5 Operations on the Cornea and Sclera

5.1 General Problems of Surgical Technique

The coats of the eye consist of lamellar tissue. From a surgical standpoint we may distinguish zones with very *regular lamellae*, such as the cornea, from zones with *irregular lamellae*, such as the sclera. These zones differ optically in their transparency, and their anatomic junction occurs in the bluish-gray transition zone at the limbus (Fig. 5.1).

The technique of surgical manipulations is greatly influenced by the *intraocular pressure*. Methods that are effective at a high pressure are not so when the pressure is low. This means that manipulations serving one and the same purpose must be performed differently before and after opening the globe.

When the intraocular pressure is *high*, the tissue in front of a cutting edge can be **immobilized** with a fixation instrument applied *anywhere* on the globe, for in this situation it will fixate the eye as a whole. When the intraocular pressure is *low*, fixation is effective only when the tissue is grasped and immobilized *very close to the cutting edge* (Fig. 2.54c).

Intraocular pressure also affects the **sharpness** of cutting instruments. Blades that are sharp at high pressure can behave as blunt instruments when the pressure is low (see

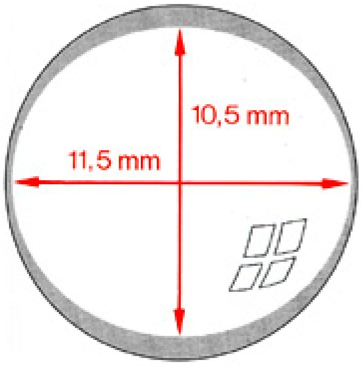


Fig. 5.1. **The corneoscleral boundary: zone of regular lamellar architecture and transition zone.** Externally, the vertical corneal diameter appears smaller than the horizontal, but internally the diameters are approximately equal in both directions. Thus, the transition zone at the limbus is wider superiorly and inferiorly than laterally and medially

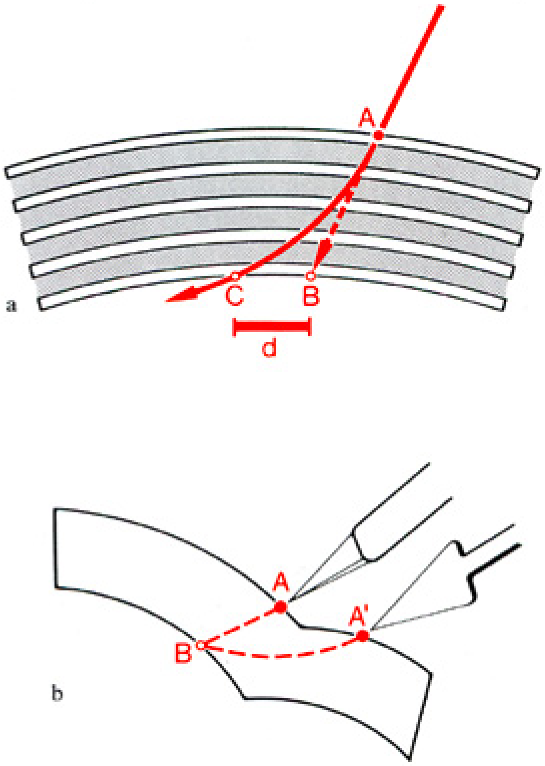


Fig. 5.2. **Effect of corneoscleral lamellar structure on cutting technique**

a Because the tissue has a lamellar structure, an incision started obliquely tends to stray onto the plane of the lamellae. Thus, a blade inserted at point *A* will not follow a straight path to point *B*, but will enter the anterior chamber at *C*. Allowance must be made for this, but the distance *d* of the lamellar deflection is difficult to estimate as it depends on the cutting ability of the blade and the sectility of the tissue.

b If the chamber is to be entered at a predetermined point *B*, a metal keratome (relatively blunt) needs to be inserted more peripherally (*A'*), while an ultra-sharp diamond blade can be inserted at *A* along a straight path aimed directly at *B*

back to index

Fig. 2.53). This must be considered when attempting to open the anterior chamber as well as in the dissection of lamellae. An incision made obliquely through the lamellae tends to stay on the original path when the intraocular pressure is high, but at low pressures it undergoes significant lamellar deflection and may even fail to reach the target (cf. Fig. 2.61). As it is difficult to assess the tendency toward lamellar deflection in a given situation, poor precision is always a risk when *oblique* incisions are used (Fig. 5.2). In work requiring high precision, then, these incisions should be avoided in favor of incisions made perpendicular or parallel to the lamellae. The *vertical incision* determines the precise depth of the cut, while *parallel dissection* determines the size of flaps.[1]

5.2 Dissection Technique

Reaching the Desired Depth. The depth of a vertical incision can be estimated from the *length of blade* immersed in the tissue (Fig. 5.3). In longer incisions it is easier to maintain a specified depth by fitting the blade with a *stop* (Fig. 5.4). However, this stop will function precisely only if the knife is held at a designated angle to the tissue surface (Fig. 5.4c). The preset depth can never be achieved along the entire cut, the difference depending on the shape of the blade and its guidance (Fig. 5.5).

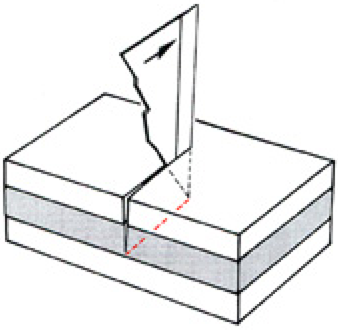


Fig. 5.3. **Vertical incision.** The depth of a vertical incision is estimated by the length of blade tip concealed by the tissue

Initiating the Lamellar Dissection. The major goal in the initial phase of a lamellar dissection is to create *sufficient space*, so that the blade can be rotated 90° for dissecting on the plane of the lamellae (Fig. 5.6).[2]

---

[1] Examples: In the limbal transition zone: Narrow flaps for 3-step incisions, wider flaps for covering antiglaucomatous fistulae. In the cornea: Lamellar grafts. In the sclera: Pockets for intrascleral implants in buckling retinal detachment operations, lamellar sclerectomies for removal of uveal tumors.

[2] This step calls for high precision if the flap must have a uniform thickness to its outer edge, as in lamellar keratoplasty.

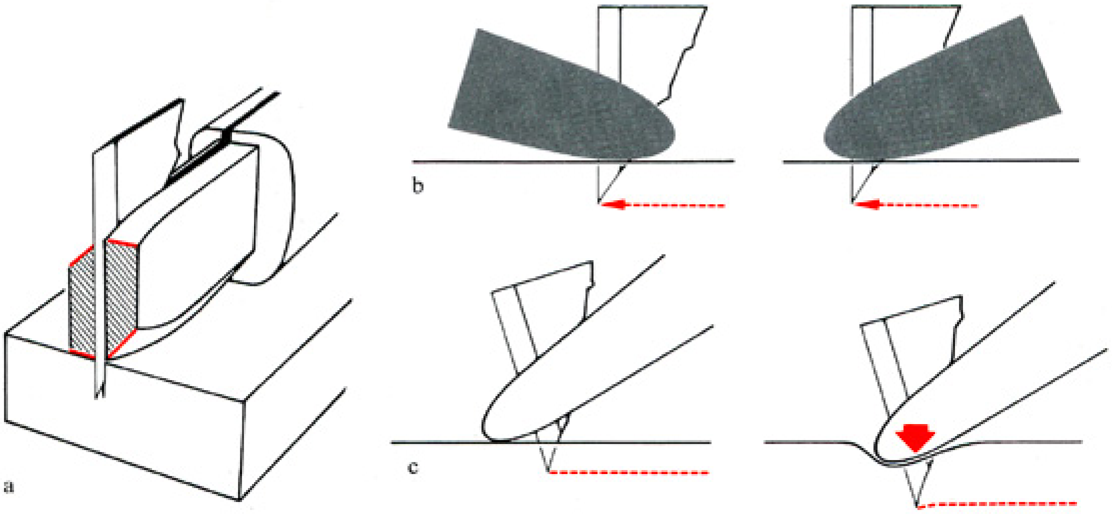


Fig. 5.4. **Incision with a preset depth**

a Example of a stop arrangement for a razor-blade holder. One jaw of the holder is square-edged and acts as a depth stop; the other jaw, which faces the surgeon, is beveled to facilitate visual control.

b The results are determined by the guidance direction of the cutting edge. They are not influenced by whether the blade is "pushed" or "pulled" through the tissue, although a forward incision (*right*) gives a better view of the tissue to be incised.

c The preset depth is reached only when the blade holder is held in a predetermined position. In other positions the entire preset blade length may not enter the tissue (*left*). If the holder is pushed down against compressible tissue (*right*), it may indent the surface and cut to a greater depth than the preset value

back to index

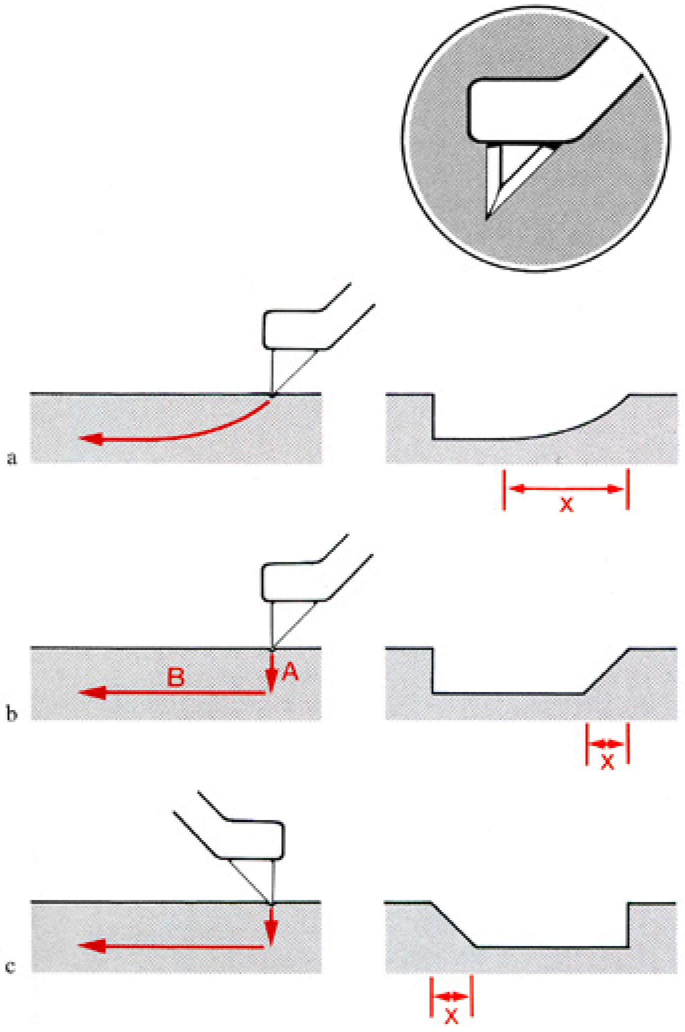


Fig. 5.5. **Profiles of vertical cuts at preset depth**. Shown here are cuts produced by a triangular diamond knife with front and rear cutting edges (inset).
Left: Paths traveled by the blade.
Right: Resulting cut profiles.
X: Portion of cut with insufficient depth.

