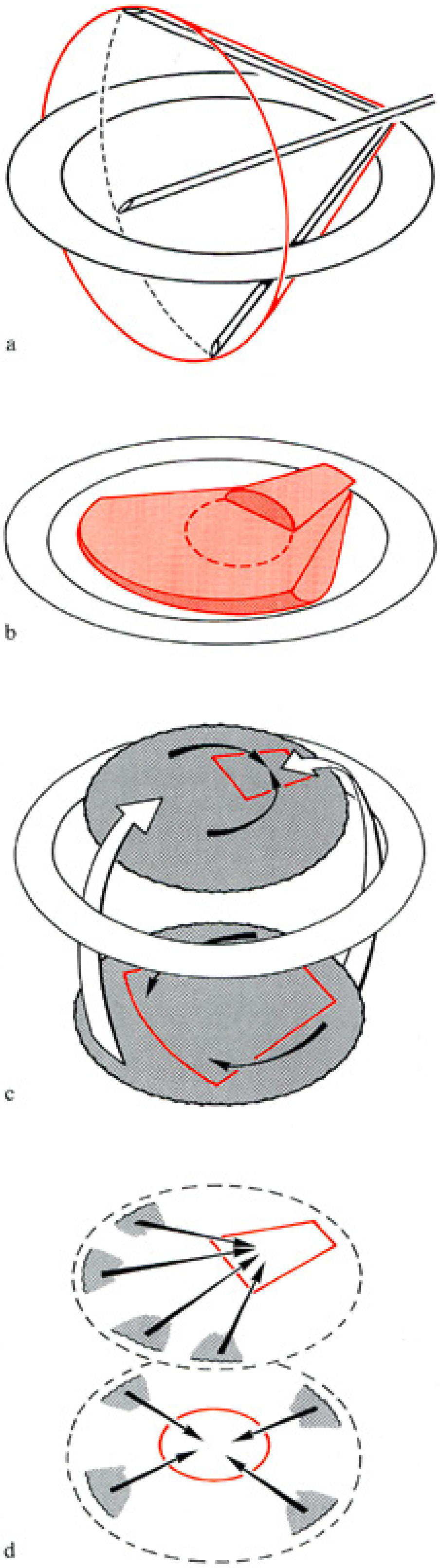


Fig. 8.73. **Basic maneuvers for phacoemulsification**

a Movements of the emulsifier: The theoretical range of action of the phacoemulsifier is a cone whose apex lies at the access opening.

b Safe regions for movements of the emulsifier. The practical range of action is limited by anatomic constraints (distance from surrounding tissues). There is a large difference, moreover, between the ranges of action in the anterior and posterior chambers since different emulsification techniques are used in each chamber. In the *anterior chamber*, emulsification is done by occlusion and the safety zone is small. In the *posterior chamber*, emulsification can be done in flow, so the safety zone is larger. Only a small fraction of this zone is safe for emulsification by occlusion (circular area at the center of the posterior chamber).

c Movements of the nucleus. To bring the material into the safety zone for emulsification in each chamber, the nucleus is rotated about its axis (*small arrows*). To bring it from the posterior into the anterior chamber, either the inferior or superior pole is elevated (*large arrows*).

d Movements of nuclear fragments. Small fragments are brought to the safety zones of emulsification by transposing them centripetally with aspiration by occlusion.
Above: Anterior chamber
Below: Posterior chamber

Practical Conduct of Phacoemulsification

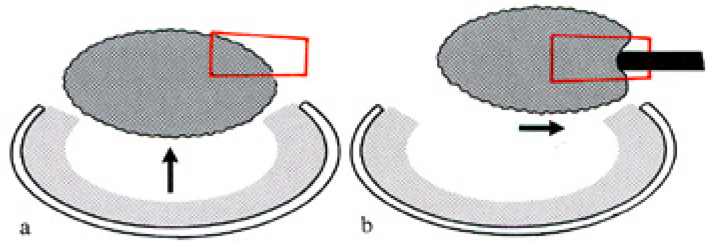
Insertion of the Emulsifier into the Anterior Chamber

During *insertion* of the instrument into the anterior chamber, the tip is held with its bevel facing downward so that it can glide smoothly along the iris surface. The sleeve is positioned so that its side openings face laterally to ensure that the openings will not snag the wound margins. This also avoids inadvertent fluid injection into corneal parenchyma which might impair transparency or dissect beneath Descemet's membrane.

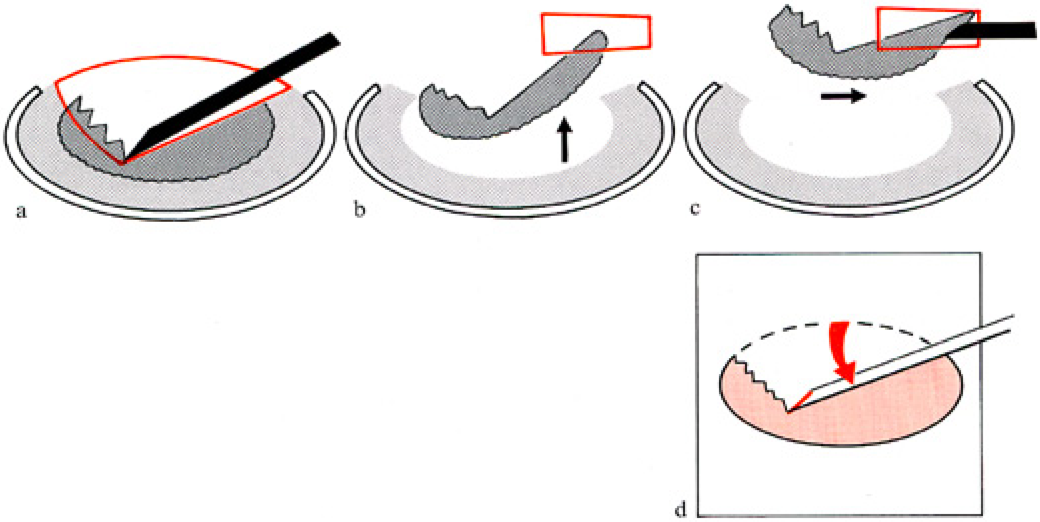
Following *entry* into the anterior chamber, a lateral position of the sleeve openings prevents tissue displacements that might occur if the openings were positioned vertically.[42] For reasons of spatial tactics, infusion is maintained continuously to compensate for outflow of the cooling stream. Note: In all manipulations with the emulsifier it is necessary to monitor not just the working tip but also its position at the access opening (Fig. 8.69), for that is where space-tactical safety is controlled.

[42] E.g., compensatory tissue shifts (iris prolapse, etc.) in case of a leaking access opening (see Fig. 2.25).

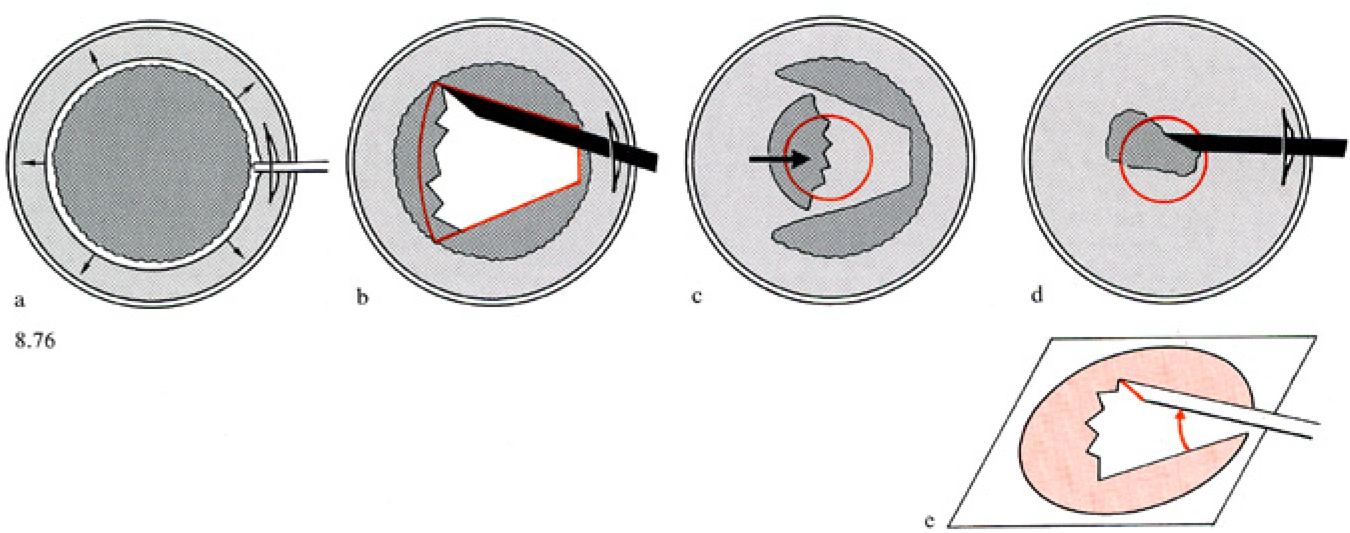
back to index



8.74 a b



8.75 a b c d



a b c d
8.76
e

back to index

Fig. 8.74. **Basic technique for emulsification in the anterior chamber**

a First step: The entire nucleus (peripheral shell and central core) is mobilized and transposed into the anterior chamber toward the safety zone for emulsification.

b Second step: The nucleus is emulsified with aspiration by occlusion within the safety zone of the anterior chamber

Fig. 8.75. **Basic technique for emulsification in both chambers**

a First step: The hard central core of the nucleus is emulsified within the safety zone for emulsification in flow.

b Second step: The softer shell is mobilized and transposed into the anterior chamber. The motion vectors have *vertical* components.

c Third step: The remaining nuclear material is emulsified by occlusion within the safety zone of the anterior chamber. All movements of the nucleus are *horizontal*.

d *Note*: Motion of the emulsifier from the empty space toward the tissue to be removed occurs on a *vertical* plane. The bevel of the tip directed toward the empty space faces *upward*

Fig. 8.76. **Basic technique for emulsification within the capsular bag**

a First step: Nucleolysis (by hydrodissection).

b Second step: Emulsification of the lens material within the safety zone for emulsification in flow (anterior cortex, anterior nuclear shell, and nuclear core).

c Third step: Transposition of the remaining nuclear shell into the safety zone for emulsification by occlusion at the center of the bag. Note: The vectors of this maneuver are strictly *horizontal*.

d Fourth step: Final emulsification by occlusion (at the center of the bag).

e *Note*: The plane of the movements of the emulsifier is *horizontal*; the bevel faces *laterally* toward empty space

Nucleolysis and Locomotion

Nucleolysis is performed either by hydrodissection or by traction (i.e., combined with locomotion). Depending on the technique selected for phacoemulsification, the entire nucleus, the shell only, or small fragments are transposed into the safety zone for definitive emulsification by occlusion. The motor for **locomotion** consists of pressure or traction. For *pressure*, the necessary gradient between the vitreous chamber and anterior chamber is produced by interrupting the infusion stream. The diaphragm is allowed to bulge forward, pushing the nucleus toward the anterior chamber.

Traction is exerted either by pulling the nuclear material with the tip while aspiration is on (i.e., aspiration for grasping and guidance motions for pulling; no ultrasound), or by pushing with a spatula, or with the tip while aspiration is switched off.

Phacoemulsification in the Anterior Chamber

For phacoemulsification in the anterior chamber, the entire nucleus (i.e., the hard central core along with the softer peripheral shell) is transposed into the anterior chamber (Fig. 8.74). Thus, the initial steps are **nucleolysis and locomotion**. For nucleolysis an (irrigating) cystotome can be used as shown in Fig. 8.47. Locomotion is sustained by a pressure difference between the vitreous and anterior chamber produced by an interruption of the infusion stream.

The second step is the **emulsification** itself. At this point the nucleus is free of its anatomic connections with the cortex and is completely mobile. Basically, emulsification in the anterior chamber is performed by occlusion. An emulsifier tip with a blunt shape is selected.

The emulsifier is used at a low power setting to prevent repulsion of the nucleus with consequent loss of occlusion. Short-burst ultrasound application is an important safety factor and helps to reestablish occlusion after each burst.

As long as the nucleus retains sufficient mass, its inertia can be utilized as a stabilizing factor. Small particles are apposed to the emulsifier tip with the aid of a spatula.

All maneuvers used to present successive portions of the nucleus to the emulsifier tip involve movements strictly on the horizontal plane (i.e., lateral displacement or rotation) to protect adjacent tissues. Vertical movements are unnecessary at this stage and are avoided since they would endanger the endothelium and posterior capsule.

There are two basic methods of phacoemulsification in the anterior chamber: 1) the nucleus is emulsified from the inside outward, i.e., the hard core is attacked first, and the softer peripheral shell is left for

‹ ›

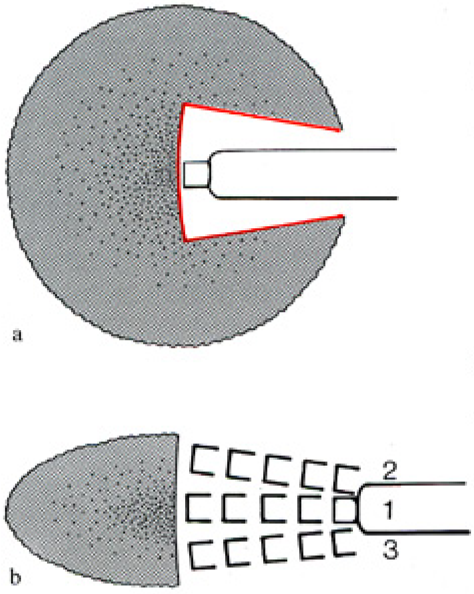


Fig. 8.77. **Methods of emulsification in the anterior chamber: Start of the emulsification**

a First the material within the safety zone is emulsified.

b Steps of the emulsification. The first step (*1*) is emulsification at the equator (see Fig. 8.78a). The second step (*2*) emulsifies the surface and provides exposure for the third step (*3*), deep emulsification

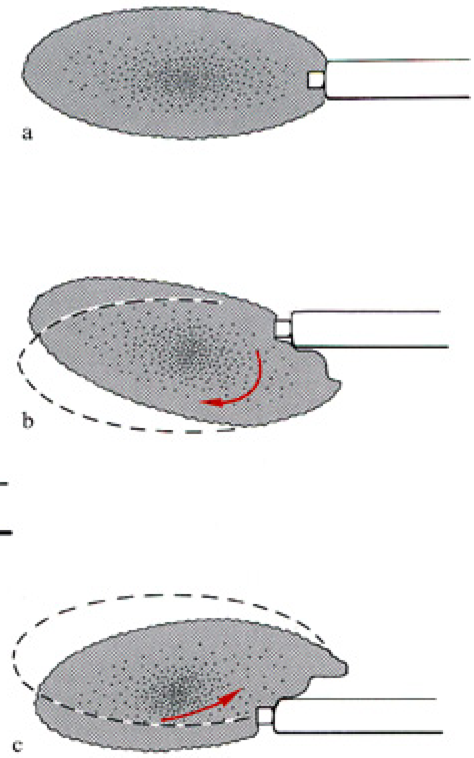
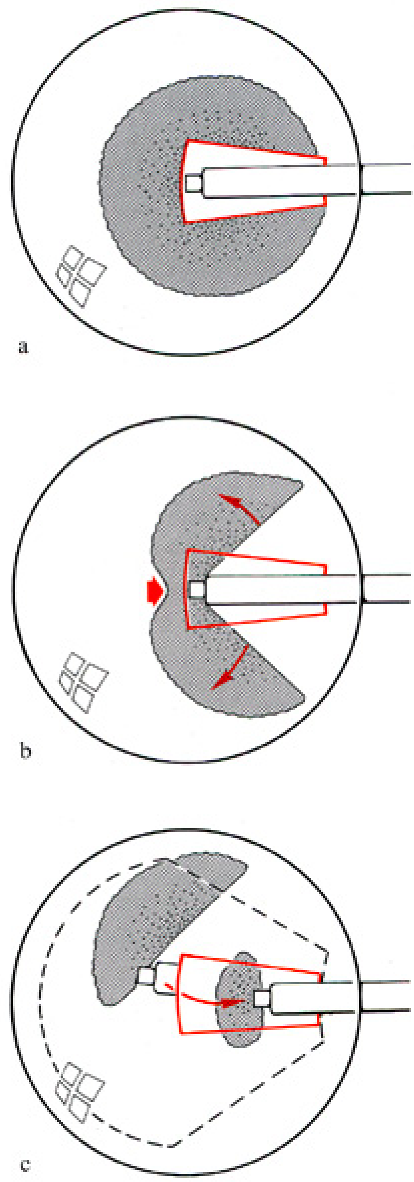


Fig. 8.78. **Emulsification of a mobile nucleus**

a If emulsification is started precisely at the equator of the nucleus, the instrument is aligned perpendicular to the surface. The resistances about the sleeve are symmetrical, and the tip penetrates horizontally into the nucleus.

b, c If the tip is applied above (**b**) or below (**c**) the equator, motion of the nucleus is checked on one side by the sleeve, causing the nucleus to tilt upward or downward



emulsification by occlusion in the final phase, or 2) the nucleus is emulsified from the outside toward the center.

In the former method the peripheral part of the nucleus already within the safety zone is emulsified (Figs. 8.77, 8.78) to gain access to the core. Then the core is successively brought into the safety zone by lateral shift (Fig. 8.79) or by rotation (Fig. 8.80). During emulsification of the hard material, the most difficult part of the procedure, the nuclear mass is still large enough for inertia to be an effective stabilizing adjunct. In the final phase the material is soft and is easily emulsified by occlusion.

In the latter method the soft shell of the nucleus is shelved away first (Fig. 8.81). When the tip reaches the core, the nuclear mass has been significantly reduced and its inertia is low. Thus, the method is safe only when the core is soft enough to be emulsified by occlusion.

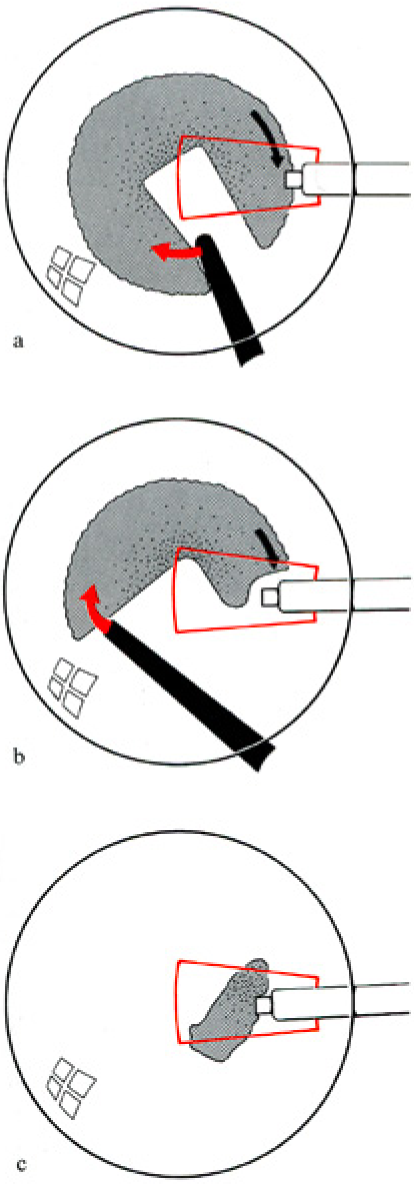
Fig. 8.79. **Methods of emulsification in the anterior chamber: Longitudinal shifting of the nucleus**

a Following the initial excavation (Fig. 8.77), the nucleus is sucked gradually toward the access opening, and emulsification is continued at its center.

b This maneuver is continued until two side fragments remain.

c The remaining fragments are grasped with the suction tip within the wide aspiration zone (*black*) and retracted toward the safety zone (*red*), where the emulsification is completed

back to index



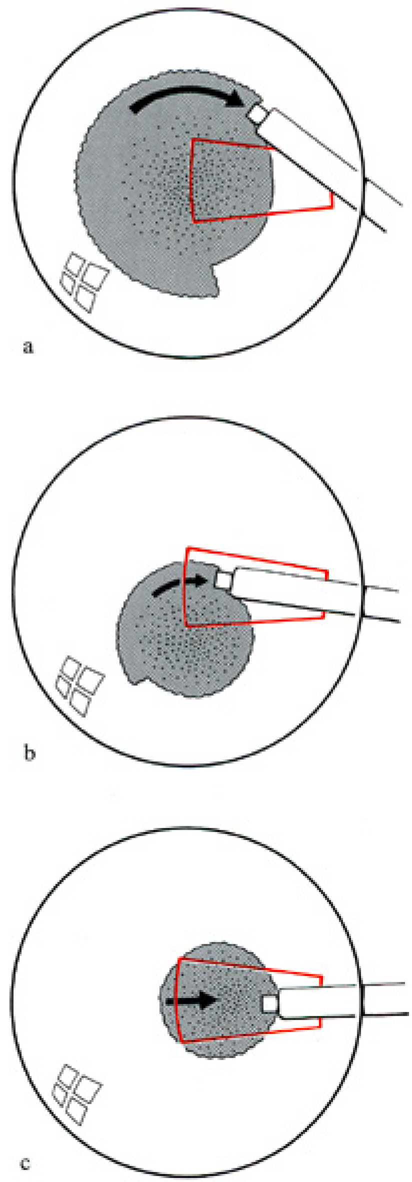


Fig. 8.80. **Methods of emulsification in the anterior chamber: Rotation of the nucleus with a spatula**

a Following the initial excavation (Fig. 8.77), the nucleus is rotated with a spatula (introduced through a second incision) until a new sector enters the safety zone, where it is emulsified.

b As the rotation maneuver is continued, new material is fed to the emulsifying tip, and the nucleus diminishes in size.

c The emulsification is completed as shown in Fig. 8.79

Fig. 8.81. **Methods of emulsification in the anterior chamber: Rotation of the nucleus by aspiration**

a When the tip is applied to the nucleus obliquely on the horizontal plane, the sleeve exerts a checking action which causes the nucleus to rotate as in Fig. 8.78, though here it rotates about a vertical axis. The safety margins in this technique are small for several reasons: First, the tip can easily stray from the safety zone. If, to avoid this, the nucleus is pushed to the center of the anterior chamber, there is a danger that the far edge of the rotating nucleus will scrape against the corneal endothelium. Second, the oblique position of the instrument at the corneoscleral incision can hamper cooling by blocking fluid outflow alongside the tip (see Fig. 1.14e).

b The rotation maneuver is continued. As the nucleus diminishes in size, it can be brought to the center of the anterior chamber for emulsification; the safety margins expand.

c Finally the central core of the nucleus is emulsified

back to index

Phacoemulsification in Both Chambers

When phacoemulsification is performed in both chambers,[43] the core and shell of the nucleus are emulsified in different chambers (Fig. 8.75). This allows optimum conditions to be selected for the emulsification of hard and soft material.

The first step is **emulsification of the core of the nucleus in the posterior chamber**. The anatomic connections between the nucleus and cortex are still intact and serve to keep the nucleus immobile. This facilitates the emulsification in flow that is optimal for the hard nuclear core. The material within the safety zone is shelved layer by layer from the surface downward. A sharply beveled tip is used for emulsification in flow (see Fig. 8.66b), and the bevel is directed upward to prevent inadvertent occlusion.

The second step is **nucleolysis and locomotion** of the remaining nuclear shell (i.e., the material outside the safety zone in the posterior chamber) into the anterior chamber. This transfer involves vertically directed vector components. Either the superior or inferior pole of the shell is raised first. The motivating force for lifting the *superior pole* (Fig. 8.82b) is pressure. This is done by interrupting the infusion flow and allowing the nuclear rim to rise. Then for nucleolysis the shell is engaged with the instrument tip and hydrodissected by reactivating the infusion stream. This method is suitable for dense nuclei that differ from the cortex in their compactness (see Fig. 8.46).

The motor for raising the *inferior pole* (Fig. 8.83d) is traction. The material is grasped with the emulsifier tip while the aspiration is on. However, aspiration is safe only for material that can be attacked with the tip opening held horizontally or upwards.[44]

The nuclear rim on the opposite side is first sculpted to make it foldable, then it is pulled toward the entry site of the instrument. Thus, this method is suitable for nuclear material that is soft enough to maintain strong occlusion, i.e., sufficiently strong to withstand the tissue resistance to nucleolysis and folding.

The third step is **emulsification of the nuclear shell in the anterior chamber**. Being soft, the material is emulsified by occlusion. The shell is successively rotated into the safety zone and removed there while the tip is held almost stationary.

[43] Currently this technique is called "emulsification in the posterior chamber" because that is where the procedure is begun.

[44] Pointing the tip backward during aspiration is hazardous to the capsule. Easily deformable material may be sucked abruptly through the large lumen of the aspirating cannula, exposing the posterior capsule to the potentially damaging effect of a large pressure gradient.

Phacoemulsification Within the Capsular Bag

In phacoemulsification within the capsular bag (Fig. 8.76), all maneuvers can be performed through a small capsulotomy. In terms of spatial tactics, then, the capsular bag may be treated as an independent pressure chamber, and its shape can be controlled by adjusting the flow parameters (see Fig. 8.57).

The confinement of all manipulations within a nearly intact bag is the main advantage of this technique, as it reduces the danger to surrounding structures, but it is also a major disadvantage due to the lack of space. The free working space in the capsular bag must be created first by the surgeon. Its greatest extent is available on the horizontal plane. Therefore, all maneuvers are performed in such a way that the instrument and nuclear material are shifted predominantly in horizontal directions.[45] The largest amplitudes for movements of the nucleus are in rotation. In case of a small capsulotomy, these rotational movements must be produced with a single instrument (e.g., with the emulsifier tip) and are not easy to perform (see Fig. 8.47b). They are facilitated by previously separating the connections between the nucleus and cortex.

[45] Many maneuvers in this technique can be explained simply as a 90° rotation on the vertical plane of manipulation in both chambers (compare Figs. 8.75d and 8.76e!).

back to index

The first step, then, is **anterior corticolysis and nucleolysis by hydrodissection**. Hydrodissection is used because there is not enough room to separate the connections by tractional movements. Since hydrodissection is most effective when the reflux resistance is high (see Fig. 8.48b), it is done prior to any further manipulations. The second step is **excavation of the nuclear center** (Fig. 8.84). This is done in two phases: creation of the initial cavity for introduction of the tip, and extension of this cavity throughout the safety zone for emulsification in flow. Occlusion is unavoidable during sculpting of the initial cavity, so short bursts of ultrasound are used at this stage. The bevel of the tip (which is sharp for the emulsification in flow that follows) is directed laterally to avoid unintended aspiration of the anterior or posterior capsule. Subsequent excavation of the nucleus within the safety zone is done in flow. The material in front of the tip remains immobile despite the previous nucleolysis, because the nucleus is well confined within the intact capsular bag. The shelving maneuver is done on the horizontal plane by sweeping the tip laterally from one border of the safety zone to the opposite border. To avoid occlusion, the bevel of the tip faces to the side, toward the cavity already formed. The anterior cortex (previously loosened by corticolysis) is simultaneously removed, allowing visual control of the underlying emulsifier tip.

The third step is **locomotion** of the peripheral nuclear shell at the opposite end of the excavation toward the center.

The material is grasped and pulled by aspiration by occlusion. To prepare this step the peripheral shell is cut into occludability, that is, into a triangular shape able to occlude a sharp beveled tip held laterally (see Fig. 8.84b).

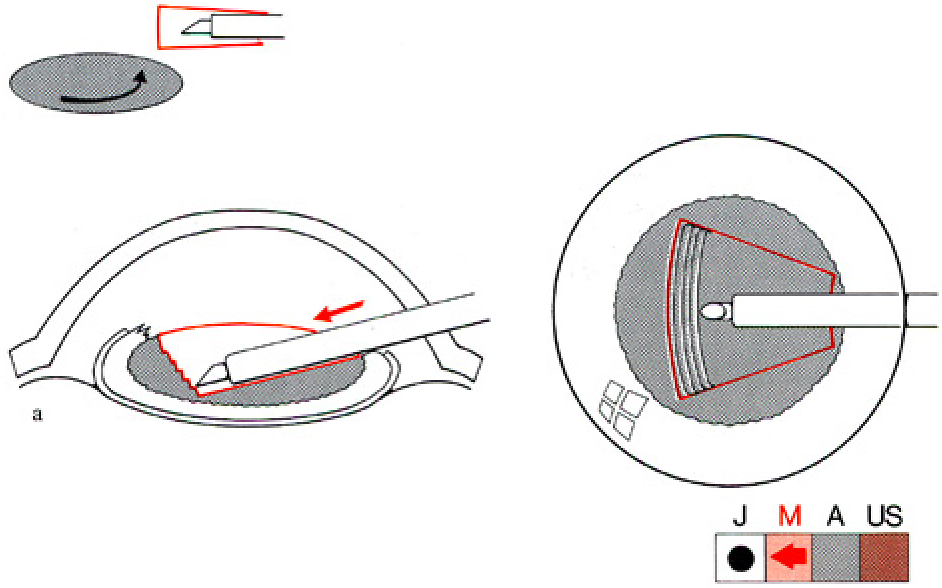
The fourth step is the **final emulsification** of the fragments within the safety zone for emulsification by occlusion at the center of the bag. The infusion pressure and outflow opening are closely monitored and controlled to maintain the shape of the emptying bag; short-burst technique prevents collapse of the bag when the emulsification is completed.

Subsequently the residual shell is rotated until new portions become accessible to the tip; then the steps of emulsification are repeated.

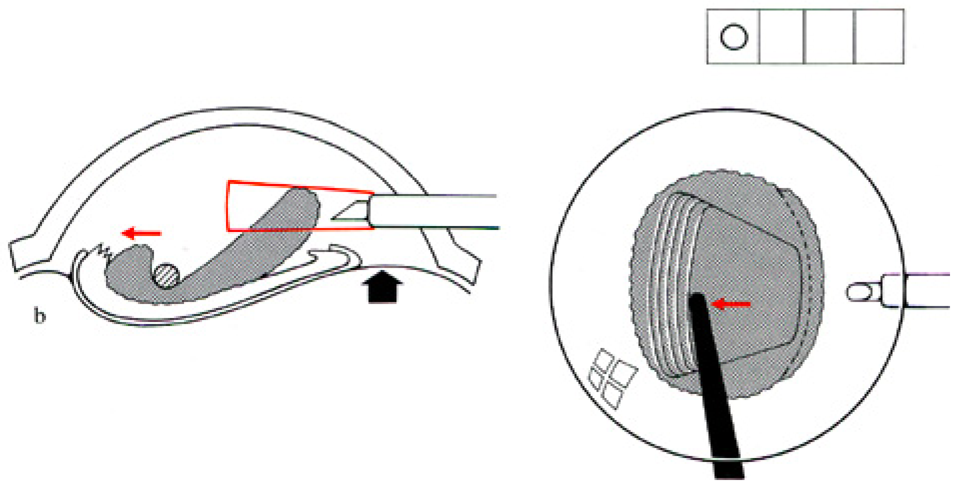
back to index

Fig. 8.82. **Methods of emulsification in both chambers: Raising the *superior* pole of the nucleus**. The diagrams of the footswitch positions show position 1 (infusion only) in the left square (*J*) with a black circle (on) or white circle (off).[46]
Following initial emulsification in the safety zone of the posterior chamber, the *superior* pole of the nucleus is moved into the safety zone of the anterior chamber. In this technique the nucleus must be hard enough to offer adequate resistance to a spatula.

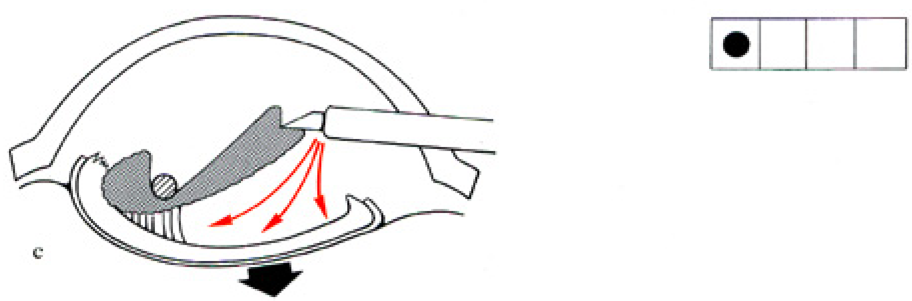
a *Initial excavation*: First the center of the nucleus is emulsified within the capsular bag, leaving a solid "step" on the opposite side (aspiration in flow).



b *Locomotion*: The step is engaged with a spatula, which shifts the nucleus *horizontally* toward the inferior pole until its superior pole appears at the pupil margin. Then the spatula is held steady while the emulsifier is withdrawn toward the access opening to make room for ascension of the superior pole. The superior pole is driven upward by lowering the pressure in the anterior chamber (discontinuing infusion, footswitch position 0) until the diaphragm bulges forward.

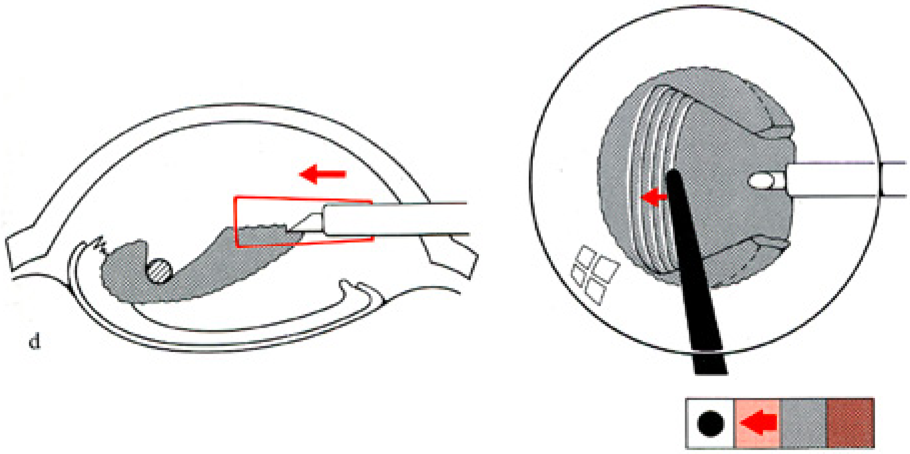


c *Nucleolysis*: The superior pole presents to the tip and is engaged, then the infusion is restarted to induce recession of the diaphragm. The nucleus is now separated from the cortex by hydrodissection; sufficient time must be allowed (in footswitch position 1) for this separation to occur. Then the tip is withdrawn slightly so that the nucleus can fall back again. Nucleolysis is completed by rotation of the nucleus with a spatula (see also Fig. 8.47b).