a If the blade is gradually introduced into the tissue while moving forward (*left*), the initial part of the cut will be more superficial than planned (i.e., than preset with the stop).

b If the blade is thrust full depth into the tissue (*A*) *before* the horizontal motion (*B*) is begun, the cut will have the preset depth for almost its full length. Only the end profiles will vary depending on the shape of the blade. Here the blade is pushed, so the longitudinal cut profile is oblique at the beginning and vertical at the end.

c If the same blade is pulled, the cut profile is vertical at the beginning and oblique at the end

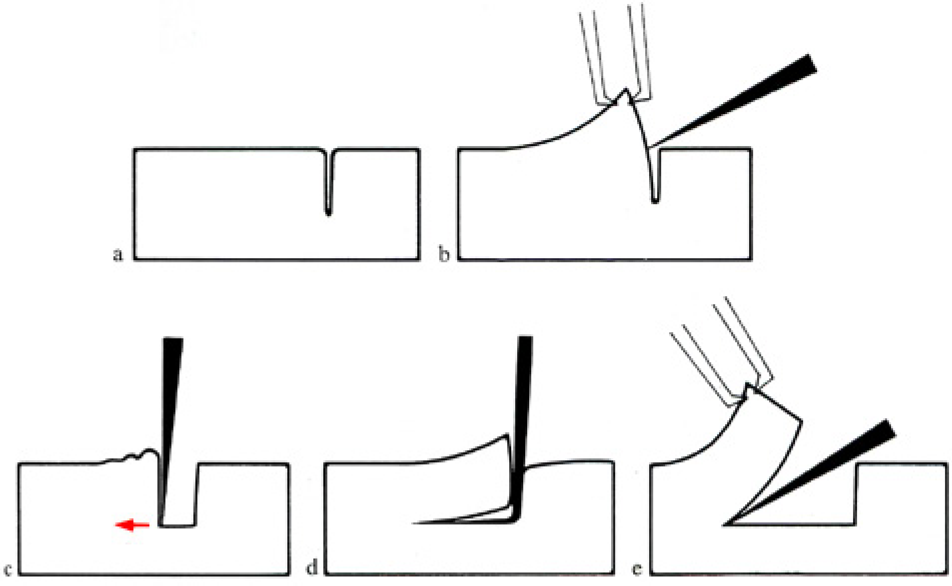


Fig. 5.6 **Starting the lamellar dissection**

a The tissue is incised to the predetermined depth as shown in Fig. 5.3 or 5.4.

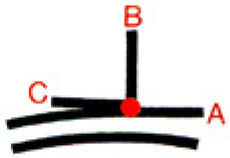
b If the wound lip is picked up with a forceps to begin the lamellar dissection, the tissue becomes stretched, and it is difficult to assess accurately the depth of the incision. The blade has to be applied obliquely and may not reach the desired plane.

c Precision is increased by passing the blade vertically to the base of the prepared groove and then pushing it laterally while keeping it in the upright position.

d Given the space limitations, a short angulated blade facilitates the initial undermining of the flap.

e As the undermined area offers sufficient space for maneuvering, the dissection may be continued with a blade inserted obliquely

back to index



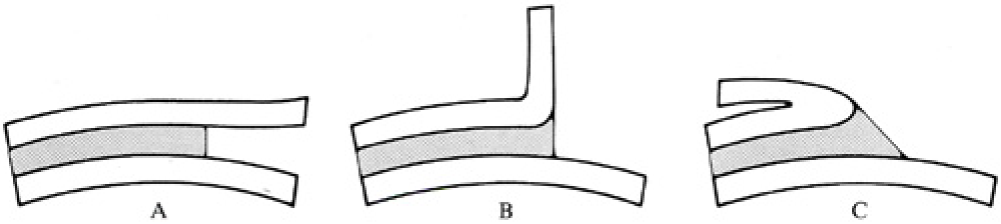


Fig. 5.7. **Dissection of lamellae.** The various techniques of lamellar dissection differ in how the mobilized flap is held while the interlamellar fibers are divided.
A: In situ flap
B: Elevated flap
C: Reflected flap
In *A* the fibers to be divided retain their anatomic position, but they are obscured by the overlying flap. *B* and *C* allow a direct view of the fibers but lead to the formation of a hinge fold, i.e., to tissue deformation with a change in tension

Continuing the Lamellar Dissection. When sufficient space has been created at the base of the cut for maneuvering the blade, various techniques are available for continuing the lamellar dissection. They differ with respect to visibility and tissue tension, and these are determined by the *angle* that is maintained *between the free margin of the flap and the plane of the dissection* (Fig. 5.7).

The dissection of an **in situ flap** (Fig. 5.8) is difficult to monitor visually and is suitable only in cases where the dissection can be performed *bluntly*.[3] The fibers to be divided are obscured by the overlying flap, and only the *position of the blade* can be evaluated. It is directly visible in the transparent cornea; in opaque tissue it can be checked indirectly by lifting the blade slightly to make a visible bulge in the tissue surface.[4]

Dissection with an *elevated* or *reflected flap* affords a clear view of the interlamellar fibers, so either technique is appropriate when *sharp* dissection is required. However, the elevating or reflecting maneuver deforms the tissue, and a hinge fold is produced which affects the position and tension of the fibers to be divided.

In the **elevated flap**, the interlamellar fibers at the ends of the hinge fold come under high tension, while the fibers at the center of the fold are lax (Fig. 5.9). This means that the cutting edge tends to encounter deeper fiber segments at the ends of the fold, and more superficial segments at the center. Another effect is that the sectility of the end fibers is increased, making those fibers easier to cut, and deviations of the dissection from the anatomical lamellar level are more likely to occur there than at the center. The fibers are less sectile centrally, where it is easier to maintain the plane of a given lamella.

The effects of the hinge fold can be reduced by *shortening its length*. This is achieved either by dividing the end fibers first and then gradually dissecting toward the center, or by subdividing a wide flap into narrower segments (see Fig. 1.54) if this is compatible with the operative goal.

In the **reflected flap** the tension of the interlamellar fibers does not stem directly from the forceps traction. Its distribution over the hinge depends far more on the *quantity* and *tension of the reflected tissue* (Fig. 5.10). Thus, a uniform tension can be maintained across the developing flap, regardless of the flap width, and this makes it easier to dissect a flap of even thickness. However, reflection of the flap bends the hinge, and the tissue offers resistance to this bending action. The degree of resistance for a given tissue and given intraocular pressure depends on the thickness of the reflected flap, so it can be decreased by reducing the flap thickness.[5]

---

[3] This technique is most satisfactory for the blunt dissection of well laminated tissue, e.g., for lamellar keratoplasty in situations where healthy cornea is retained beneath the excised areas. The safety of the blunt dissection is enhanced by low sectility (low intraocular pressure).

[4] It is safe to perform the lifting movement separately from the cutting movement, i.e., to discontinue cutting while checking the blade position, and vice-versa.

[5] Where high precision is required, as in preparation of the bed for lamellar keratoplasty, it is best achieved by dissecting thin lamellae layer by layer.

back to index

‹ ›

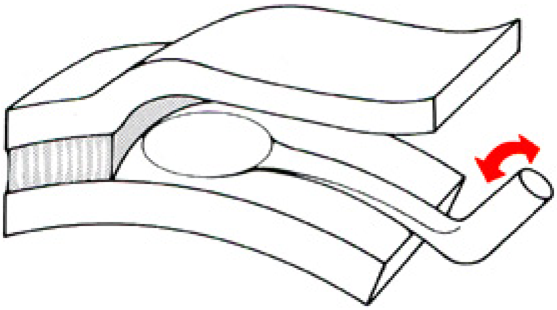


Fig. 5.8. **Lamellar dissection of an in situ flap**. Tissue deformation is slight and is minimal when the blade or its neck has the same curvature as the substrate (i.e., the ocular surface). The interlamellar fibers to be divided retain their natural position. Their tension depends on the thickness of the blade

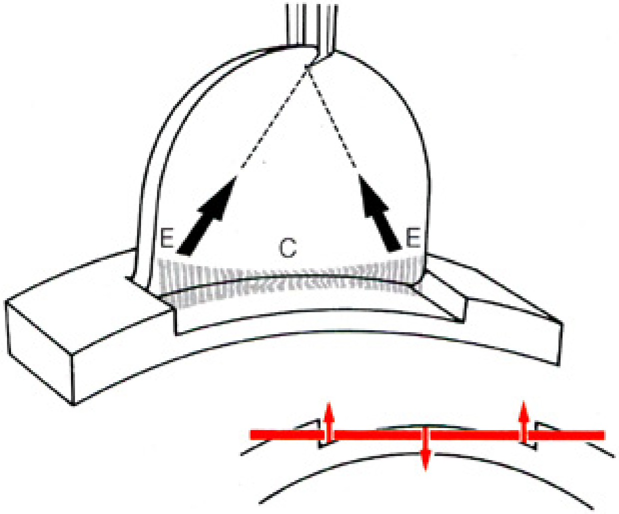


Fig. 5.9. **Hinge formation by an elevated flap**. Elevating the flap creates a hinge fold with characteristic effects: The lateral edges of the flap (*E*) are raised and the adherent fibers are made tense, while the center of the flap (*C*) is depressed and its fibers are lax. If division of the fibers is started at the edges, the hinge becomes shorter, and the central fibers gradually come under tension