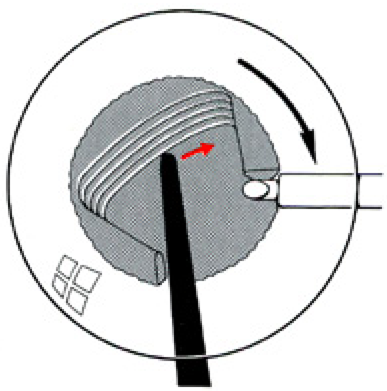
[46] Position 1 was not drawn in the previous figures, because infusion was on during the entire procedure.

back to index



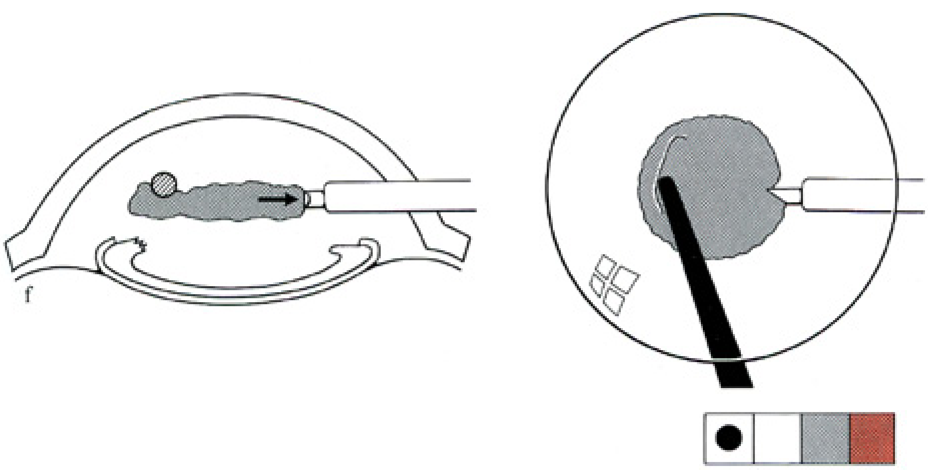
d

d *Emulsification of the nuclear rim*: The mobilized material of the superior nuclear rim is shifted from the posterior chamber into the safety zone of the anterior chamber by repeating the maneuver in Fig. **b**. Then the material is emulsified in flow.



e

e The entire rim is shelved away by bringing new portions to the emulsifier tip. This is done by rotation with the spatula and by lifting with the maneuver in Fig. **b**.

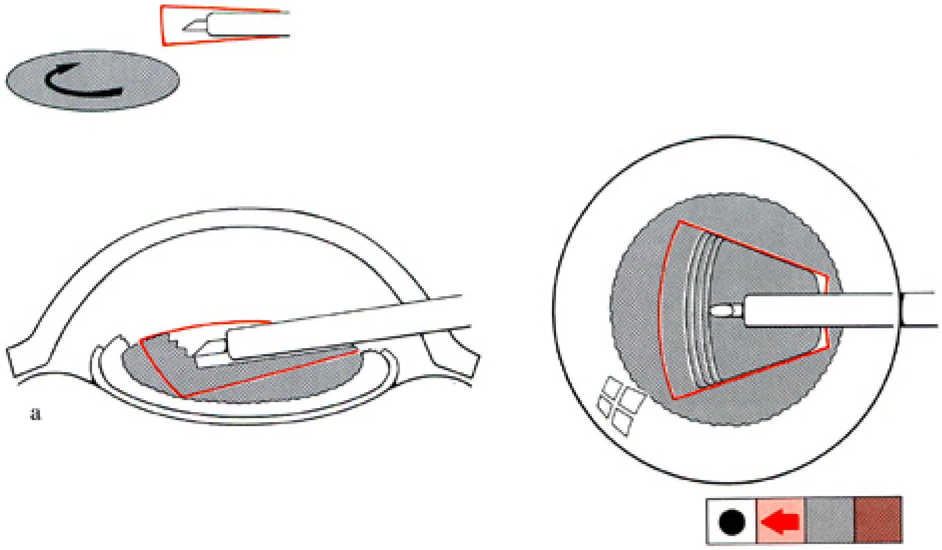


f

f *Emulsification of the posterior shell*: Finally the flat, rimless posterior shell of the nucleus is moved to the anterior chamber through aspiration by occlusion. There it is (stabilized with a spatula if necessary) emulsified by occlusion. *Note*: To avoid improper alignment of the shell on occlusion, the bevel of the emulsifier is directed laterally now

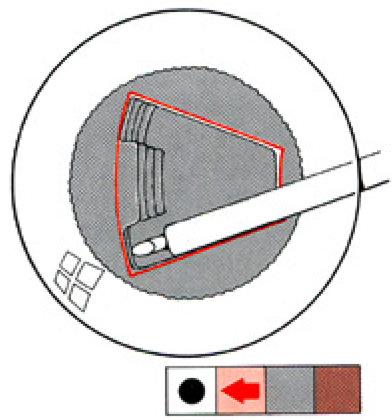
Fig. 8.83. **Methods of emulsification in both chambers: Raising the *inferior* pole of the nucleus**. Following initial emulsification in the safety zone of the posterior chamber, the *inferior* pole is drawn into the anterior chamber. This method is best suited for nuclei soft enough to be folded after partial excavation.

a *Initial excavation*: The nucleus is excavated in the posterior chamber by aspiration in flow to the extent the safety zone allows.



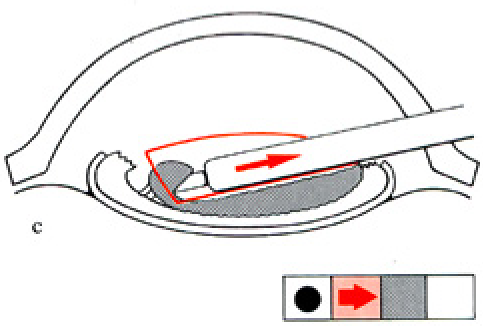
a

b *Preparation for folding maneuver*: On the far side of the excavation, grooves are cut toward the periphery at both lateral ends so that the intervening border of the nucleus can be folded more easily. These grooves extend beyond the safety zone. Thus the nuclear material is first grasped with suction[47] and then is pulled toward the safety zone for emulsification.



b

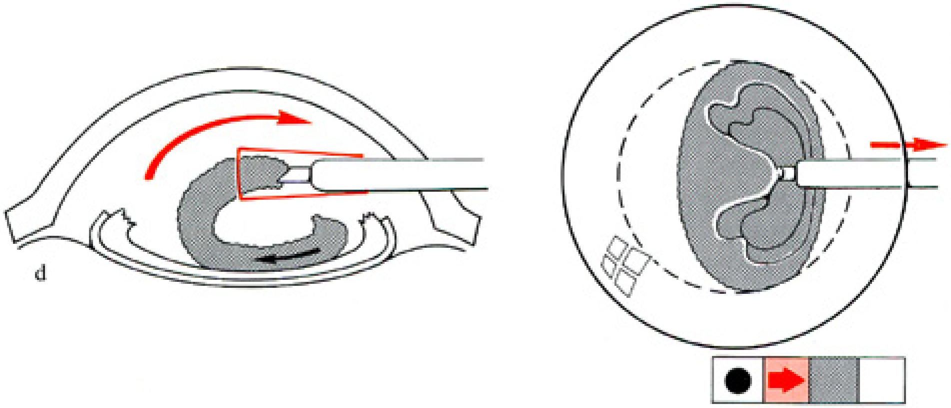
c Now the tip is kept immobile, and the groove is cut by a short burst of ultrasound (emulsification by occlusion).



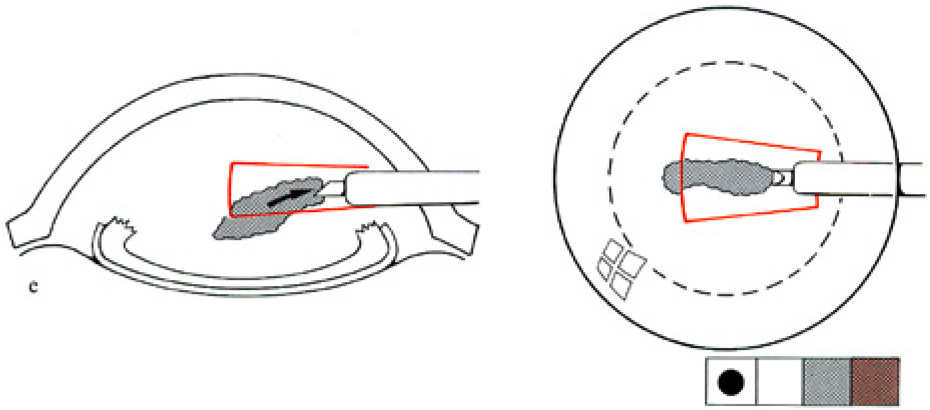
c

[47] Remember that the safety zone for aspiration alone (*black outline*) is larger (see Fig. 8.72).

back to index



d *Raising the inferior pole* into the safety zone of the anterior chamber: The rim between the grooves is now grasped with suction (footswitch position 2: Aspiration only, no vibration), folded upward, and pulled toward the access opening. This dislocates the nuclear shell into the anterior chamber.



e *Removal of the nucleus* is completed within the safety zone of the anterior chamber (aspiration by occlusion)

back to index

Fig. 8.84. **Phacoemulsification in the capsular bag.** The basic steps in the procedure are the removal of the nuclear core within the safety zone for emulsification in flow, and removal of the portion of the shell opposite the capsulotomy. Subsequently the nucleus is rotated, and other parts are made accessible to the emulsifier.

a–j Sequence of manipulations.
v–z The results obtained after each step.

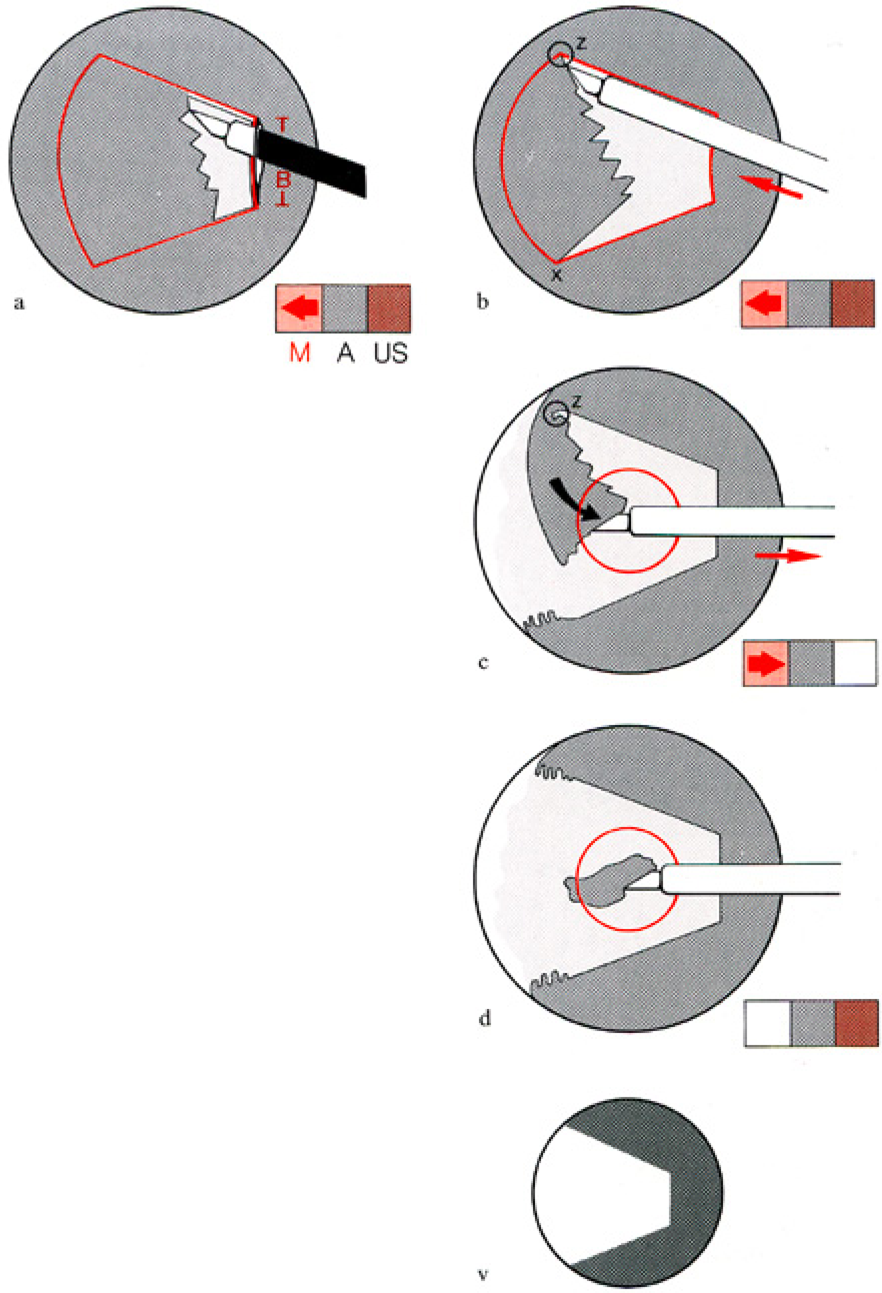
a *Sculpting the initial cavity*: The emulsifier is introduced into the lens through a small capsulotomy whose width depends on the planned arc through which the tip will be swept (i.e., the base B of the safety zone for emulsification in flow). A flat-beveled tip is chosen to minimize the risk of unintended occlusion (see Fig. 8.66b). The bevel faces laterally toward the space already excavated.

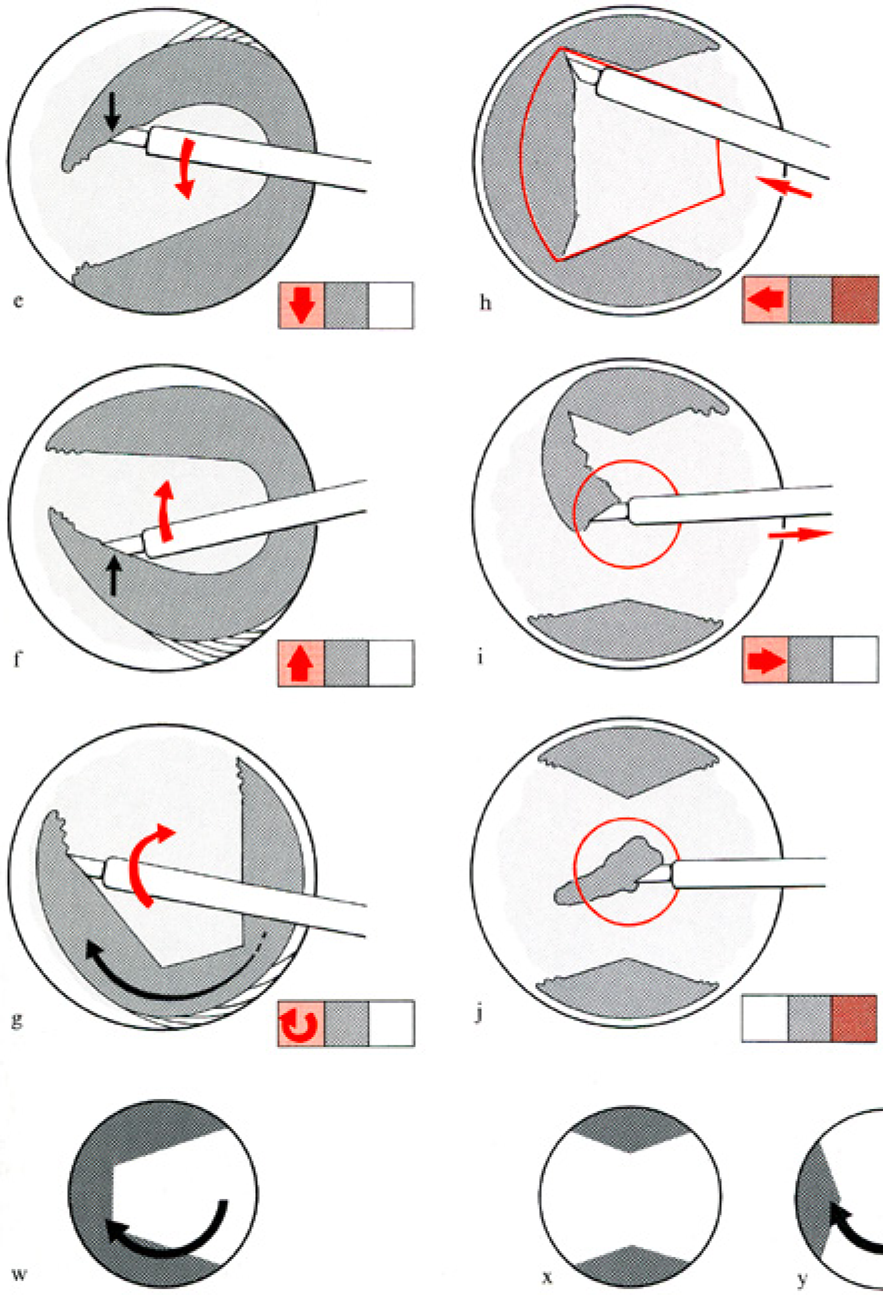
b *Excavation of the nuclear core* by emulsification in flow. With the bevel facing laterally, the cavity is extended by swiveling the emulsifier horizontally. On the side opposite the capsulotomy, a triangular wedge is left in the nuclear shell to serve as a "handle" for pulling it toward the center. The triangle is not isosceles: One side (toward x) is made shorter and steeper than the other to allow for solid occlusion by the beveled tip; the other side, longer and flatter, can easily pivot about point Z at its end.

c *Mobilization of the wedge*. The steep part of the triangle is grasped by occlusion with the aspirating tip (no vibration) and is pulled centripetally.

d The wedge is emulsified by occlusion at the center of the bag.

v Result of **a–d**: Removal of nuclear material in the safety zone and adjoining shell.





e–g *Nucleolysis and locomotion of the remaining nucleus.*

e One lateral wing is mobilized by pulling it toward the center with the emulsifier (aspiration by occlusion, no ultrasound). The maneuver is facilitated by preliminary nucleolysis (hydrodissection).

f Same maneuver on the opposite wing.

g Locomotion by rotation through 180°.

w At this stage the nucleus previously on the side of the capsulotomy has been moved to the opposite side and now is accessible within the safety zone for emulsification in flow.

h–j *Repetition of the emulsification steps (b–d).*

x Now only the lateral wings of the shell remain. If they cannot be pulled directly toward the center with the tip, the nucleus is rotated again.

y Rotation through 90° brings one of the lateral wings into the safety zone for emulsification in flow.

z Rotation through 180° brings the remaining lateral wing into the safety zone

back to index

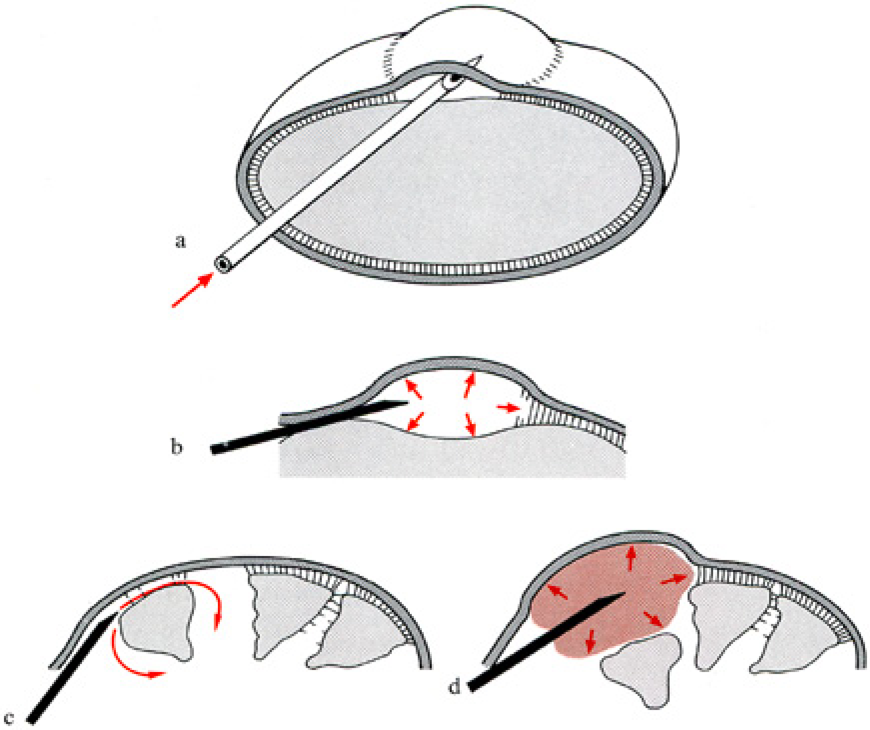


Fig. 8.85. **Corticolysis by hydrodissection**

a Fluid injected beneath the capsule produces a pressure chamber whose expansion separates the capsule from the cortex (see also Fig. 8.49b).

b Only large and compact fragments offer sufficient backflow resistance to allow a pressure chamber to be formed.

c With smaller fragments, resistances to the reflux and spread of watery fluid are too low, so a pressure chamber is not formed.

d Viscoelastic material provides its own flow resistance and thus can separate even small cortical fragments from the capsule (see Fig. 2.19)

8.3.4 Delivery of the Cortex

The cortex of the lens has a soft consistency. Applied forces tend to rupture the cortex and break it up into fragments. As this makes it difficult to manipulate the cortex as a whole, the cortex is removed *piecemeal*. Differences in the size and compactness of the cortical fragments will necessitate the use of various delivery techniques.

Mobilization of the Cortex (Corticolysis)

The cortex is separated from the lens capsule on a preexisting *anatomic cleavage plane*, which can be developed by pressure or traction.

Pressure is applied by injecting fluid into the interspace between the cortex and capsule to create a *pressure chamber* (Fig. 8.85a, b). The advantage of corticolysis by hydrodissection is that it does not affect the suspension of the lens and therefore is safe even when the capsule or zonule is weak.

Similar considerations apply to corticolysis by hydrodissection as to nucleolysis as far as resistances to forward flow and reflux of the fluid are concerned. These resistances can be produced only by injecting the fluid *prior to* removal of the nucleus. If corticolysis by hydrodissection is attempted *after* delivery of the nucleus, it is not only more difficult to inject the fluid precisely between the capsule and cortex, but the corticolysis also becomes much less effective. In this situation hydrodissection can at best mobilize large, compact fragments (Fig. 8.85b). Small cortical remnants, on the other hand, are poorly mobilized because watery fluid tends to flow around them (Fig. 8.85c). However, corticolysis of small fragments can still be accomplished by the use of *viscoelastic material* (Fig. 8.85d).

In mobilization by **traction**, the cleavage plane is torn open by ap-

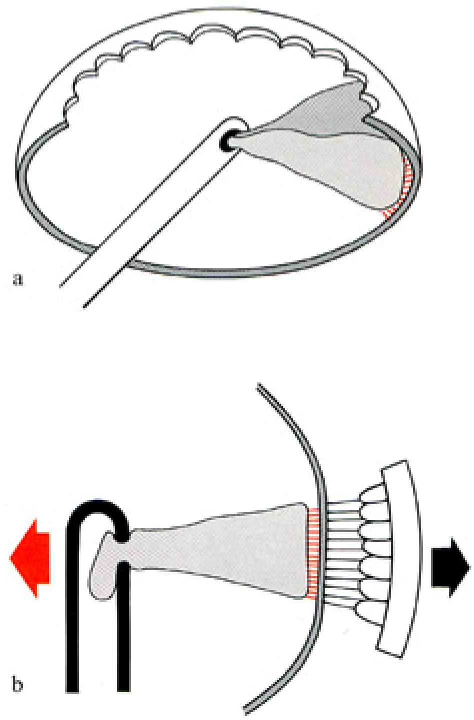


Fig. 8.86. **Corticolysis by traction**

a Cortex is fixed to the cannula by suction and stripped away by traction on the cannula.

b The traction chain encompasses the instrument (and its fixation to the cortex), the cortex, the corticocapsular attachments (the intended cleavage zone), the capsule, the zonule, the ciliary body, and the sclera

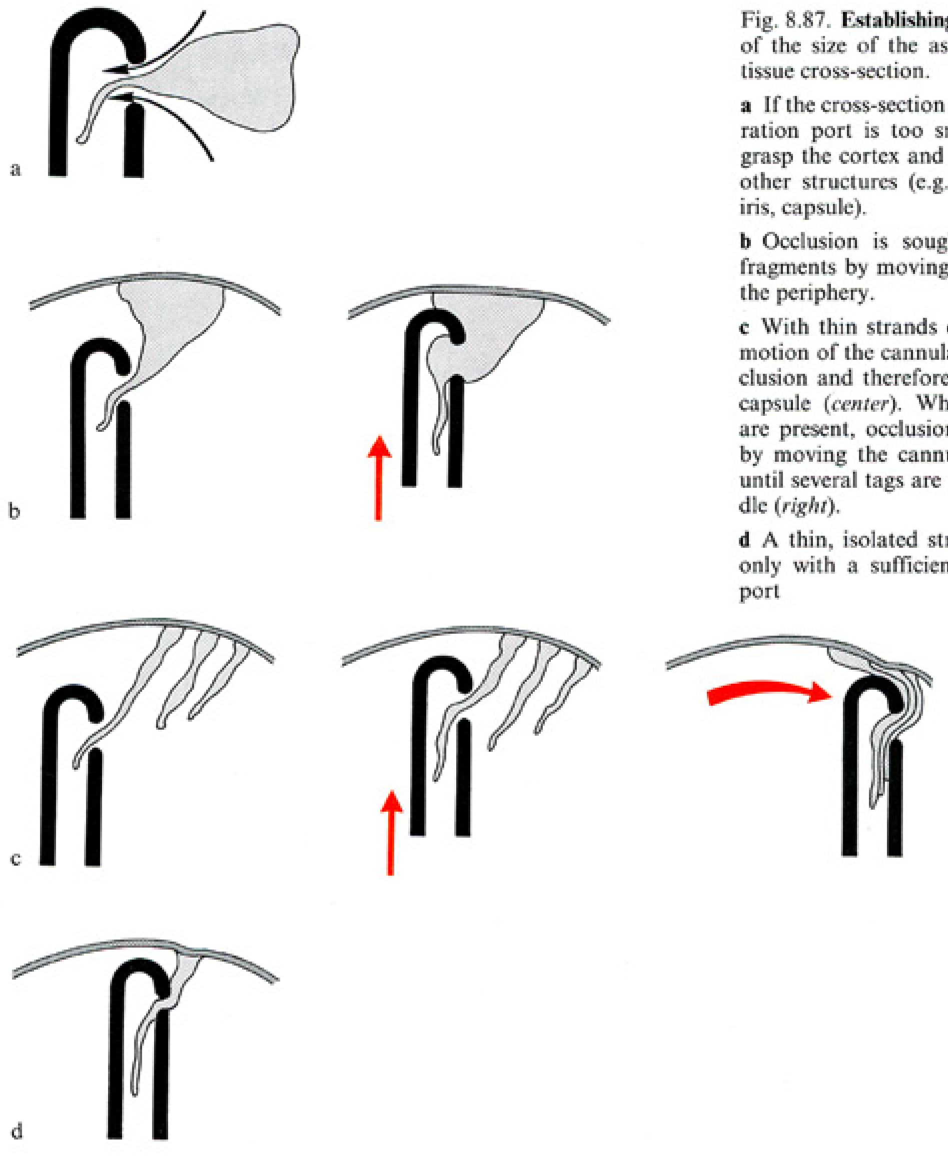


Fig. 8.87. **Establishing occlusion.** Relation of the size of the aspiration port to the tissue cross-section.

a If the cross-section of cortex in the aspiration port is too small, the tip cannot grasp the cortex and will tend to aspirate other structures (e.g., chamber contents, iris, capsule).

b Occlusion is sought in large cortical fragments by moving the cannula toward the periphery.

c With thin strands of cortex, peripheral motion of the cannula cannot provide occlusion and therefore risks aspirating the capsule (*center*). When multiple strands are present, occlusion can be established by moving the cannula circumferentially until several tags are gathered into a bundle (*right*).

d A thin, isolated strand can be grasped only with a sufficiently small aspiration port

plying tension to the cortex on one side and to the capsule on the other. *Tension on the cortex* is produced by guidance motions with a grasping instrument, the cortex itself acting as an instrument for transmitting the applied tensile forces to the cleavage zone (Fig. 8.86).[48] *Countertension on the capsule* is produced by tension on the zonule. Actually there is a traction chain comprising the instrument, cortex, capsule, zonule, ciliary body and sclera, and the weakest "link" in this chain will give way when traction is applied. Thus, the technique of corticolysis by traction aims at concentrating the effect of the forces on the corticocapsular attachments.[49]

For **grasping** of the cortex, *aspiration cannulas* are used which fixate the material by occlusion. The surgeon's task is first to establish the occlusion and then maintain it while applying traction to the cortex.

The **size of the aspiration port** should conform to the size of the particle to be grasped. If the opening is too small, the cannula cannot grasp enough tissue to transmit forces to the corticocapsular interface; if too large, occlusion is not obtained (Fig. 8.87a). If the rela-

[48] For the cortex to function in this capacity, it must not be transsected at the grasping instrument. Thus, suction cutters are not suitable *traction* instruments for corticolysis from the capsule fornix. They are used as *cutting* instruments in lensectomy for the removal of the whole lens (including the capsule) and the anterior vitreous.

[49] This is difficult in the presence of a torn capsule, weakened zonule (subluxated lens) or cyclodialysis. If the sclera gives way, it can be reinforced by attaching a stabilizing ring (see Fig. 1.47).

back to index

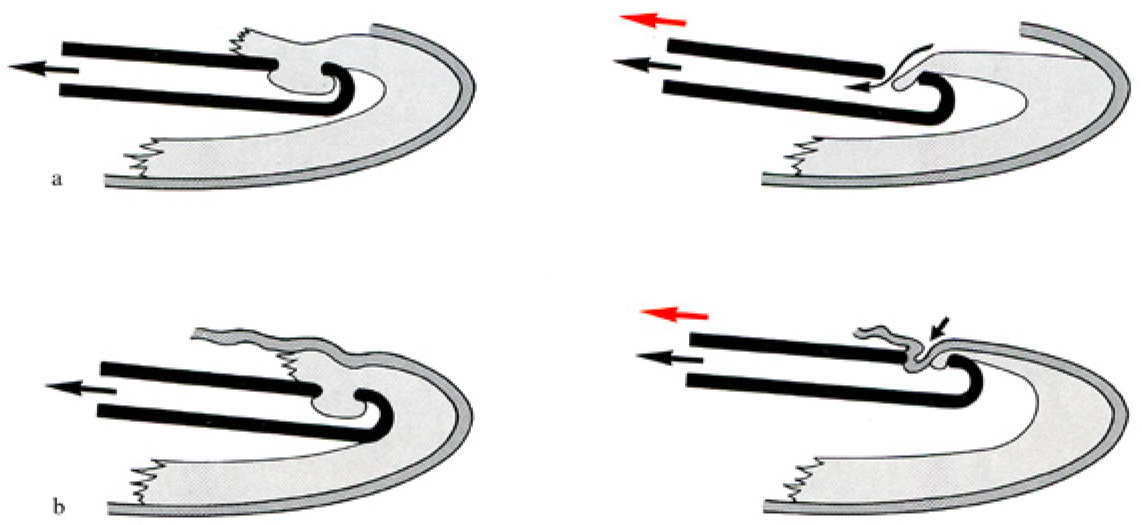


Fig. 8.88. **Achieving occlusion by a cannula with an upward-directed side opening**
Left: Establishing occlusion
Right: Loss of occlusion during guidance movements

a Here the capsule margin terminates peripheral to the remaining cortex, and the suction tip grasps the cortex outside the capsule area (*left*). If occlusion is deficient, chamber fluid will be aspirated. When traction is exerted on the cortex (*right*), the suction tip moves away from the capsule margin and poses no danger to it.

b Here the capsule margin extends farther centrally than the residual cortex, and the cortex is grasped beneath the capsule (*left*). If occlusion is deficient, the suction tip will seize capsular tissue. The capsule may remain in the danger zone even while traction is applied to the cortex[53]

tion of the cannula opening to particle size is unfavorable, the surgeon can *reposition the cannula* in an attempt to locate a site where occlusion can be established. The cannula is moved to a position where there is more accessible cortex – peripherally for large particles (Fig. 8.87b) and parallel to the capsule sinus for thin strands (Fig. 8.87c). A cannula with a very *small opening* may be needed to grasp tiny individual fibers (Fig. 8.87d).

The **choice of the direction** of the aspiration port depends basically on the *location* of the particle to be aspirated. However, it is also important to consider the effects that would occur if the occlusion were primarily deficient[50] or became so during the corticolysis.[51] To avoid inadvertent aspiration of adjoining vital structures,[52] it is safest to keep the cannula opening pointed in a direction where only additional cortex can be aspirated, i.e., laterally (Fig. 8.89). It is relatively safe to direct the opening toward large aqueous-filled spaces. It is less safe to direct the opening toward the anterior capsule remnants, the capsular sinus, or the posterior capsule, since a break of occlusion in these cases would endanger the capsule and zonule (Figs. 8.88–8.91).

The actual cleavage mechanism, **traction**, is produced either by *suction* or by *guidance motions* of the aspiration cannula. This traction is resisted by the tissue attachments that must be ruptured in the corticolysis, i.e., by the interconnections among the cortical fibers (*intracortical resistance*) and the connections between the cortex and capsule (*corticocapsular resistance*). If these resistances are too high, the occlusion will break and traction will be lost.

It is useful, then, to distinguish between cortex whose attachments are so firm that the slightest motion of the aspiration cannula will disrupt the occlusion ("*firm cortex*") and cortex that will follow motions of the cannula and peel away from the capsule ("*peelable cortex*") (Fig. 8.92).

When dealing with a **firm cortex**, the only way to maintain the necessary occlusion is to hold the aspiration cannula *steady* against the cor-

---

[50] The quality of occlusion cannot be controlled if the occlusion is attempted under conditions of poor visibility.

[51] Occlusion may be lost during cortical traction if the resistance to corticolysis is too high. A sudden break of occlusion may also occur when material held by the cannula is suddenly sucked into the opening and aspirated through the lumen.

[52] Recall that the full pressure differential between the initial and terminal pressures becomes active the moment occlusion is lost.

[53] Aspiration with an upward-directed cannula orifice may be dangerous when attempted under conditions of poor vision, for then it cannot be determined whether cortex (*left*) or capsule (*right*) presents to the opening.