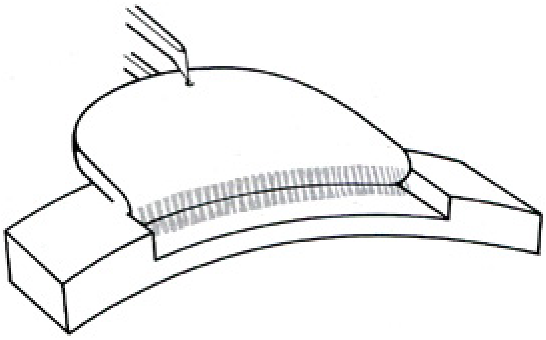


Fig. 5.10. **Hinge formation by a reflected flap**. When the flap is reflected as it is developed, the hinge tends to be curved; the tension of the interlamellar fibers depends on the flap thickness, and therefore the fibers can be made uniformly tense. Unequal tension develops only if there is substantial resistance to bending of the hinge axis

back to index

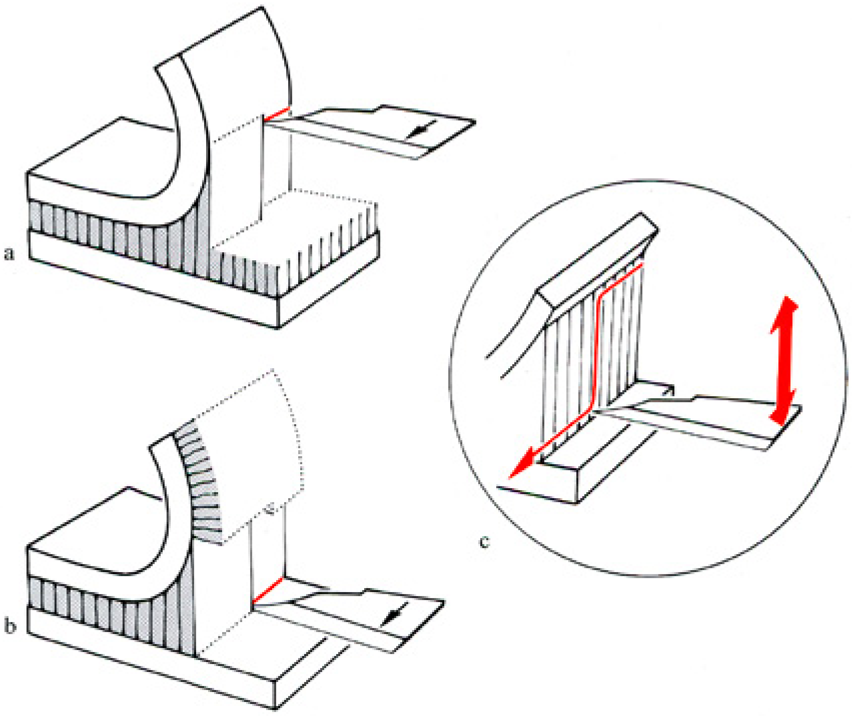
‹ ›

Fig. 5.11. **Development of an elevated flap.** The interlamellar fibers to be divided are perpendicular to the tissue surface, so a blade held perpendicular to the fibers is parallel to the lamellae themselves.

a Sectioning the fibers close to the flap yields a thin superficial lamella.

b Sectioning the fibers at their base yields a thicker flap.

c The plane of the dissection is adjusted by *vertical* movements of the blade



Since changing the position of the flap alters not only the tension on the interlamellar fibers but also their direction, the *direction of blade movements* must be changed accordingly. In the *elevated flap*, the fibers are pulled upward. Cutting the fibers at their upper end yields a thinner flap, while cutting at their lower end yields a thicker flap. Thus the flap thickness is changed by vertical movement of the blade (Fig. 5.11). In the *reflected flap*, the exposed fibers acquire a more horizontal orientation, so the flap thickness is changed by horizontal movements of the blade (Fig. 5.12).

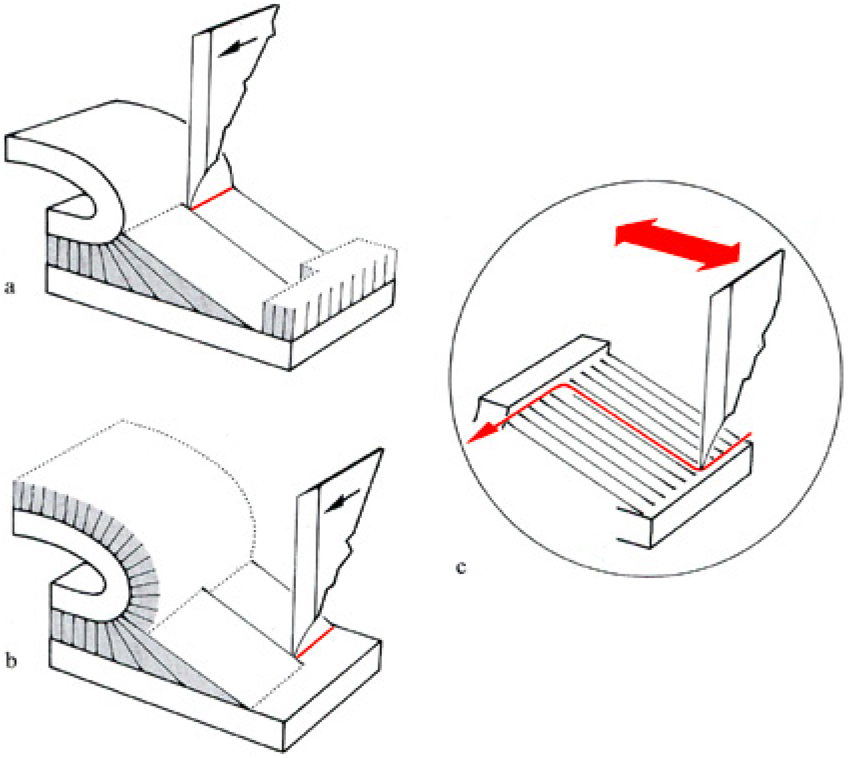


Fig. 5.12. **Development of a reflected flap.** The interlamellar fibers are oriented roughly parallel to the direction of the lamellae. The blade is held vertically.

a The superficial lamella is made thinner by dividing the fibers close to the fold.

b A thicker flap is obtained by sectioning the fibers near their base, or farther away from the fold.

c The plane of the dissection is adjusted by *horizontal* movements of the blade, i.e., by moving it closer to the fold or farther from it

back to index

❮ ❯

5.3 Planning the Approach to the Eye Interior

Considerations in planning the approach for an intraocular procedure include not only the size of the incision but also its method of closure. The major concern is accessibility to the ocular interior, i.e., the *size of the useful access opening*. But equal attention must be given to planning the *wound closure*. Effective closure implies not only perfect geometric *apposition* of the wound margins but also a *watertight* wound that will maintain its integrity even under mechanical stress.

Both *anatomic* and *geometric* factors are relevant in these considerations.

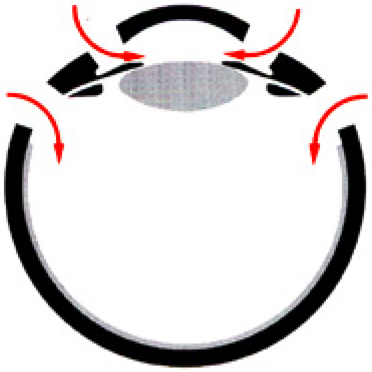


Fig. 5.13. **Approaches to the eye interior.** The *vitreous chamber* is reached with fewest complications through the pars plana. A more anterior approach is obstructed by the ciliary muscle and may provoke bleeding from the vessels of the ciliary processes. Approach behind the pars plana would perforate the retina. The *anterior chamber* is best approached from the limbal region so that any postoperative scars will not impair vision

5.3.1 Anatomic Factors in Opening the Globe

The *maximum possible length* of a useful access opening is limited by anatomic and topographic constraints. Anatomic factors also influence closure by determining the biologic healing potential of the wound (i.e., long-term closure).[6]

The best route of approach to the *vitreous chamber* is through the sclera over the pars plana of the ciliary body. The best approach to the *anterior chamber* is through the limbal region (Fig. 5.13).

In opening the **vitreous chamber**, the position of the pars plana can either be estimated from statistical data on the limbal distance or determined directly by diaphanoscopic transillumination (Fig. 5.14). Whether the incision is made radially or parallel to the limbus will depend on the relation of the proposed incision to the *course of the larger uveal vessels*. The exposed vessels themselves can be difficult to distinguish from surrounding pigmented tissue by visual inspection. They are identified either by diaphanoscopic transillumination or by diathermy, which produces appreciably less tissue shrinkage over the large vessels.[7]

There are various routes of approach to the **anterior chamber** from the limbal region, each offering advantages and disadvantages in terms of the surgical lesions inflicted on anatomic structures.

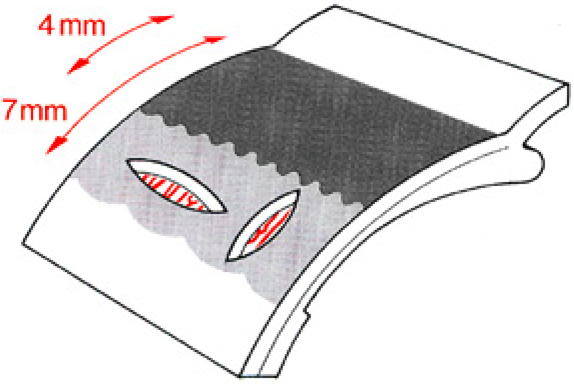


Fig. 5.14. **Approaches to the vitreous chamber.** The danger of hemorrhage on perforation of the vascularized uvea depends on the relation of the incision to the course of the vessels. Incisions that cross the vessels (*left*) expose multiple vascular branches, and a suitable access site can be found between them. Incisions parallel to the vessels (*right*) can be made longer without vascular injury but make it more difficult to locate an avascular interval. The *dark-shaded area* represents the ciliary zone that absorbs more light under diaphanoscopic illumination. *Note*: The limbal distance of the ora serrata is shorter nasally (6 mm) than temporally (7 mm)

---

[6] The healing potential of vascularized tissue (sclera, limbus) is greater than that of avascular tissue (cornea).

[7] Shrinkage is reduced over blood vessels because convective heat transfer is higher than in the neighboring avascular tissue (see Fig. 2.138).

back to index

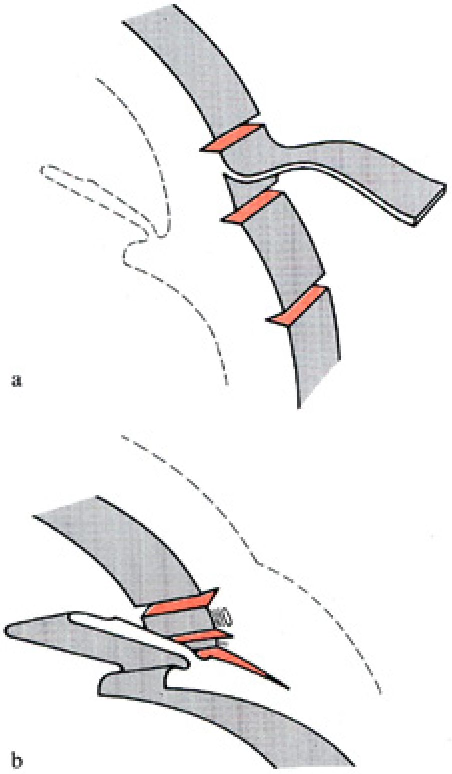


Fig. 5.15. **Approaches to the anterior chamber**

a *Outer surface*

Scleral incision:	Vascularized	Subconjunctival
Limbal incision:	Nearly avascular	
Corneal incision:	Avascular	

b *Inner surface*

Subciliary approach:	Implies cyclodialysis
Angular approach:	Traverses the structures of the chamber angle
Corneal approach:	Perforates Descemet's membrane and the endothelium

The routes of approach differ **externally** (Fig. 5.15a) in their *vascularity*, a major factor determining the quality and rate of wound healing and the potential for hemorrhage. They also differ in the opportunity for coverage with conjunctival flaps, which are useful for effecting rapid closure and wound repair but may obstruct the view of the operating field in the anterior chamber.

Internally (Fig. 5.15b) it is important to consider the relation of the incision to the structures of the chamber angle. A *corneal approach* enters the chamber at a distance from the iris root, facilitating the removal of synechiae and incarcerations and decreasing the likelihood of their formation in the postoperative period.

Entering *at the chamber angle* may damage the trabecular meshwork and the drainage channels. The peripheral location of the incision favors the development of synechiae.

A *subciliary approach* requires division of the ciliary attachment to the scleral spur and, unless permanent cyclodialysis is planned, is suitable only for narrow openings. It gives excellent access for the division of peripheral synechiae. It is also a good approach for injecting air or fluid to reform the anterior chamber against a high counterpressure, since the access opening is quickly tamponaded by the ciliary body when the cannula is withdrawn.

5.3.2 Geometric Factors in Opening the Globe

The geometry of the wound determines the *size of the useful access opening* in relation to the wound length that is visible externally. Geometric factors also determine the *quality of the wound closure* at the end of the operation (short-term closure).

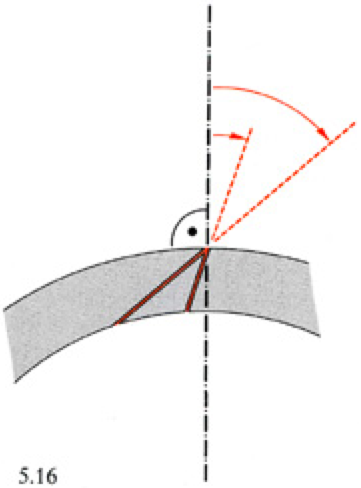
Planning the Useful Opening

The *wound length* visible on the external surface of the eye gives no clue to the *useful opening* that is available to the operator. The lengths of the external and internal openings may differ greatly owing to the thickness of the ocular wall.

The ratio of the internal and external openings for a given incision technique is influenced by the **width of the wound surfaces**. As the wound surface becomes wider, it is more likely that a large discrepancy will exist between the external and internal openings. The width of the wound surface in turn depends on the *angle between the wound surface and the ocular surface* (Fig. 5.16) and on the level at which the *incision* is made (Fig. 5.17). The ratio of the inner and outer wound length is further influenced by the shape of the cutting instruments (Fig. 5.18).

Access through a **minimal opening** greatly limits the mobility of an inserted instrument (Fig. 5.19); but *several* such openings spaced widely apart can allow virtually the same free mobility as a single large opening while avoiding the closure problems that may be associated with a large incision. Thus, the necessary size of the access opening is determined less by the need to insert instruments than by the *size of the tissue parts* that must be removed from the eye.

back to index



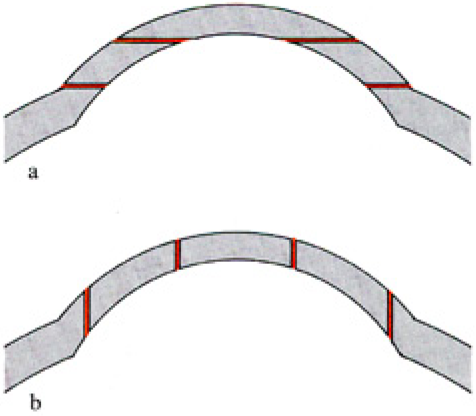
5.16

Fig. 5.16. **Width of the cut surface.** The width of the cut surface depends on the angle of the incision relative to the perpendicular on the globe surface

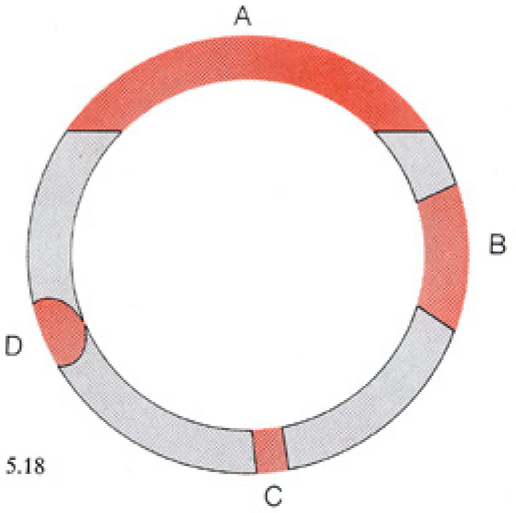
Fig. 5.17. **Change in the cut surface on parallel shift of the incision.** Parallel incisions in a thick-walled dome (such as the cornea) have surfaces of varying size.

a In incisions parallel to the iris, the area of the cut surface (*red*) increases toward the apex.

b In incisions perpendicular to the iris plane, the cut surfaces become smaller toward the apex



5.17



5.18

Fig. 5.18. **Internal and external wound lengths for various types of incision**

A Cataract knife incision: The discrepancy between the internal opening and external wound length is substantial.

B Keratome incision: The discrepancy is smaller.

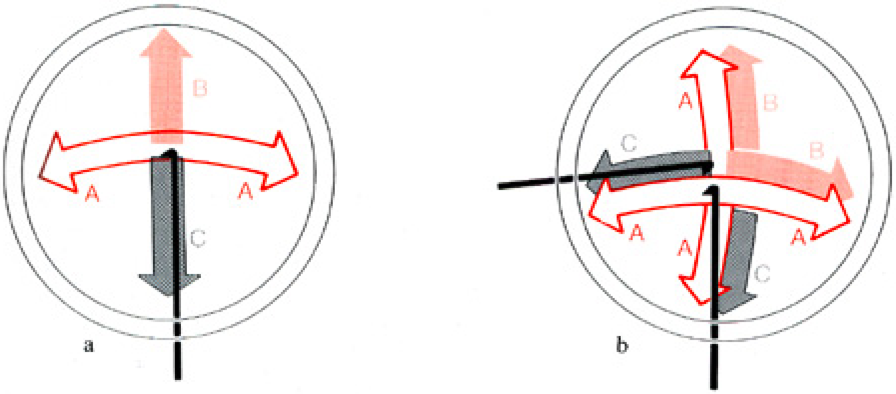
C Stab incision with a stab knife: Both wound lengths are equal.

D Incision with a pointed knife: The internal and external openings do not depend on instrument shape and can be fashioned as desired. Here the internal opening was made very small to assist closure, and the external opening was made large for better instrument maneuverability

Fig. 5.19. **Limitation of the mobility of instruments introduced through small openings**

a Assuming that a given instrument has only one working characteristic in each direction of motion, i.e., swiveling (*A*), advance (*B*), and withdrawal (*C*),[8] it is clear that only one type of action can be performed in the anterior chamber in each direction.

b If an additional small opening is placed 90° from the first, different types of action can be performed using the same instrument