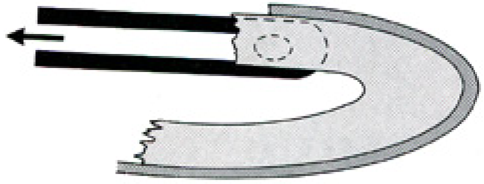


Fig. 8.89. **Achieving occlusion by a cannula with a laterally directed side opening.** If occlusion becomes deficient, adjacent cortical matter is seized by the suction tip and occlusion reestablished. There is little danger of aspirating the capsule

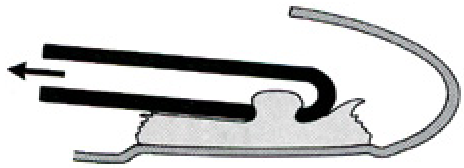


Fig. 8.90. **Achieving occlusion by a cannula with a downward-directed side opening.** The main danger here is aspiration of the posterior capsule. With its opening turned downward, the cannula should be used only for grasping particles that guarantee occlusion throughout the procedure, e.g., solid cortical fragments whose firm consistency keeps them from being sucked through the opening right away

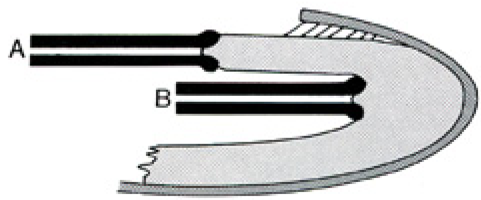


Fig. 8.91. **Achieving occlusion by a cannula with a forward-directed opening.** Here the side-effects of deficient occlusion depend on the level at which the suction tip grasps the cortex. If the cortex is grasped beneath the anterior capsule (*A*), the suction is directed parallel to the capsule and poses no danger to it. If occlusion is deficient, the tube will simply aspirate more cortex.[54] If the cortex is grasped in the capsular sinus region (*B*), deficient occlusion would allow aspiration of the equatorial capsule with a risk of zonule rupture

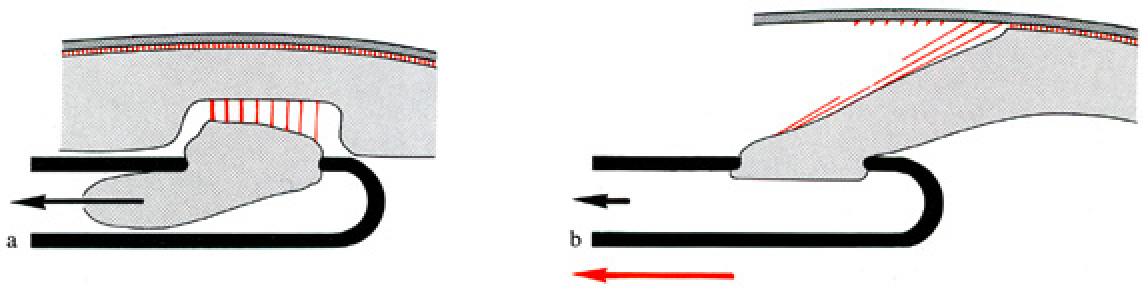


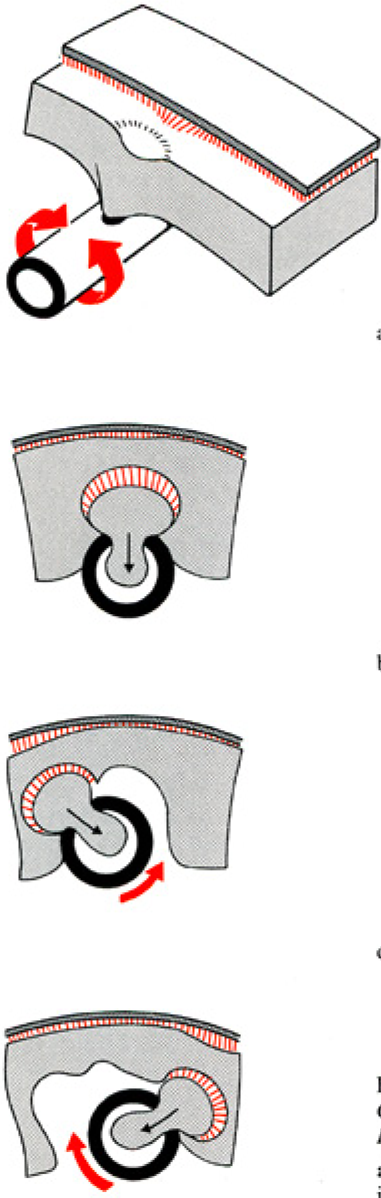
Fig. 8.92. **Traction on the cortex**

a Firm cortex: The intracortical and corticocapsular attachments are stronger than the occlusion. Since occlusion is lost when the cannula is moved, the cannula must be pressed against the cortex and held stationary. Traction is effected entirely on *aspiration*.

b Peelable cortex: The occlusion is stronger than the cortical resistance. Aspiration serves only to maintain the occlusion, and traction is exerted by *moving* the cannula

[54] This is true only if the tip is actually beneath a tense capsule. If there are loose, floating capsule remnants ahead, they might be seized inadvertently by the tip.

back to index



a

b

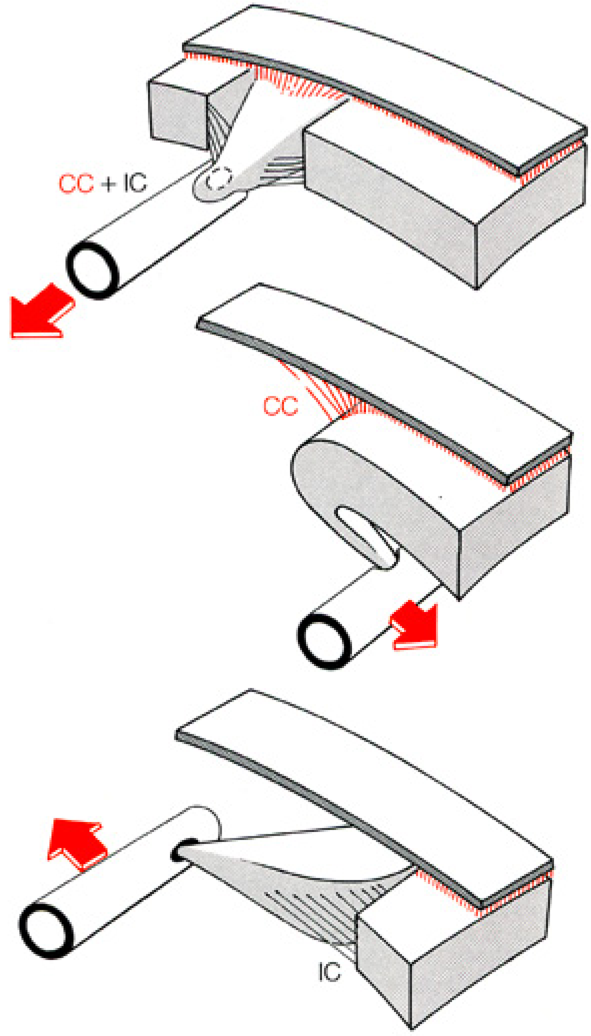
c

d

Fig. 8.93. **Removal of firm cortex**

a, b The aspiration port is pressed tightly against the cortex to secure occlusion. The cannula is held stationary during aspiration.

c, d To maintain occlusion during the procedure, the cannula is simply rotated to appose the aspiration port to new portions of the cortex



a

b

c

Fig. 8.94. **Removal of peelable cortex**
CC corticocapsular attachments
IC intracortical attachments

a Making the initial gap. At this stage the intracortical attachments are intact and active on both sides of the particle to be grasped. Tension on the intracortical and corticocapsular attachments is diffuse. If these resistances are too high the initial gap is produced by aspiration alone (according to the technique shown for firm cortex in Fig. 8.93).

b The initial gap having been formed, the intracortical attachments are intact on only one side of the particle to be removed. As the corticolysis proceeds, the goal is to place tension on the corticocapsular and intracortical attachments separately rather than jointly so that the total resistance to the traction is reduced. By applying *circumferential traction away from the initial gap*, tension can be placed selectively on the corticocapsular attachments below the anterior capsule.

c Following separation of the corticocapsular attachments below the anterior capsule, the intracortical attachments are ruptured by applying *circumferential traction toward the initial gap*

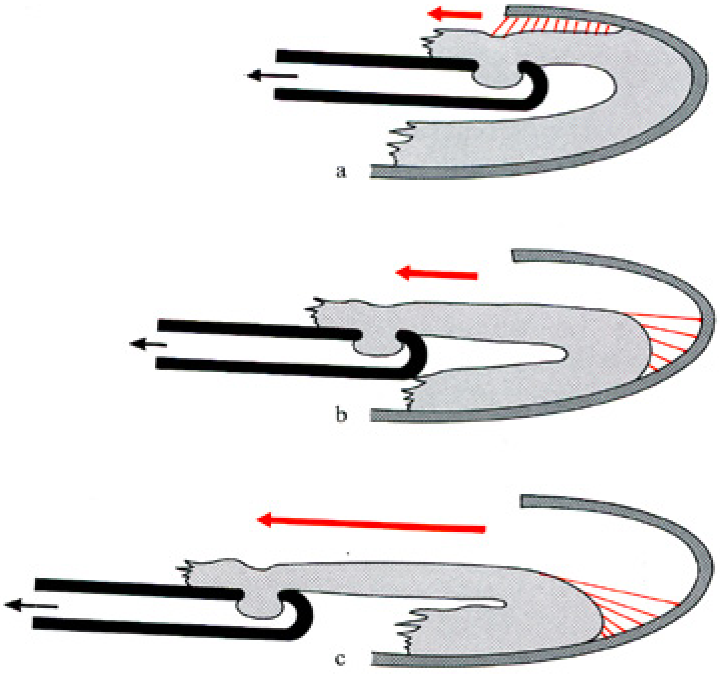


Fig. 8.95. **Removal of peelable cortex.** Resistances encountered by centripetal traction. Initiating traction below the anterior capsule.

a Traction on cortex below the anterior capsule places a diffuse tension on the corticocapsular attachments.

b When the sinus is reached, tension becomes selective, and resistance to separation is decreased.

c As the cortex is stripped from the posterior capsule, tension becomes even more selective and resistance minimal

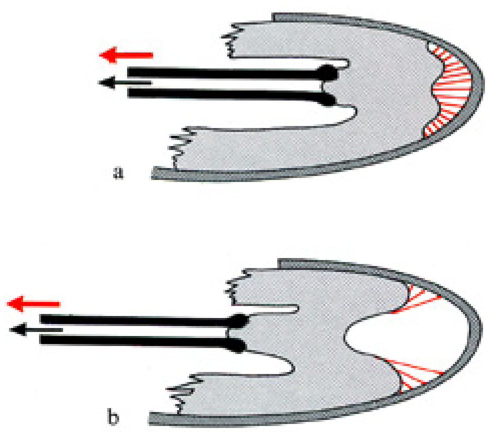


Fig. 8.96. **Removal of peelable cortex.** Initiating centripetal traction in the sinus.

a If traction is initiated in the capsule sinus, the tension is diffuse and the resistance to separation is high (danger of transmission to the zonules).

b As the traction is continued, selective tension is exerted on the corticocapsular attachments at both the anterior and posterior capsule

tex and rely entirely on suction to effect the corticolysis.[55]

Traction on a **peelable cortex**, on the other hand, is produced by *guidance motions* of the aspiration cannula (Fig. 8.92b). Occlusion is maintained by moving the cannula in directions where the lowest resistances are encountered, i.e., in directions that stress the *intracortical* and *corticocapsular* attachments separately and selectively (see Fig. 2.55c). The highest resistances are encountered during formation of the initial gap, i.e., extraction of the first piece from the intact cortex (Fig. 8.94a). During removal of the remaining strips, the intracortical resistances are reduced by almost half.

When starting corticolysis from the anterior cortex (Fig. 8.95) separation from the *anterior capsule* is the most difficult phase because there the countertension against traction at the cortex is low. In *centripetal movements* the traction is opposed by a diffuse resistance from corticocapsular attachments (Fig. 8.95a), and tension becomes selective only when the dissection has reached the capsular sinus (Fig. 8.95b). Conversely, if corticolysis is initiated at the sinus (Fig. 8.96) tension is diffuse at the sinus and becomes selective at the anterior and posterior capsule.

After an initial gap has been formed, *circumferential motion* of the cannula facilitates separation from the anterior capsule (Fig. 8.94b and c).

[55] This requires use of a cannula that can both aspirate and remove firm material. Matter too solid for removal in this way must be delivered by the same techniques used for the lens nucleus. The suitability of firm cortex for hydrodissection can be exploited by injecting fluid to weaken the corticocapsular bonds before applying traction to the cortex itself.

Removal of the Cortex

There are three basic methods for removing the mobilized cortex:

1. The cortex is **aspirated** through the lumen of the cannula. This is held stationary at the center of the anterior chamber because that is the least hazardous position in case occlusion is broken (Fig. 8.97d *left*).
2. The particles are flushed from the anterior chamber by **irrigation** (i.e., by positive pressure) (Fig. 8.97d, *center*). The cannula opening is held close to the chamber outlet as a safety precaution in case of compensatory bulging of the diaphragm (see also Fig. 2.24).
3. The particle is withdrawn from the eye while fixed at the cannula tip (i.e., by **guidance motions**). In this method the cannula is passed into and out of the eye for each individual particle (Fig. 8.97d *right*).

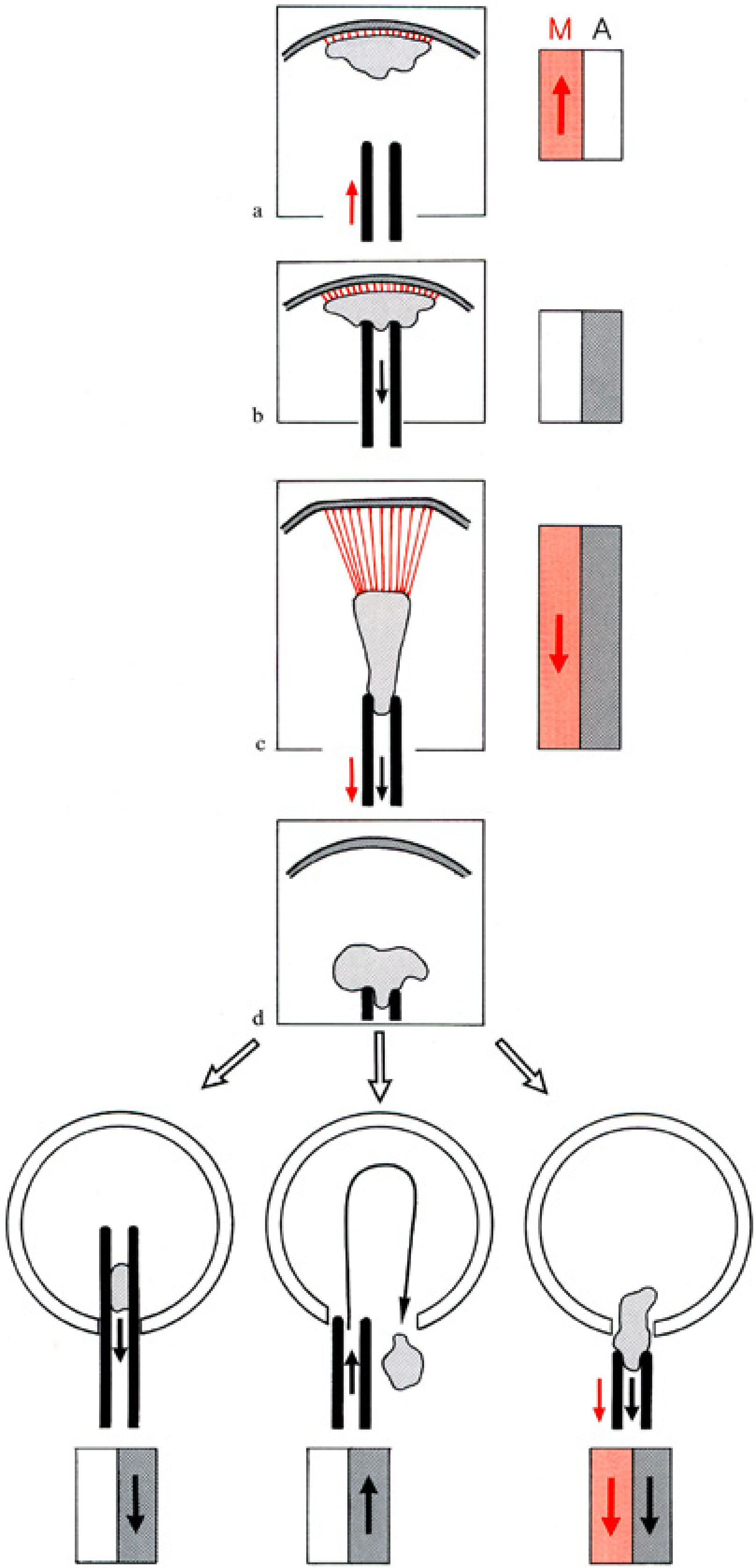


Fig. 8.97. **Phases in delivery of the cortex.** *Bicolor column*: Guidance motions (*M*) and use of aspiration (*A*) in the various phases.

a *Seeking occlusion*: Through guidance motions, the suction tip is applied to the cortical fragment. Aspiration is not switched on until the tip is fully apposed to the fragment.

b *Grasping*: Guidance motions are discontinued, and aspiration is switched on. The cannula is held immobile at this stage so that concomitant motion of the capsule or iris, signifying inadvertent aspiration, can be recognized.

c *Traction*: Guidance motions are resumed while aspiration is maintained.

d *Removal. Left*: The particle is aspirated through the lumen of the cannula itself, which is held stationary.
Center: The particle is removed by irrigation. Motion of the cannula is limited to regulating the cross section of the access opening. *Right*: The particle is retracted from the chamber with the cannula, i.e., by a continuation of phase **c** (guidance motions of the cannula while aspiration is on)

back to index

❮ ❯

Summary of the Procedure for Delivery of the Cortex

Delivery of the cortex can be divided into four phases based on the forces that are applied (i.e., aspiration and guidance motions, Fig. 8.97):

1. **Seeking occlusion**. Only the cannula is moved. Suction is *not* activated until the cannula opening is seated firmly against the cortex (to prevent aspirating aqueous, iris or lens capsule).
2. **Grasping** (establishing firm occlusion). The grasping force is produced by *activating the suction*. The operator performs *no guidance motions* at this time so that he can detect any concomitant motion of the iris or lens capsule signalizing unintended aspiration.[56] When the operator is certain that the cannula is well occluded by cortex only, he may proceed to the next phase.
3. **Traction**. The grasped cortical matter is torn away from the capsule. *Guidance motions* and *suction* are applied concurrently.
4. **Removal**. Whether the cannula is held stationary in this phase or maneuvered by guidance motions, and whether positive or negative pressure in the cannula is used, depends on the selected mode of transport.

8.3.5 Operations on the Posterior Lens Capsule

The posterior lens capsule is delicate and easily torn. Once a *tear* is initiated, it will spread in response to the slightest force. Directly behind the lens capsule is the *anterior hyaloid*, which is even more vulnerable. Thus, any manipulation of the capsule threatens the integrity of the vitreous body and must be planned with that risk in mind.

Surgical procedures on the posterior capsule are further complicated by the difficulty of *visual control*.[57] Thus the surgeon must rely partly on indirect signs to identify the boundaries of the capsule and its relation to other structures.