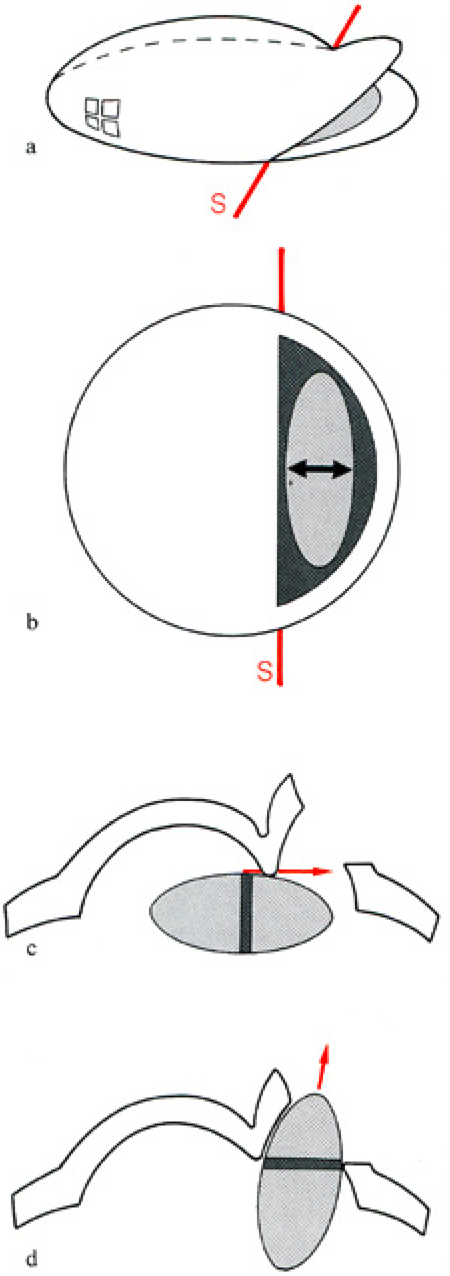


5.19

---

[8] For example, cystitomes are blunt in A, somewhat less blunt in B, and sharp in C (see Fig. 8.33); angled injection needles are sharp in A and blunt in B and C (see Fig. 8.34); phacoemulsifying probes are sharp in A and blunt in all other directions.

back to index



5.20

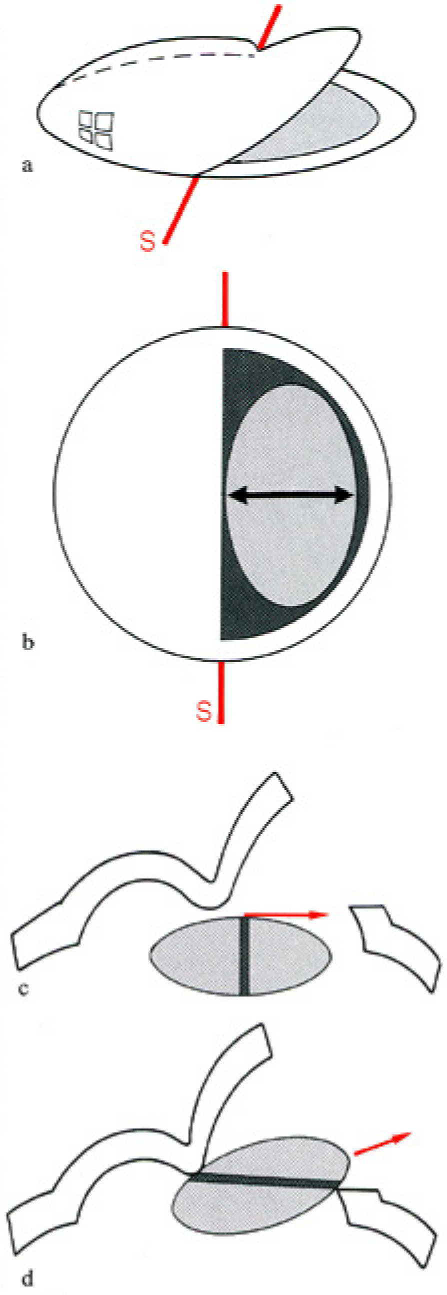
Fig. 5.20. **Effect of hinge formation on the useful opening for lens delivery. Position of the hinge fold in a 120° section**

a Perspective view of the hinge fold. *S*: Hinge axis.

b Overhead view: The fold constricts the opening for lens delivery. *Red*: Transverse lens diameter that must negotiate the opening on the plane of the hinge axis.

c Side view: The fold in the 120° section may form *in front of* the largest transverse lens diameter. That part of the lens is driven *against* the fold at the start of the expulsion maneuver, with a danger of endothelial damage.

d Reorientation of the lens during delivery: To negotiate the constricted opening, the lens must rotate into an upright orientation causing a corresponding volume shift in the vitreous chamber



5.21

Fig. 5.21. **Effect of hinge formation on the useful opening. Position of the hinge fold in a 180° section**

a In this section the hinge fold is farther back from the exit.

b This results in considerable gain of space, and the opening can accommodate a large lens diameter.

c The hinge fold is positioned *over* the greatest lens diameter, and the lens moves *away from the fold* on delivery. Thus, only smaller portions of the lens pass beneath the fold, and there is less risk of endothelial touch than in Fig. 5.20c.

d Emergence of the lens through the opening: The larger opening necessitates little lens reorientation during delivery, and the effects on the vitreous chamber are milder

The useful opening in **large incisions** is determined not only by the geometry of the incision in the ocular wall but also by the *position of the hinge axis*. The fold may constrict the useful opening and render it too small for the delivery of tissue parts that it could otherwise accommodate. Because of the hinge phenomenon, procedures in which the ocular incision is to be opened by raising a flap will require an incision of greater length than in other procedures (Figs. 5.20 and 5.21).

back to index

❮ ❯

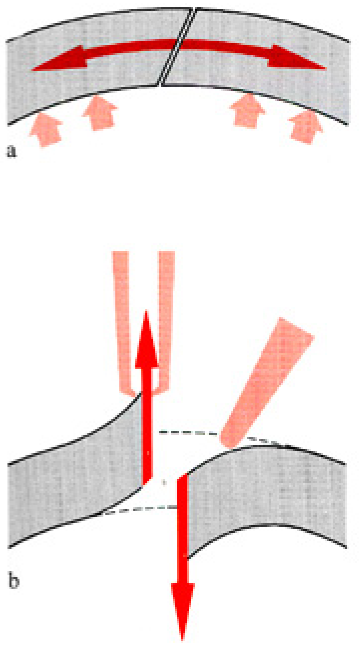


Fig. 5.22. **Mechanisms of wound opening**

a Gaping: A wound gapes when its surfaces are pushed or pulled apart by forces applied *tangentially*.

b Flap mechanism: A wound can be opened in a *perpendicular* direction by elevation or depression of the wound margin (e.g., with a fixation forceps or spatula)

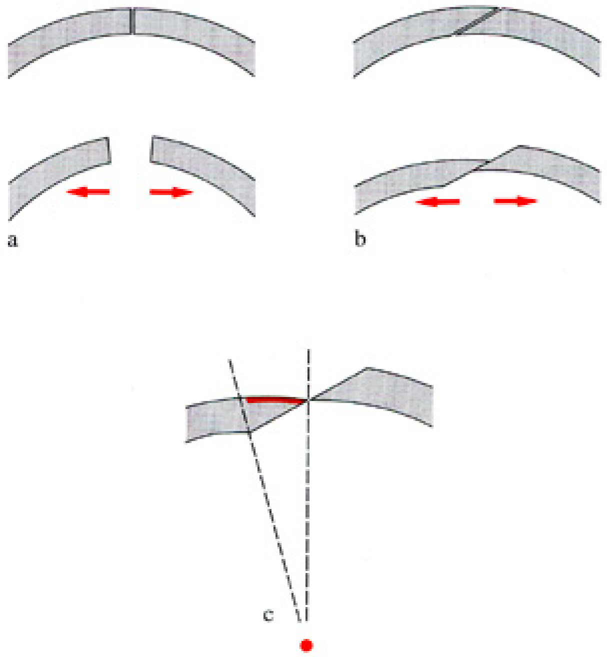


Fig. 5.23. **Gaping of wounds**

a In a perpendicular incision, the slightest dehiscence is sufficient to cause gaping.

b Oblique incisions form "valvular" openings that can remain watertight even when their edges are shifted.

c When the distance of the shift equals the projection of the wound surface onto the ocular surface (*red*), the incision begins to gape

Planning the Closure

In planning the wound closure, it is important to analyze the behavior of the incision in response to tangential and perpendicular forces (Fig. 5.22). *Tangential forces* are produced by an increase in wall tension (e.g., a rise of intraocular pressure), and they cause the edges of the incision to separate laterally ("wound gape"). *Perpendicular forces* are exerted locally (by instruments or by ocular structures themselves), and they either elevate or depress the wound margin.

Gaping occurs if the internal wound margin on one side can no longer meet the external margin on the other side, so that a communication is formed between the interior of the eye and the outside air. In a *perpendicular incision*, even the slightest shifting of its margins will

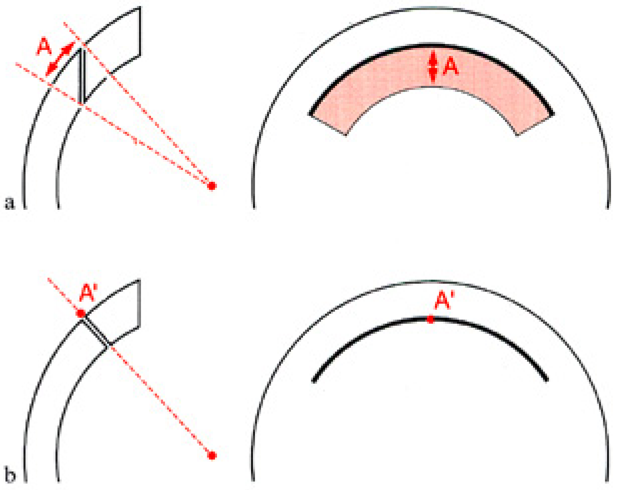


Fig. 5.24. **Margin of watertightness**

a The larger the projected area of wound surface onto the ocular surface (*A*), the more competent the valve.

b In perpendicular incisions the deep and superficial wound edges (as projected onto the surface) coincide, so the projection of the wound surface is a line. The margin of watertightness in a perpendicular incision is zero

back to index

cause gaping (Fig. 5.23a). Any incision that is not perpendicular produces a *valvular opening* that will remain closed when its edges shift relative to each other (Fig. 5.23b). The permissible extent of this shift, called the *margin of watertightness*, is expressed by the **valve rule**: *Incisions through the ocular wall produce valves whose margin of watertightness equals the projection of the surface of the incision onto the ocular surface* (Fig. 5.24).[9]

When the intraocular pressure rises, then, a perpendicular (= nonvalvular) incision will always gape[10] while an oblique (= valvular) incision will close even more tightly.[11] Thus, a valvular incision is not opened by a general rise of intraocular pressure, and it can be opened only by the action of local perpendicular forces which raise or lower the wound margin (see Fig. 5.22b).

This perpendicular mechanism of wound opening is applicable to all incisions that do not follow the path of a great circle on the globe (Fig. 5.25). The movable portion of the ocular wall, called the flap, is rotated about the imaginary "**hinge**" that connects the ends of the incision.[12]

Whether the flap can rotate outward or inward (i.e., can be raised or depressed) depends on whether the outer or inner wound margin is overriding. Rotating the flap may or may not open the wound. This depends on the location of the hinge axis and is defined in the "**hinge rule**": *A wound acted on by a perpendicular force will remain watertight if its hinge axis lies entirely within the wound surface.*

For **flaps that rotate outward**, the hinge rule states that the wound will remain watertight if the imaginary hinge axis does not intersect the internal wound margin when both are projected onto the ocular surface (Fig. 5.26). Thus, we can draw a distinction between wounds which are watertight by virtue of their geometry, and those which are not. The decisive factor is the length-to-width ratio of the wound surface: Long incisions made at a steep angle are easily opened, whereas short incisions made at a shallow angle tend to remain watertight (Fig. 5.27). Valvular incisions that follow a great circle path on the eye (Fig. 5.25a) are watertight by the hinge rule, regardless of their length.[13]

The distinction between watertight and non-watertight wounds is important from the standpoint of operative tactics. Watertight wounds will remain effectively closed of their own accord.[14] Non-watertight wounds, on the other hand, require suturing for secure closure. The purpose of the sutures is to subdivide the wound into segments which individually are watertight by the hinge rule. The sutures (or more precisely, the points where the stitches cross the external wound margin) function as the artificial vertices of new hinge axes (Fig. 5.28). As the hinge rule implies, the sutures should be spaced so that the new hinge axes do not intersect the internal wound margin[15] (Figs. 5.29, 5.30).

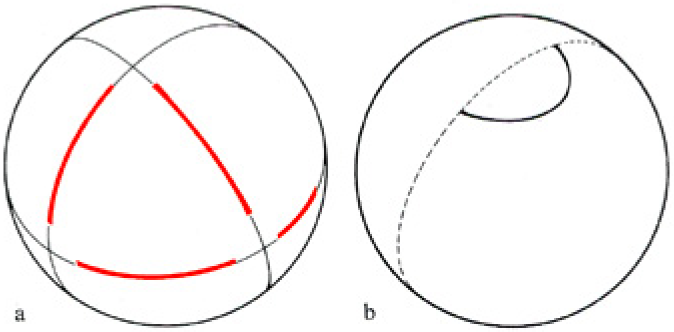


Fig. 5.25. **Incisions with and without flaps**

a Incisions that follow a great circle path on the eye cannot form flaps.

b Flaps are formed by incisions that do not lie on a great circle

---

[9] The valve rule applies only if the wound is able to form a functional valve. Incongruent wound surfaces (incongruent grafts, trauma) and incarcerated foreign matter (tissue fragments, foreign bodies, viscous substances) make the wound incompetent as a valve.

[10] This tendency makes the perpendicular incision excellent for antiglaucomatous fistulas. The difficulty is to keep the blade on a perpendicular path through multiple tissue layers.

[11] Owing to their valvular properties, keratome and cataract knife incisions could be left unsutured in earlier times when suitable threads and needles were unavailable.

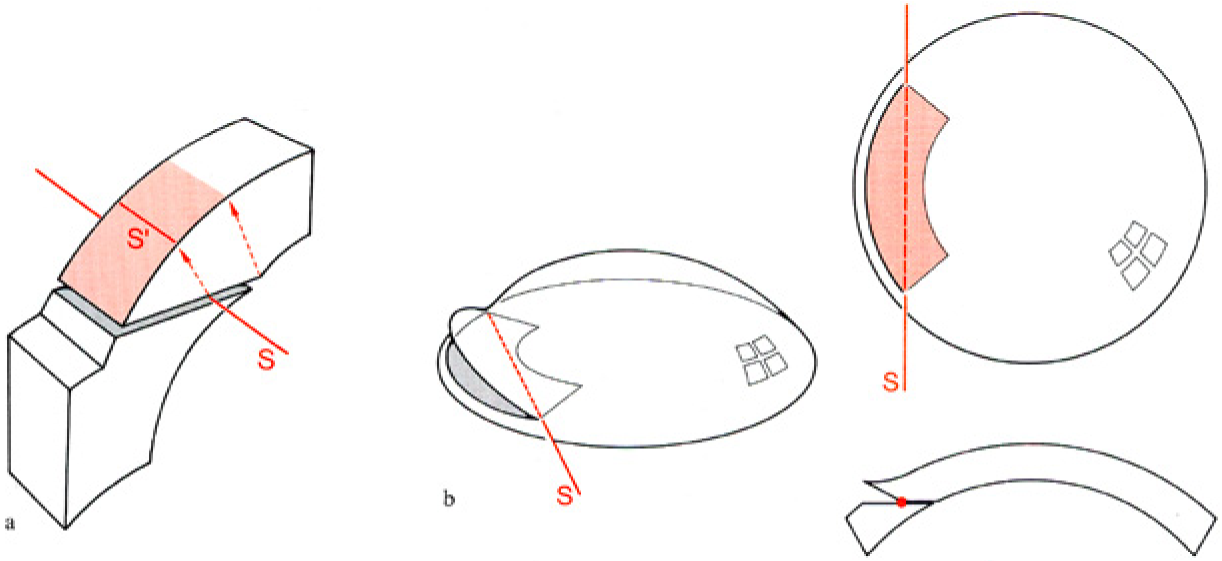
[12] Rotating a flap creates a fold only if the tissue has a "hinge fold capability," i.e., if the forces applied to the flap are transmitted to the ends of the incision. The necessary rigidity either is inherent in the tissue or is produced secondarily by the application of tension (with forceps or by repressurization of the globe).

[13] Such wounds are apt to *gape*, however, if the incision is perpendicular (i.e. nonvalvular).

[14] Provided there is no obstacle between the wound surfaces. Tissue incarceration may be the surgical goal (iridencleisis) or may occur as an undesired complication (iris prolapse, vitreous prolapse).

[15] As projected onto the ocular surface.

back to index



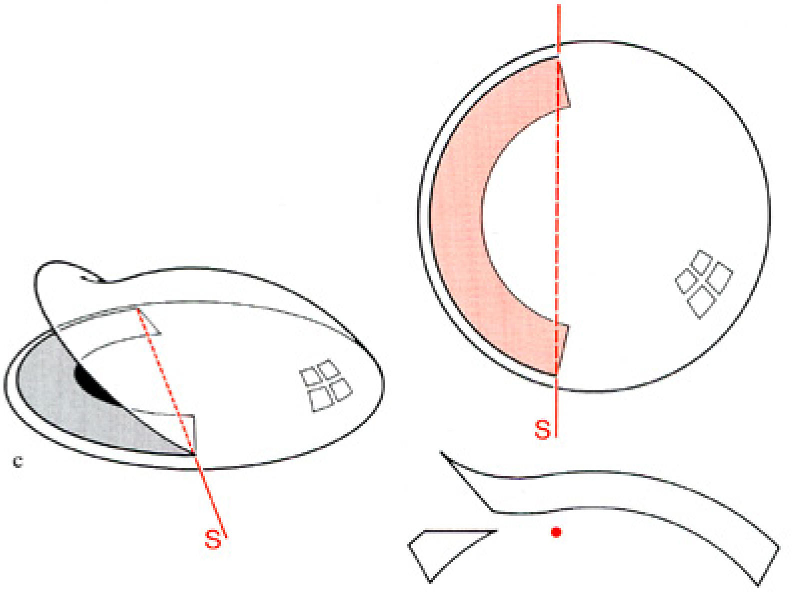


Fig. 5.26. **Hinge rule for outward-rotating flaps**

a Projection of the hinge and wound surface onto the ocular surface, as used in subsequent illustrations. *S* imaginary hinge axis, *S'* its projection; *pink area*: The projected wound surface.

b Geometrically watertight wound. A line connecting the outer extremities of the wound forms the hinge axis, which lies entirely within the wound surface. The line does not intersect the internal wound margin when projected onto the ocular surface, hence the wound is watertight.

c Nonwatertight wound. The internal wound margin is intersected by the hinge axis, hence rotation of the flap creates a communication between the interior of the eye and the outside

back to index

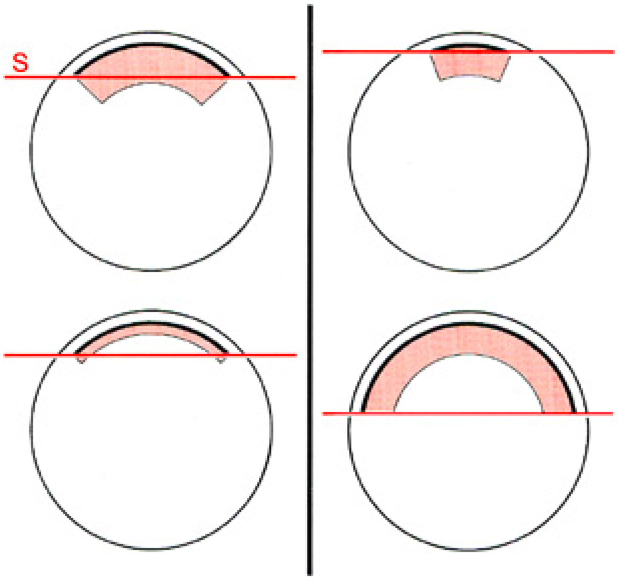


Fig. 5.27. **Sample applications of the hinge rule**. *Left*: In wounds of equal length, the width of the projected wound surface determines whether or not the wound is geometrically watertight. *Right*: In wounds with (projected) surfaces of equal width, the wound length determines watertightness.