Polishing the Posterior Capsule

Polishing is a method for cleaning the posterior capsule of any residual cortical remnants and opacities that are adherent to its anterior surface.

Residual **cortical fibers** *too fine* to occlude the opening of an aspiration cannula are *wiped away* with a blunt instrument (e.g., spatula, irrigation cannula) that is applied directly over or alongside the residual matter. Polishing instruments applied to the *surface* of the fibers need not come in contact with the capsule itself. The instrument grips the particles through *friction*; therefore its working end is finely roughened and has a relatively large surface area (Fig. 8.98a).

By contrast, instruments applied *alongside* the residues must come in contact with the posterior capsule in order to function. They mobilize the particles by blocking their evasion during guidance motions. The instrument must actually press against the capsule, *making it tense*, so that the contact becomes sufficiently strong to prevent particles from slipping underneath. The efficacy of this maneuver depends on the lower *edge* of the instrument, which must appose firmly to the capsule surface (Fig. 8.98b). This necessarily creates force vectors directed toward (perpendicular to)

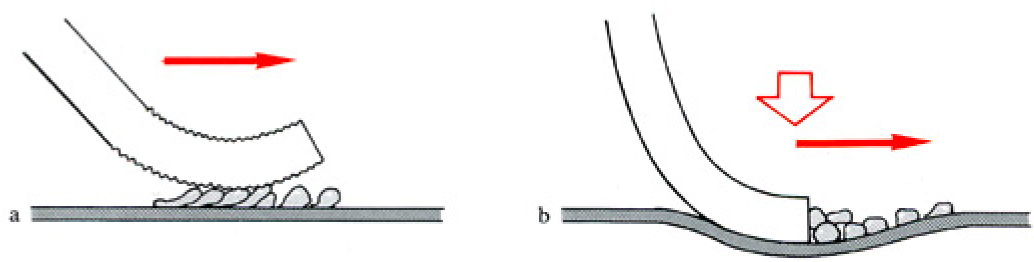
[56] Immobility of the tip on grasping is especially important if a small pupil prevents direct visualization of the cannula opening.

[57] The lens capsule is transparent and invisible under coaxial illumination. Also, it is usually too thin to cause scattering sufficient to be seen under oblique illumination.

Fig. 8.98. **Polishing the posterior capsule**

a Instrument applied to the *surface* of the cortical residue. Forces are transmitted by friction against the surface of the residual fibers. If the undersurface of the polishing instrument is large and roughened, minimal forces are needed. Once contact is established, the instrument is moved strictly parallel to the lens capsule.

b Instrument applied *alongside* the cortical residue. To function properly, the polishing instrument must appose flush to the capsule surface and must tense the capsule so that the cortical fibers will not push it away from the instrument. This tension implies force vectors directed perpendicularly toward the capsule (*large arrow*). Once adequate tension has been established, the polishing instrument is moved strictly parallel to the capsule surface (*small arrow*)



back to index

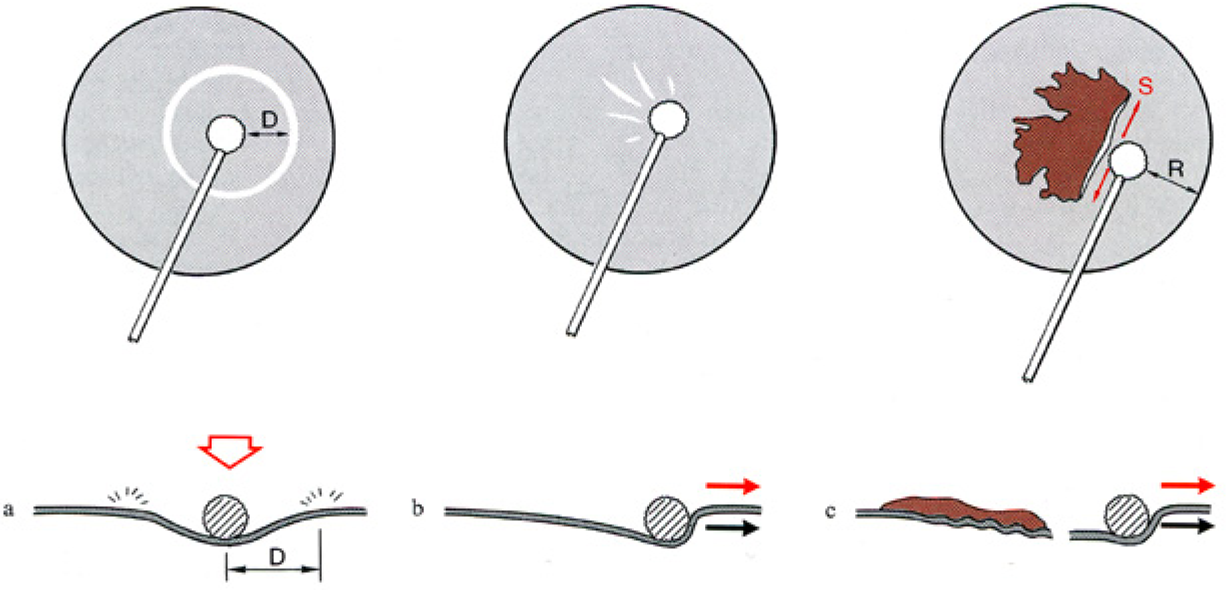


Fig. 8.99. **Visual monitoring of the polishing maneuver**

a By making the capsule tense, the polishing instrument forms an indentation whose borders are made visible by light reflexes. When the reflex appears halo-like, the distance *D* between the edge reflex and instrument indicates the diameter of the indentation and is proportional to its depth. *D* should remain constant as the instrument is moved. This signifies that the instrument is moving freely over the capsule without obstruction, and that a constant capsule tension is being maintained.

b Traction folds signify concomitant motion of the capsule, i.e., that the instrument has "snagged" the capsule and is dragging it. Capsule tension increases on the side of the folds.

c If the capsule is stiffened by a fibrotic plaque, traction folds may not appear, so excessive tension is not easily recognized. The border between the plaque and normal capsule is prone to tearing due to the difference in elasticity. The main risk of rupture exists in motion away from the plaque margin (*R*); motions parallel to the margins of the fibrosis (*S*) are safest

the capsule itself.[58] Since the operator has no appreciable tactile feedback, he must rely on visual criteria when deciding how much force to apply. The forces produce an *indentation* of the capsule, recognizable by a circular edge reflex whose distance from the site of instrument contact indicates the depth of the indentation (Fig. 8.99a).[59]

Once contact has been established, further application of perpendicular forces is suspended, and the polishing instrument is now moved strictly parallel to the capsule surface. Visual control shows a concomitant movement of the edge reflex, whose diameter should remain constant. *Traction folds* (Fig. 8.99b) signify excessive tension of the capsule; they are a warning sign of impending rupture.

Excessive local tension may escape notice at sites where the capsule is indurated by *fibrotic plaques*. The danger of tearing is usually greatest at the plaque margin, where the rigid fibrosis "fixates" the normal, elastic capsule. Polishing at the edge of the plaque is safest with strokes parallel to the margins (Fig. 8.99c).

The **fibrotic plaque** itself is not easily removed. Its *anterior surface* is smooth and is continuous with normal capsule, so it is difficult to engage with an instrument. The *posterior surface* of the plaque is often embedded in folds of the underlying capsule, making it difficult to establish a plane of separation. Moreover, the plaque has a much tougher consistency than the capsule, so any dissecting instrument passed into the interfacial area will have a tendency to deviate toward the less resistant capsule. Consequently, attempts to remove fibrotic plaques entail a *high risk of capsule rupture*.

[58] The capsule cannot be made tense unless the zonule is intact. Subluxation of the lens or zonule weakness due to pseudoexfoliation can make it impossible to polish the capsule.

[59] A lax capsule (e.g., following removal of a giant nucleus) requires considerable indentation. Visual monitoring then becomes difficult because adequate indentation may move the contact site out of the focus of the microscope, so refocusing is required. Also, the localized "dimple" in the posterior capsule becomes less pronounced, so the circular edge reflex is weak. Hence it is dangerous to use sharp-edged polishing instruments, and a lax capsule is preferably polished with a blunt instrument that touches only the surface of the cortical fibers.

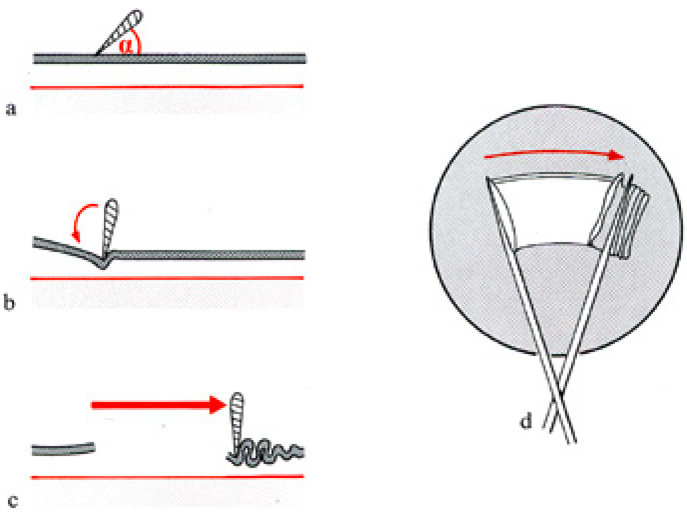


Fig. 8.100. **Posterior capsulotomy by tearing with a discission knife**

a The knife is applied to the capsule at an angle (α) of approximately 45°.

b The blade angle is increased to 90° to optimize friction at the contact site.

c The knife is guided in a sweeping motion parallel to the capsule surface. *Note*: The instrument is used not as a knife but as a "grasping instrument" which tears rather than cuts the capsule.

d Lateral sweeping motion produces tear

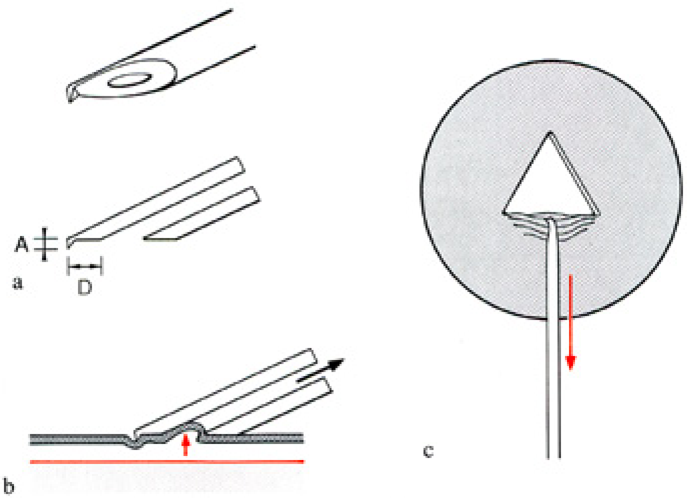


Fig. 8.101. **Posterior capsulotomy using an aspirating cannula with an angled tip**

a The outermost tip of the cannula is bent *toward* the beveled surface to form a hook. The tip should not be longer than the thickness of the capsule (*A*).

b The beveled surface of the cannula is placed against the capsule, sinking the hook into the tissue. Gentle suction aids the fixation of the capsule to the cannula so that the fixating force vectors are directed away from the vitreous rather than toward it. *Note*: If the cannula has a very flat bevel, the distance *D* from the opening to the tip (and thus to the capsulotomy) is large, so the risk of inadvertently aspirating vitreous is decreased.

c Traction on the cannula produces a triangular capsulotomy analogous to Fig. 8.30a

Posterior Capsulotomy

The main difference between anterior and posterior capsulotomy is that the anterior capsule overlies lens matter that may be damaged without compromising the surgical goal, since its removal is already planned. However, the posterior capsule overlies *vitreous*, which must be preserved. Every effort is made, therefore, to direct a minimum of force posteriorly in a planned posterior capsulotomy. *Cutting* with knives or scissors tends to produce force vectors directed toward the vitreous. The safest way to open the posterior capsule surgically is by *tearing*, where applied forces exert a grasping function and separation is directed parallel to the capsule surface.[60]

Because the capsule itself is grasped, *contact* between the instrument and capsule must be stronger than in polishing. *Traction folds* are a positive sign, indicating that the desired effect is being achieved. The contact area between the instrument and capsule should be very small to achieve a maximum concentration of *pressure*. If sharp-edged instruments are used for this purpose, they do not act as cutting instruments but as ultrafine contact spatulas that first grip and then tear the tissue (Fig. 8.100). The "grip" can be improved by suction (Fig. 8.101). Once the capsule is opened, protection of the anterior hyaloid is aided by allowing aqueous or viscoelastic material to flow into and *widen* the interspace (Fig. 8.102).

[60] The principles governing the application of laser light to the capsule are discussed in Chap. 2.3.

back to index

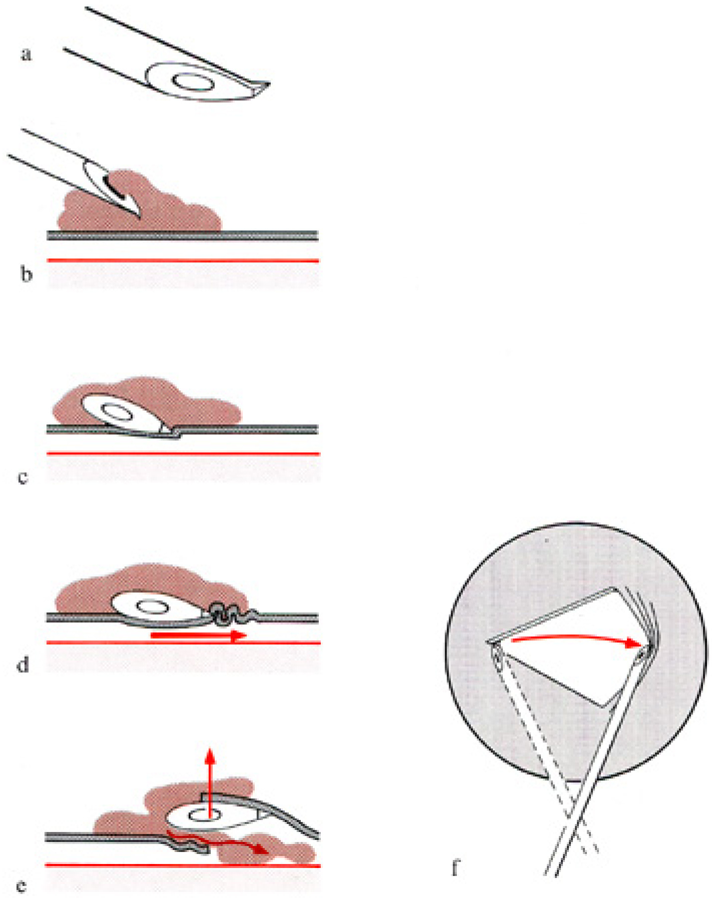


Fig. 8.102. **Posterior capsulotomy using an injecting cannula with an angled tip (injection of viscoelastic material)**

a The tip of an infusion cannula is bent *away* from the beveled surface.

b Viscoelastic material is injected over the proposed capsulotomy site.

c The cannula is placed against the capsule with the tip pointing in the direction the cannula will be moved.

d The cannula is pushed along the capsule surface, raising a tissue fold that is engaged by the sharp tip.

e The cannula is lifted and tears open the capsule. This lifting maneuver creates a suction effect that draws viscoelastic material from the anterior chamber beneath the capsule. Additional viscoelastic material can then be actively injected beneath the capsule to protect the anterior hyaloid.

f The capsulotomy is enlarged by a sweeping motion of the cannula

Management of Incarcerations of the Posterior Lens Capsule

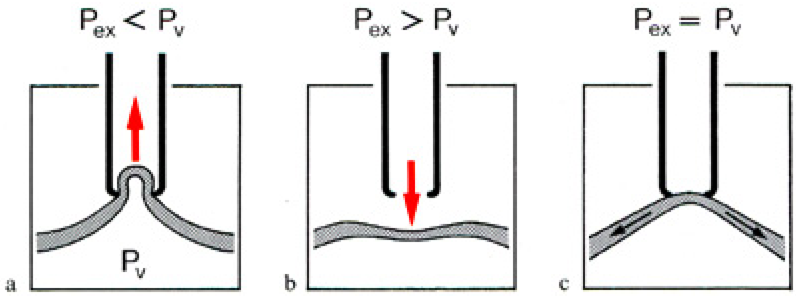
In case of an inadvertent occlusion of the aspiration port by the posterior lens capsule, the fate of the latter depends on the pressure differential between the spaces on both sides of the capsule (Fig. 8.103).

If the suction is on, the pressure in the aspiration system is lower than in the vitreous space, and the lens capsule is sucked into the aspiration port (Fig. 8.103a), where it is apt to be torn.

If the pressure in the aspiration cannula is then raised above the vitreous pressure by a *back-flush* of fluid, the capsule can be repelled (Fig. 8.103b).

If a back-flush system is not incorporated into the aspiration system, the only recourse is to keep the pressure on both sides of the membrane equal and to rely on the intrinsic tension of the capsule for its retraction (Fig. 8.103c). In practice, the pressures in all parts of the hydrodynamic system are brought to atmospheric (=0): In the aspiration system a valve to the outside air is opened. The globe is transformed into a pressureless system (see Fig. 1.3c) by keeping open the access portal and stopping the infusion stream (Fig. 8.104b).

Interrupting the infusion stream for this purpose may seem paradoxical since it may appear that the flow of the infusion is pushing the capsule away from the aspiration cannula. But in fact the infusion raises the pressure within the globe and thus pushes the capsule into the aspiration port (Fig. 8.104a). Only in a pressureless system can the infusion be exploited to repel the capsule, provided short bursts are used which infuse so little volume that no pressure increase can result (Fig. 8.105).



8.103

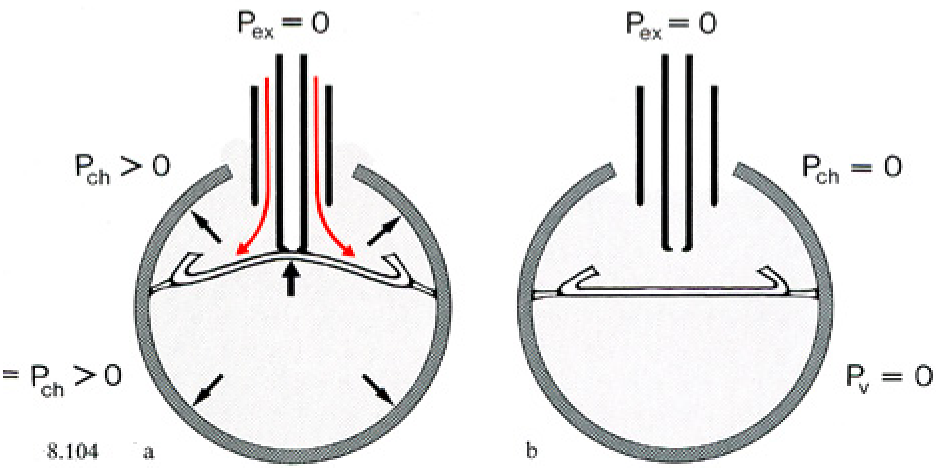
Fig. 8.103. **Effect of pressure differentials on the behaviour of an occluding lens capsule**

P_{ex} outflow pressure
P_{ch} chamber pressure
P_v vitreous pressure

a If the pressure in the precapsular space (aspiration system) is lower than in the retrocapsular space (vitreous chamber), the occluding membrane is sucked into the aspiration port.

b If the pressure in the aspiration system becomes higher (through back-flush), the membrane is pushed back and occlusion no longer exists.

c If the pressures on both sides of the membrane are equal, the tension of the capsule determines whether the frictional resistance between the incarcerated capsule and the aspiration port can be overcome and the capsule released



8.104

Fig. 8.104. **Releasing an incarcerated capsule without back-flush**

a If the aspiration is stopped and the pressure in the aspiration system is brought to zero, there will be a pressure differential at the aspiration port if the infusion stream continues and keeps the intraocular pressure above zero

b If the infusion is also stopped, the pressure in the globe falls to zero (provided the outflow path from the chamber remains open)[61]

8.105

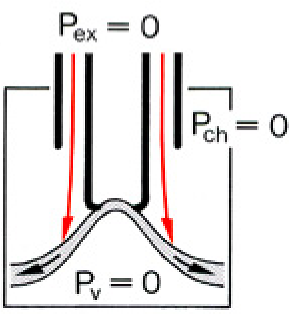
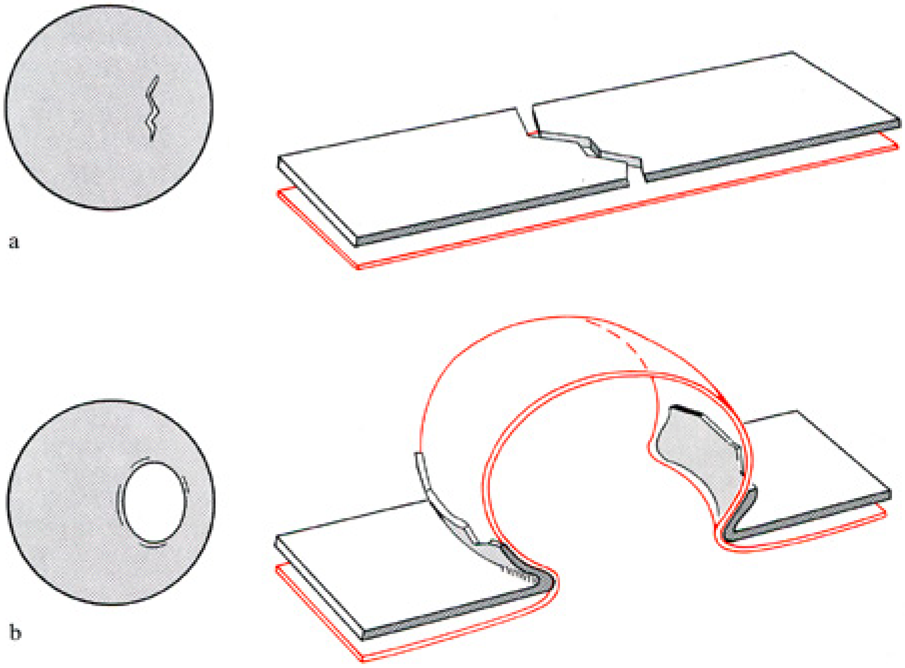


Fig. 8.105. **Retraction of the posterior lens capsule in a pressureless system**

Bursts of infusion so short that they cannot raise the intraocular pressure increase the tension of the capsule and allow for retraction of the membrane

[61] This is true only if the pressure in the vitreous chamber is zero. If there is positive vitreous pressure, only the pressure in the anterior chamber becomes zero. There remains a pressure differential at the aspiration port, and there is no way to repel the incarcerated capsule (unless one succeeds in providing a back-flush with pressures above those in the vitreous).



8.106 a b

Management of Posterior Capsule Rupture

All measures following rupture of the posterior capsule are geared toward the behavior of the *vitreous*. The goal is to isolate the posterior capsule and anterior segment from the vitreous body.

If the anterior hyaloid remains behind the capsule, the surgery may proceed as for a planned capsulotomy. This uncomplicated situation is recognized by observing the *margins of the tear*, which should retain their original linear or sharply angulated shape (Fig. 8.106a).

If the vitreous moves *forward*, it will separate or even enlarge the capsule tear. The defect in the elastic capsule then becomes circular in shape – a sign that an active force is pushing apart the margins of the tear (Fig. 8.106b).

If the *anterior hyaloid* has remained **intact**, the prolapse can be repositioned and the margins of the posterior capsule reapproximated. Since there is still a boundary between the vitreous chamber and anterior chamber, the problem can be solved by space-tactical means. Raising the anterior chamber pressure to a level exceeding the vitreous pressure will push the prolapse backward. This requires a watertight wound closure.

If the operating plan prohibits definitive closure of the anterior chamber (e.g., prior to the insertion of an IOL), the pressure in the anterior chamber cannot be raised; *fluid* injection has no effect. If *air* is injected in this situation, it functions less as a space-tactical instrument than as an expanding spatula. The bubble presses on the prolapsed vitreous only from above, so it is effective for flattening the prolapse but it will not necessarily reduce it (Fig. 8.107).[62] For reducing a prolapse with *viscoelastic substance*, the material is injected first around the sides of the prolapse to reapproximate the everted margins of the lesion (Fig. 8.108). The viscoelastic ring contains the material that is injected later towards the center in order to direct so that is directed the prolapse back through the capsule lesion.[63] Once the torn margins of the capsule are fully reapproximated, the *reduction* is complete (Fig. 8.106a).

If the *anterior hyaloid* is **ruptured** and the vitreous prolapse is not reducible by the method described, reduction must be accomplished by decreasing the vitreous volume, i.e., by *anterior vitrectomy*.

[62] The main advantage of having air over a flattened vitreous prolapse is that the bubble defines areas in the anterior chamber that are devoid of vitreous and so are available for surgical manipulations. Note, however, that vitreous may reappear in the anterior chamber following absorption of the air in the postoperative period.

[63] In this final phase of the reduction when only downward-directed forces are needed, air can also be injected over the viscoelastic material. This can be done as soon as the capsular tear has lost its circular shape and its margins have started to move closer together.

back to index

❮ ❯

◄

Fig. 8.106. **Behavior of the breached posterior capsule**

a If the anterior hyaloid remains in its anatomic location behind the lens capsule, the capsule lesion will have straight or sharply angled margins.

b If vitreous prolapses through the breached capsule, it will separate the margins of the lesion, which now appears circular due to the interaction between the evenly distributed forces of the protruding vitreous and the evenly distributed resistance of the capsule

Fig. 8.107. **Attempt to reposition intact prolapsed vitreous with air** ►

a An injected air bubble compresses the prolapse from above and will reduce it if the anterior chamber is closed and the pressure can rise there[64].

b If the anterior chamber is not completely watertight, expansion of the bubble will cause a compensatory loss of aqueous. The prolapse is flattened but not reduced.

c With a large prolapse, there is insufficient aqueous to compensate for the volume shift, and the expanding bubble will tend to expel vitreous from the eye rather than reduce the prolapse

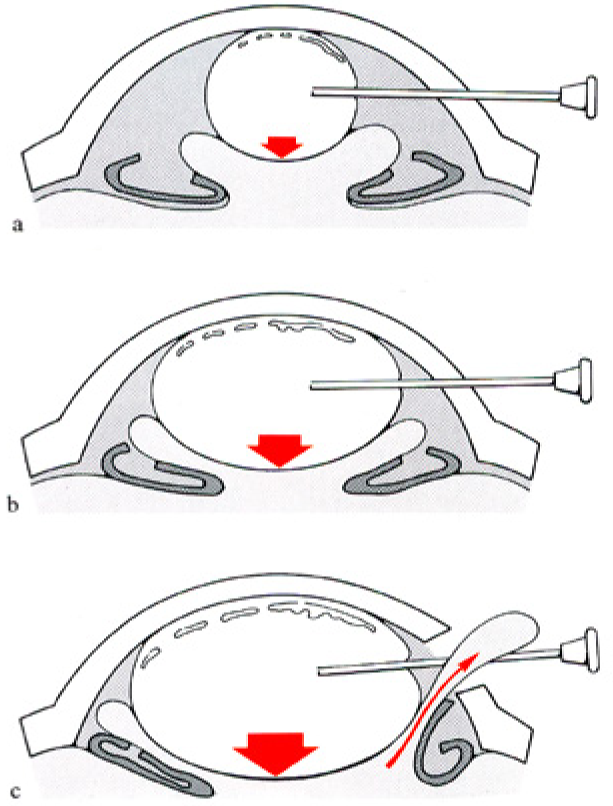
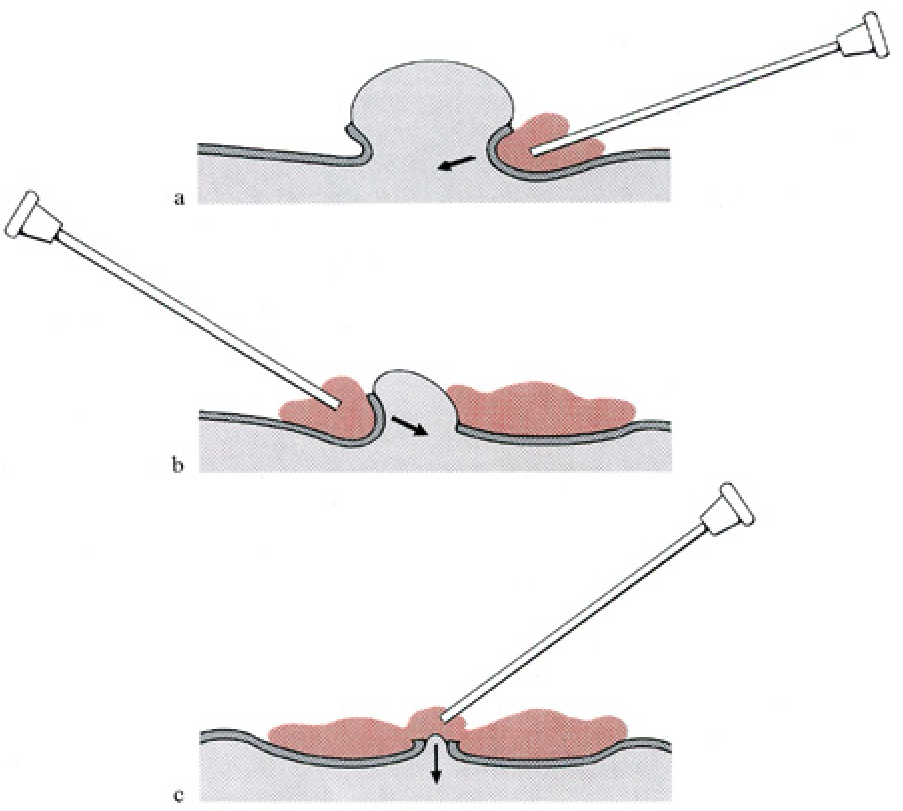


Fig. 8.108. **Reduction of an intact vitreous prolapse with viscoelastic material** ►

a Starting from the periphery of the capsule and working toward the center, a "viscoelastic spatula" is injected toward the everted capsule margin to push it back toward the prolapse and hold it in place.

b This procedure is continued all around the lesion until the capsule margins are so positioned that pressure from above will no longer evert them. Contained in this way by viscoelastic material, the prolapse can only move downward when compressed from above.

c Finally viscoelastic material is injected onto the prolapse from above, effecting the reduction



[64] *Note*: As the pressure rises the air bubble is compressed. Successful pressure increase, then, is recognizable by a discrepancy between the amount of injected air and the resulting increase in bubble size.

back to index

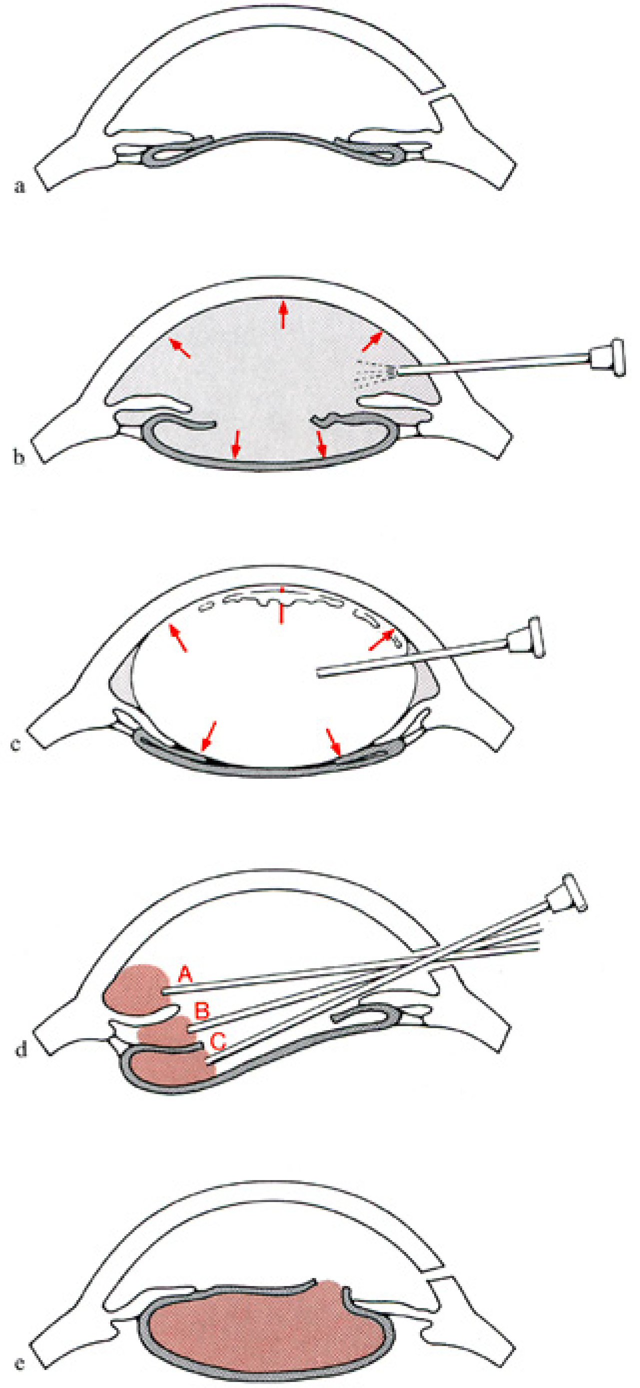


Fig. 8.109. **Space-tactical situations after evacuation of the capsular bag**

a Obliteration of the retroiridal subcompartments. Any forward motion of the diaphragm following evacuation of the capsular bag will restrict the interspaces between the iris, anterior capsule, and posterior capsule.

b Reformation of the anterior chamber with watery fluid. As the anterior chamber is repressurized, the posterior capsule is restored to its anatomic position. The position assumed by the iris and anterior capsule remnants depends on their tissue tension. The iris moves onto the plane of the iris root. The tension of the anterior capsule remnants depends on the size and shape of the capsulectomy.[65]

c Obliteration of the subcompartments by air injection. The air pressure chamber opens the chamber angle but depresses the iris against the capsule layers, narrowing the spaces between them.

d Selective reexpansion of the subcompartments by injection of viscoelastic material into the chamber angle (*A*), the iridocapsular interspace (*B*), and the intercapsular space (*C*).

e Separation of the anterior and posterior capsule layers in the presence of a small capsulotomy. Total visco-occupation of the collapsed capsular bag restores its shape and increases its tension

[65] A plain circular capsulectomy may leave the capsule remnants tense, whereas an excision with angled or jagged edges relieves tension and leaves tags of tissue that float in a watery medium.

back to index

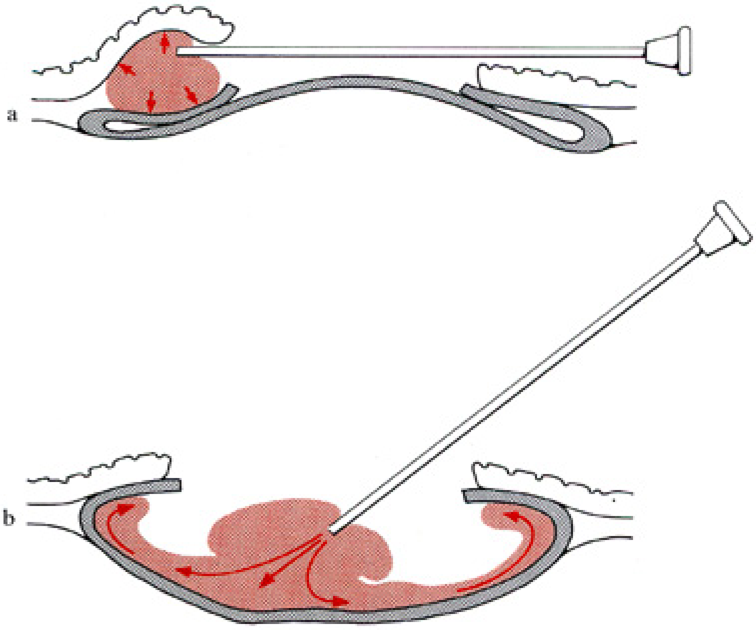


Fig. 8.110. **Selective placement of viscoelastic material in the iridocapsular or intercapsular interspace**

a Expansion of the *iridocapsular* interspace. The cannula tip elevates the iris away from the anterior capsule, and the viscoelastic material is injected toward the undersurface of the iris. This presses the anterior capsule against the posterior capsule and prevents viscoelastic material from entering the space between the capsule layers.

b Expansion of the *intercapsular* space. The posterior capsule is pressed back away from the anterior capsule by first injecting the viscoelastic material toward the center of the posterior capsule (center of the pupil). From there the material spreads peripherally along the surface of the posterior capsule, thereby expanding the space between the two capsule layers

Measures on the Lens Capsule Relating to the Insertion of Intraocular Lenses

The iridocapsular and intercapsular spaces may become obliterated following evacuation of the capsular bag. The anterior capsule tends to fall back onto the posterior capsule, and both capsule layers may appose to the undersurface of the iris (Fig. 8.109a). This makes it difficult to position a retropupillary IOL accurately.