The incisions in the *top* row are geometrically watertight; those in the *bottom* row are not watertight and require sutures for closure

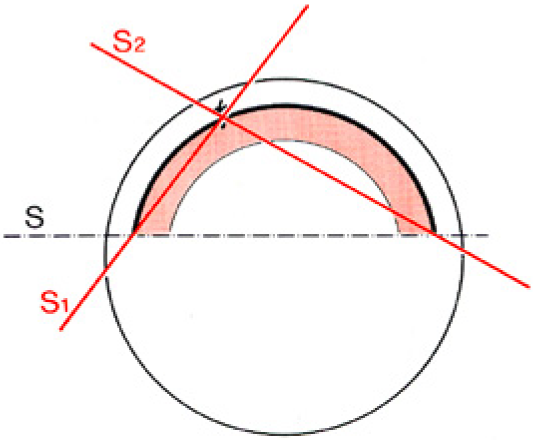


Fig. 5.28. **Use of sutures to establish watertightness**. The suture divides the wound into segments whose watertightness is determined by the new hinge axes (S_1 and S_2). The segment on S_1 is watertight, while that on S_2 must be subdivided further

Incisions with narrow surfaces require more sutures to effect closure than incisions with wide surfaces (Fig. 5.31). Closure is more difficult in *perpendicular* incisions, because it is impossible to create a new hinge axis that does not intersect the internal wound margin.[16] In theory an infinite number of sutures would be required, but in practice the problem is solved by the use of compression sutures.[17] Conversely, the closure of *valvular* incisions is satisfactorily accomplished with simple apposition sutures.

Inward-rotating flaps act as a valve against forces that press the flap outward. Consequently the wound remains watertight when the intraocular pressure rises, but it may be opened by a force that presses the flap inward. Again, the *hinge rule* determines whether the wound will remain watertight when the flap is turned. But in contrast to outward-rotating flaps, an inward-rotating flap remains closed as long as the hinge axis does not intersect the *external* wound margin. In the sutured wound, moreover, the points of *intramural* (deep)

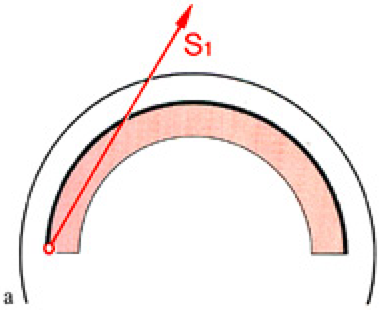
---

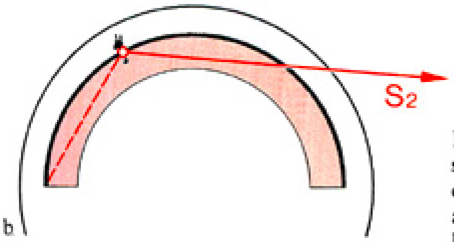
[16] As projected onto the ocular surface.

[17] The placement of these sutures is then determined by the size of the compression zones (see Fig. 2.109). Compression sutures always distort the tissue, as discussed in Chap. 2.1.4.

back to index

‹ ›





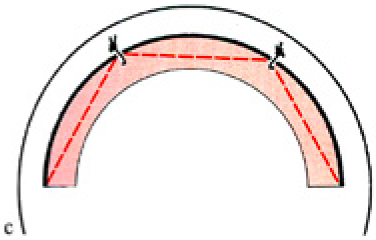


Fig. 5.29. **Determining the minimum number of sutures required for watertight closure of a wound**

a The location of the first suture is found by drawing a line (S_1) from the outer end of the incision that just bypasses the interior wound margin. The suture is placed at the point where that line crosses the external margin of the incision.

b Another line (S_2) is drawn in the same way from the first suture, and the second suture is placed at its intersection with the external wound margin.

c A line from the second suture reaches the opposite end of the incision without crossing the internal margin. Therefore no further sutures are necessary to effect a watertight closure in this example

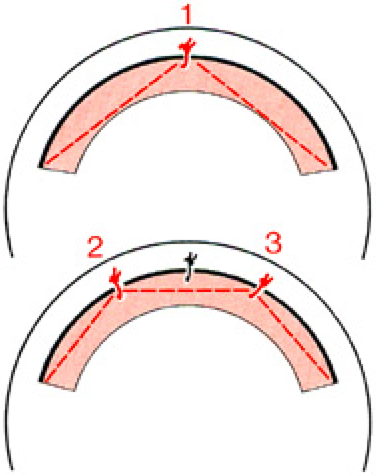


Fig. 5.30. **Increasing the safety margin in suturing**. "Safety sutures" can maintain closure in the event that a suture placed as described in Fig. 5.29 breaks or comes loose. In the drawing above, suture *1* is capable of dividing the wound into watertight segments. Sutures *2* and *3* are safety sutures placed so that their hinge axes do not intersect the interior wound margin. Note that the sutures are not spaced evenly along the wound line, but 2 and 3 lie closer to suture *1*

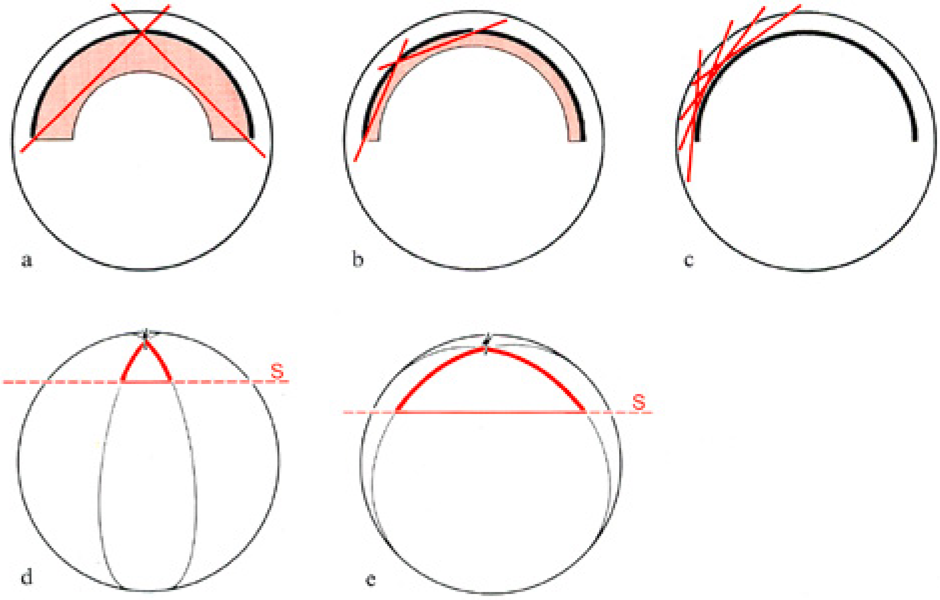


Fig. 5.31. **Minimum number of sutures needed for outward-rotating flaps**

a If the wound surface is broad enough, a single suture may be sufficient.

b Narrower wound surfaces require more sutures.

c In a perpendicular wound each hinge axis forms a chord that intersects the (projected) wound margin. In theory, an infinite number of sutures would be required.

d and **e** *Suturation of "gothic arch" incisions.* Flap wounds made by two incisions which follow a great circle path are divided into two watertight segments by a single suture placed at the apex of the arch, regardless of the size of the flap. Only the outer wound edges are shown in the drawings; the projection of the wound surface is omitted (for a practical example of the gothic arch incision, see Fig. 5.63)

back to index

❮ ❯

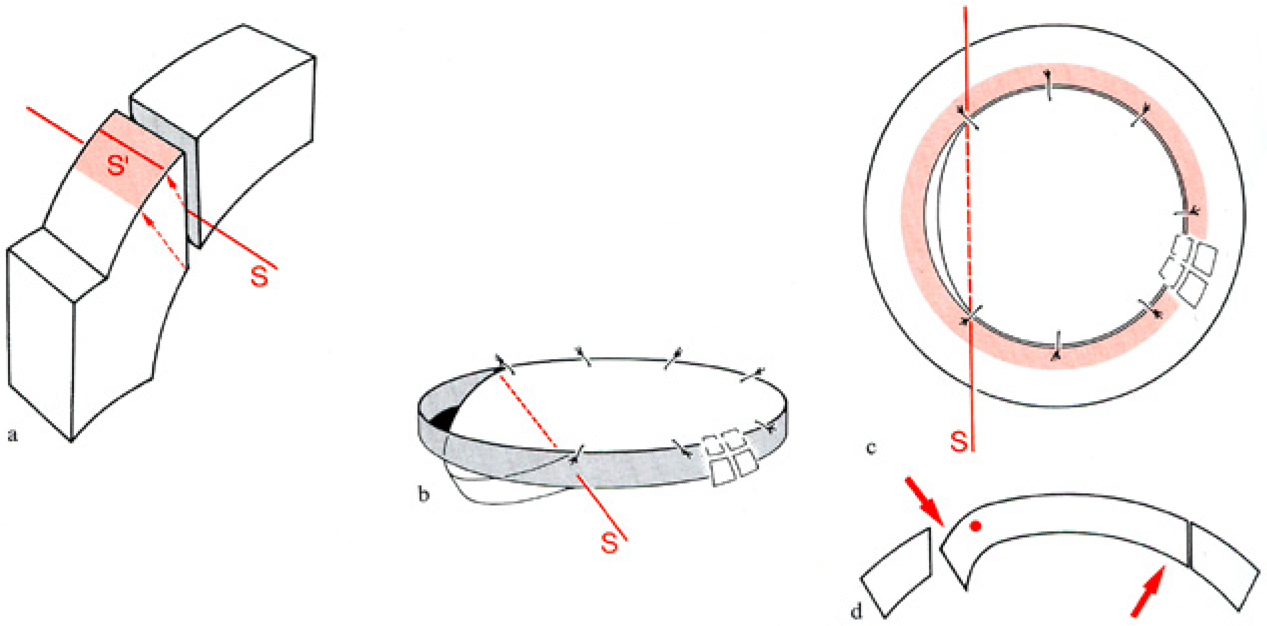


Fig. 5.32. **Hinge rule for inward-rotating flaps** (illustrated for the suturing of a trephine disk)

a Projection onto the ocular surface. *S* hinge axis; *S'* projected hinge axis; *pink area*: Projected wound surface.

b, **c** If the projection of the imaginary hinge axis intersects the external wound margin, the wound will open when the flap is rotated inward.

d Outward pressure cannot open the flap (*right arrow*). Inward pressure will open the wound if the hinge axis lies outside the projected wound surface (*left arrow*)

As a result, flaps that are formed by two such segments ("gothic arch" flaps) have interesting properties (Figs. 5.31d and e): They can be effectively closed by a single suture placed at the apex of the flap, because the suture divides the wound into two watertight segments, regardless of the length of the incisions or the apex angle of the arch.

suture passage form the vertices of the new hinge axes (Fig. 5.32).