Selection of Pre- and Intercapsular Insertion Sites

Selective reopening of the desired intraocular compartment for positioning the supporting loops of an IOL is a problem of spatial tactics.

If the space is reexpanded with **watery fluid**, it is necessary first to restore the anterior chamber as a pressure chamber. This requires a wound closure that can retain sufficient watertightness during the insertion maneuver.[66] A satisfactory space can usually be developed between the capsule layers and the iris. Success in separating the anterior and posterior capsule layers themselves depends on the tension of the anterior capsule. This is influenced by the shape of the anterior capsulotomy (Fig. 8.109b) and cannot be increased secondarily by the injection of watery fluid.

Basically, **air injection** merely enlarges the anterior chamber. It removes the corneal endothelium from the field of manipulations and widens the chamber angle. However, the iris and capsule layers are pressed backward as a unit, and the interspaces among them are compressed (Fig. 8.109c).

The different compartments can be selectively shaped with **viscoelastic materials**. The iridocapsular and intercapsular spaces can be expanded segmentally or over their whole circumference (Fig. 8.109d, e).

The *selective placement* of viscoelastic material into subcompartments is easy if the remnants of the anterior capsule are plainly discernible. However, if the capsule remnants are not accessible, the viscoelastic material may be injected toward the adjacent membranes, i.e., toward the iris to press it forward or toward the posterior lens capsule to press it backward (Fig. 8.110). If the posterior capsule is breached, the rupture site must first be tam-

[66] Requirements in this regard depend on the level of the vitreous pressure, for an equal level must be established in the anterior chamber to restore a normal chamber depth and normal anatomic relations within the eye.

back to index

❮ ❯

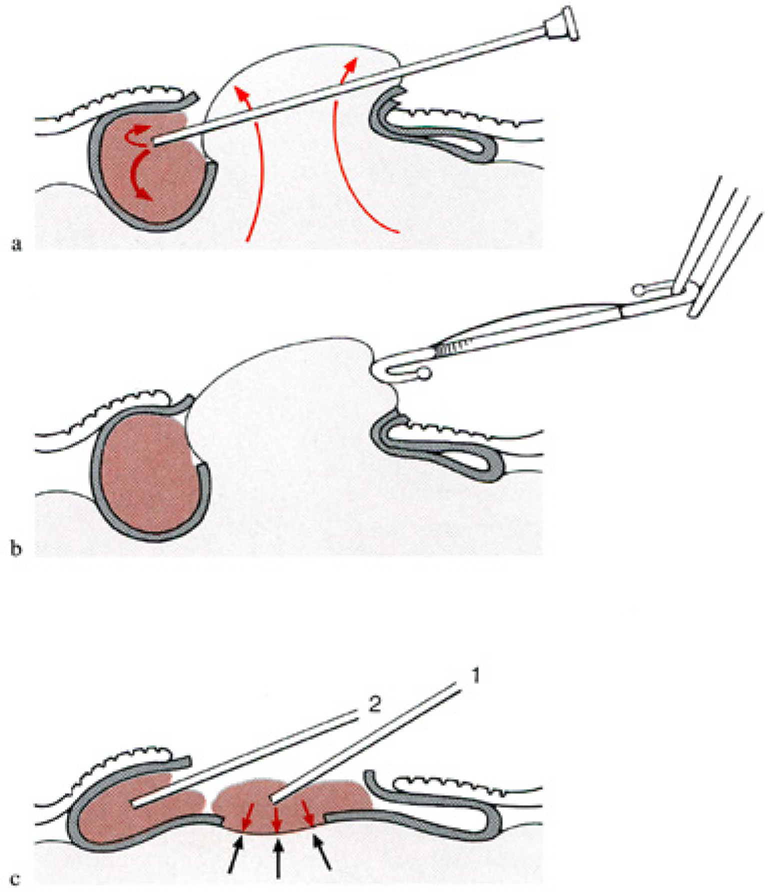


Fig. 8.111. **Expanding the peripheral compartments following rupture of the posterior capsule**

a Expansion of the retroiridal space by injected viscoelastic material causes compensatory vitreous prolapse through the rupture site.

b This prolapse, often invisible within the viscoelastic medium, prevents the placement of IOL haptics behind the iris.

c The first step, then, is to tamponade the rent in the posterior capsule (see Fig. 1.23) before proceeding to expand the retroiridal space

ponaded before the subcompartment is expanded peripherally (Fig. 8.111).

The use of viscoelastic materials has the additional benefit of increasing the tension of the capsule and smoothing it out so that implants can glide over the capsule surface without becoming snagged in folds. Further, "visco-occupation" of the anterior chamber can immobilize the implant in any position along its insertion path without the need for instrument fixation. Thus, malposition of an implant during insertion can be corrected by releasing the IOL, reorienting it, regrasping it in a better position, and guiding it optimally to the implantation site.

The increased resistance of the viscoelastic material, however, can cause the implant to deviate from the intended path during insertion either at the surface or within the viscoelastic bolus itself. **Deflection** at the *interface between a liquid and viscoelastic medium* (Fig. 8.112) is best avoided by eliminating such interfaces altogether, i.e., by placing the viscoelastic material along the entire insertion route from the corneoscleral incision to the implantation site. If the implant must traverse an interface, the degree of the deflection is minimized if it is passed through at an angle approaching 90°.

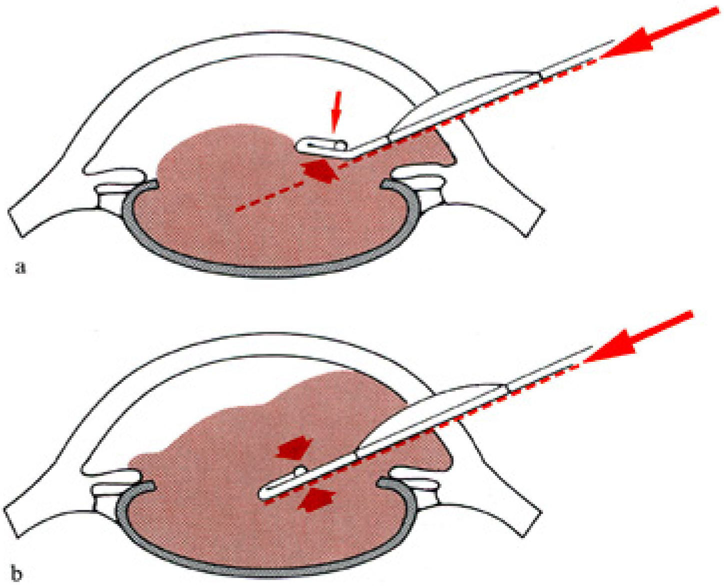
Deflection can even occur *within the viscoelastic medium itself* when the moving implant presents an angled surface to the medium (Fig. 8.113). The asymmetrical resistances that produce this deflection are unavoidable during the insertion of an angulated implant; however, the effect of these resistances can be reduced by inserting the implant very slowly.

In practice, deflection is mainly a problem when an implant with soft, elastic supporting haptics is used. If the implant is handled by those haptics during insertion, their elasticity will provide the force for guiding the optic portion into the desired position. This elasticity is opposed by the elastic resistance of the viscoelastic material beneath the optic portion, which tends to repel the implant and push it back.

Once the implant has been maneuvered to its definite position, it must be held in that position for a moment so that the surrounding viscoelastic material can yield and stabilize. If the haptics are released too soon, the molecular chains will not have time to rearrange below the implant, and they will repel it from the desired position.

If the resistance of the viscoelastic material is too high in relation to the elasticity of the haptics (as in implants with a large optic portion), it becomes impossible to insert the implant by manipulation of the haptics. The larger the optic portion, the more one has to rely on techniques in which the implantation instrument grips the optic portion of the IOL directly (Fig. 8.114).

back to index

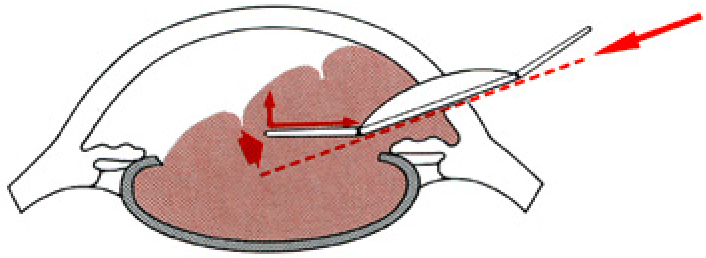


8.112 a b

Fig. 8.112. **Deflection of soft haptics at the interface between liquid and viscoelastic media**

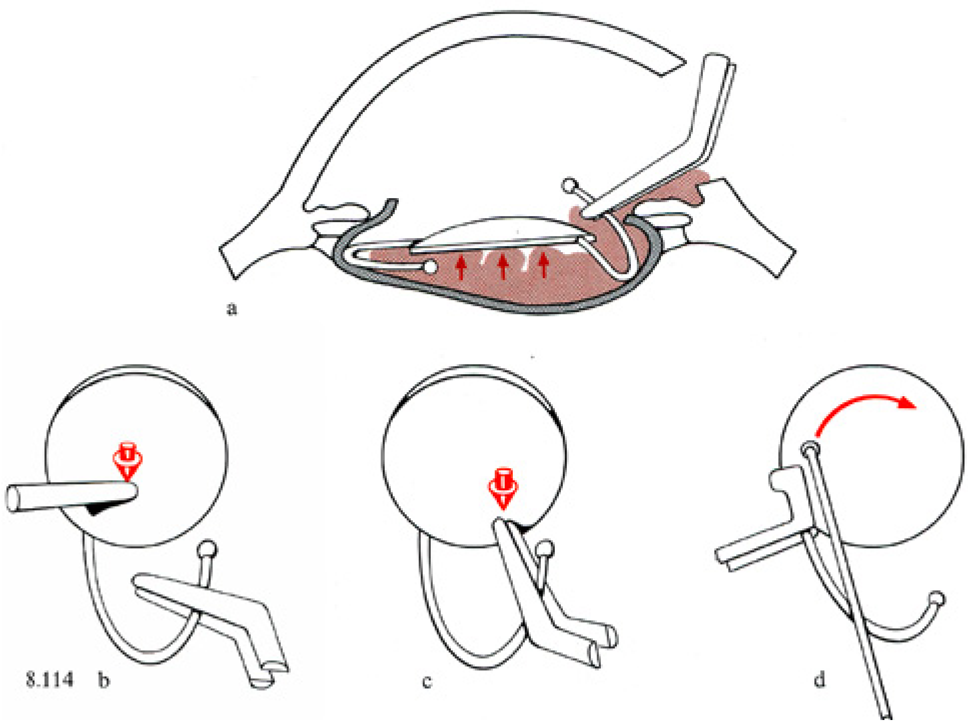
a If viscoelastic material has been injected only into the deep portions of the anterior chamber, the resistance at the interface is higher on the side of the viscoelastic material (*wide arrow*) than on the side of the watery fluid (*thin arrow*). Deformable haptics are deflected and cannot be inserted behind the iris.

b If the viscoelastic material forms a continuous medium from the corneal incision to the destination, the haptics encounter equal resistances above and below, and deflection does not occur



8.113

Fig. 8.113. **Deflection tendencies within the viscoelastic medium.** If the haptics are positioned at an angle to the optic portion of the implant, they will encounter asymmetric resistances when the implant is moved on the plane of the optic portion. Resistance to the motion of the haptic (*medium arrow*) has a component that exerts an upward force on the haptic (*wide arrow*)



a

8.114 b c d

Fig. 8.114. **Overcoming viscoelastic resistance to the optic portion of an IOL**

a Viscoelastic material in the capsular bag offers high resistance against placement of the large optic portion of an implant.

b This resistance can be overcome by pressing the optic portion downward with a spatula.

c The implantation forceps itself, if properly shaped, can be used to exert counterpressure on the optic portion of the IOL. Note that while in **a** the haptic is gripped with the tips of the forceps, here it is gripped farther back on the forceps, whose tips can then project over the optic portion and push it down.

d Here the optic portion is seated with a laterally applied insertion spatula whose front surface has a guide slot. (The back surface of the spatula is hook-shaped for retraction of the iris and lens capsule)

back to index

Artificial Capsule for Aiding IOL Insertion

The lens capsule provides a useful guide surface for the placement of retropupillary IOLs. Through its resistance, it can direct the haptics of the implant to their fixation sites in the ciliary sulcus or intercapsular sinus. Without this guide surface, it is difficult to keep the haptics on the intended path.

If the lens capsule is absent following an intracapsular delivery or an extensive tear of the posterior capsule, an *artificial guide surface* can be formed by utilizing the membrane-like properties of interfaces. This is done by injecting an air bubble behind the pupil and holding it in place by filling the prepupillary space with viscoelastic material (Fig. 8.115). The haptics of the implant are applied to the surface of the bubble at small angles so that they glide along its surface and do not penetrate it. In that way they can be safely guided through the pupil and along the posterior face of the iris into the ciliary sulcus.

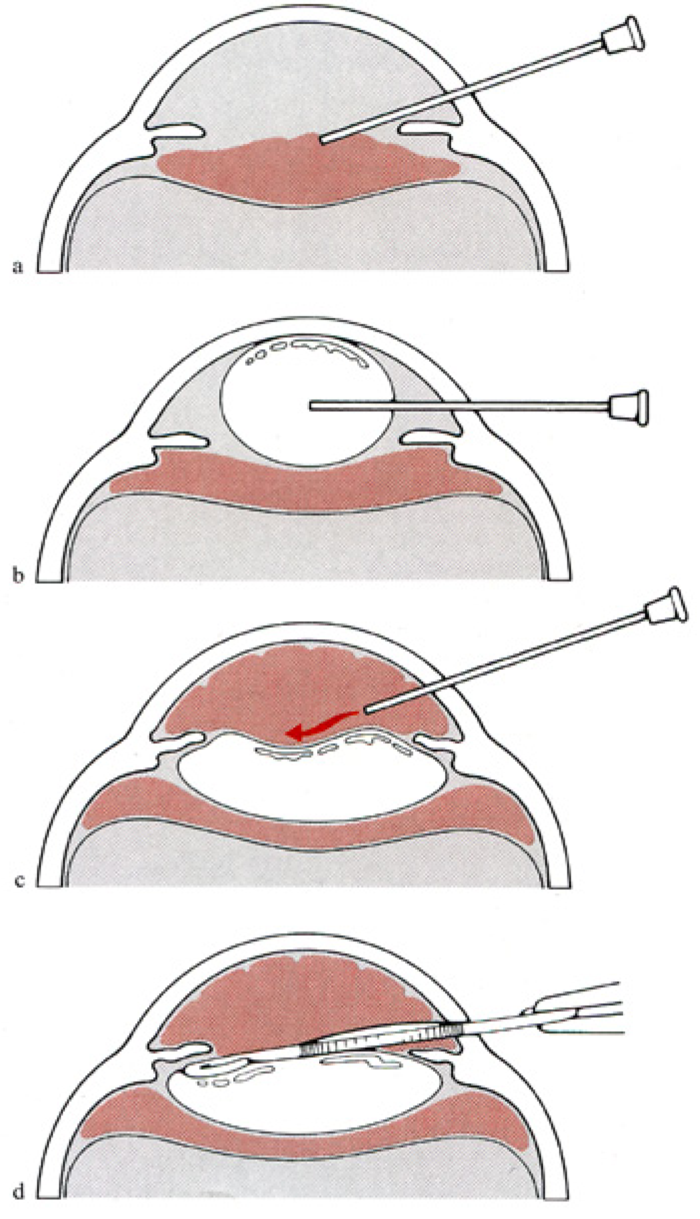


Fig. 8.115. **"Air sandwich" as an artificial lens capsule**

a A protective layer of viscoelastic material is placed over the vitreous surface. This layer should just cover the anterior hyaloid as a protection. If too much material is injected, there will be insufficient volume for the subsequent injections during steps **b** and **c**.

b An air bubble is injected above that layer.

c Another layer of viscoelastic material is injected above the air bubble, pressing the bubble down behind the pupil.

d The *haptics* of the intraocular lens glide along the bubble surface into the ciliary sulcus. The buoyancy of the bubble keeps the *optic portion* of the implant elevated and holds the IOL against the undersurface of the iris