The key factor in determining the correct spacing of the sutures, thus, is the distance of the point of deep suture passage from the external wound line (Fig. 5.33). The wider the wound surface and the deeper the suture, the fewer sutures are needed to effect satisfactory closure[18] (Fig. 5.34).

Incisions whose external wound line follow the path of a **great circle** represent a special case. Incisions of this type cannot be opened by rotation about an axis (see Fig. 5.25a).

---

[18] Note the difference between the suturing of outward and inward rotating flaps: In the outward rotating flap, the *bridging* parts of the suture loops form the ends of the hinge axis, so the depth of the suture is irrelevant for closure (it is relevant only for a secure grip of the loops in the tissue). Conversely, in the inward rotating flap, the *intramural* passages of the thread form the end of the hinge axis, and so the depth of the suture is critical (compare with Fig. 5.26).

back to index

‹

›

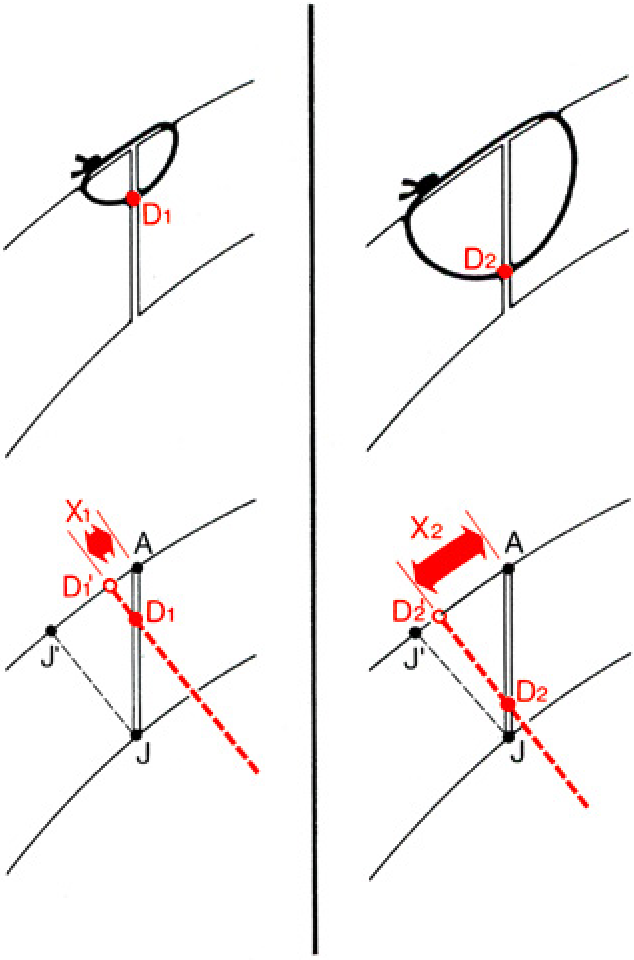


Fig. 5.33. **Location of hinge axis for inward-rotating flaps**. The points of deep suture passage *D* form the new vertices of the hinge axis. The deeper the suture, the greater the projected distance *X* from the external wound margin *A*.

D' Projection of suture passage onto the ocular surface.

J Interior wound margin; *J'* its projection onto the ocular surface.

Left: Superficial suture

Right: Deep suture

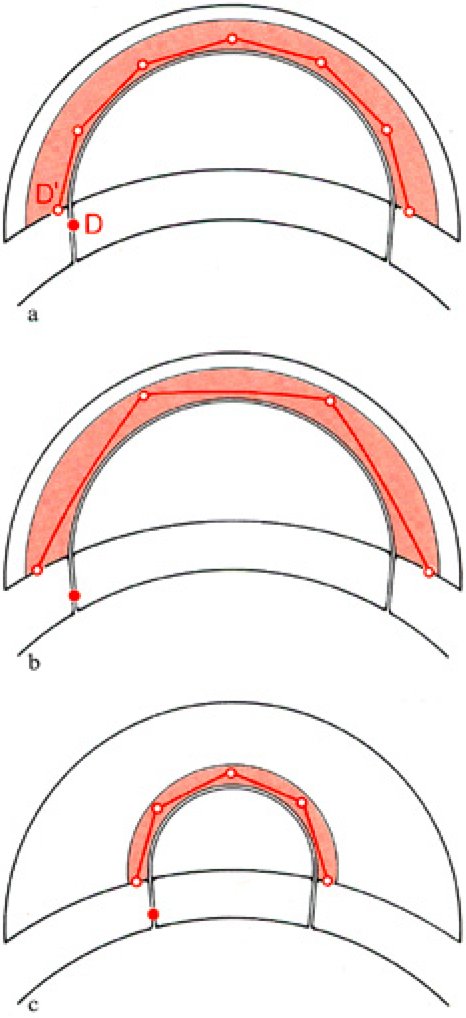


Fig. 5.34. **Minimum number of sutures needed to divide an inward-rotating flap into watertight segments** (illustrated for a trephine disk). Effect of suture depth (*D*) and width of wound surface. *Pink*: Projection of the wound surface onto the ocular surface.

a With superficial sutures the vertices of the hinge axes project close to the external wound margin. The number of sutures is correspondingly large.

b With deep sutures the vertices are more distant from the external wound margin, and fewer sutures are needed.

c If the trephine disk is small, the projected wound surface is narrowed, and the projected vertices are less distant from the external wound margin (despite the same suture depth as in **b**). Despite the shorter wound length, more sutures are required than in **b**

back to index

‹ ›

5.3.3 Comparison of Different Incision Profiles

Several criteria should be considered when selecting the profile of an incision:

Freedom of choice of anatomic reference points (Fig. 5.35). When the incision is made on a single plane, the positions of the external and internal wound margins correlate with the inclination of the cut surface. In multiple-plane incisions they are mutually independent, and they can be varied as needed while the incision is performed.

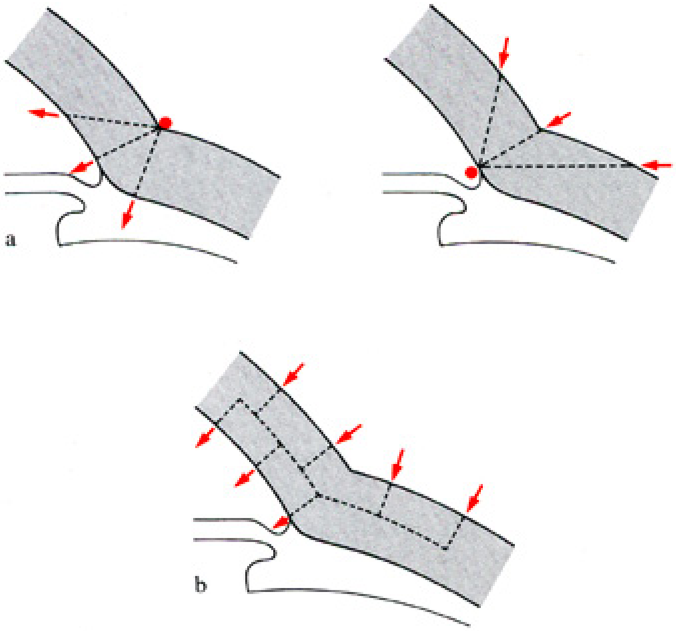


Fig. 5.35. **Anatomic factors in selecting the incision profile**

a Single-plane incisions: Once the position of the external (*left*) or internal (*right*) wound margin has been established, the location of the remaining wound margin (i.e., the width of the wound surface) depends on the angle at which the incision is made (*arrows*).

b Multiplane incisions: The positions of the external and internal wound margins are mutually independent and can be varied during the course of the incision according to requirements of specific situations (see Fig. 5.63)

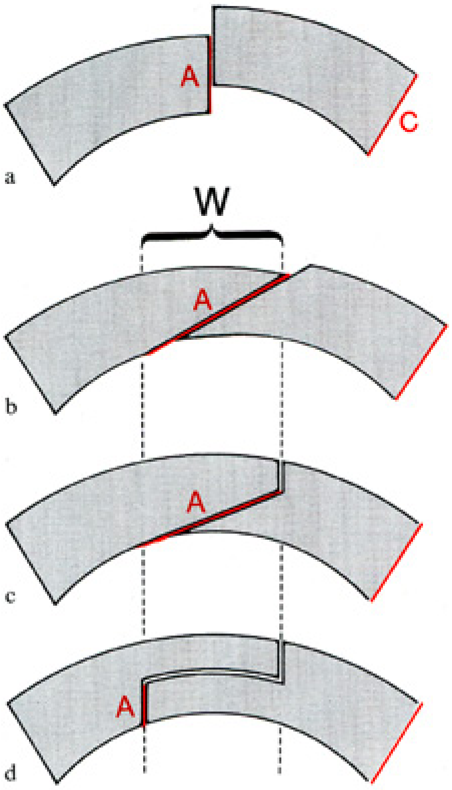


Fig. 5.36. **The properties of various incisions**

	Margin of water-tightness	Precise apposition	Lamellar deflection	Tissue thickness on opening of chamber	Technical complexity of incision
a) Perpendicular incision	0	easy	none	A = C	+
b) Single-plane oblique incision	W	difficult	high	A ≫ C	+
c) 2-plane step incision	W	easy	low	A >=< C depending on W	++
d) 3-plane step incision	W	easy	none	A < C	+++

A = thickness of tissue layer that must be sectioned as a last step prior to entering the chamber.
C = corneal thickness.
W = projection of wound surface onto ocular surface

back to index

‹ ›

Margin of watertightness (Fig. 5.36). Both the *valve rule* and *hinge rule* state that the tendency of a wound to remain watertight when acted on by a tangential or perpendicular force depends on the width of the wound surface as projected onto the ocular surface. This dimension generally serves to characterize the stress resistance of a wound.[19]

Apposability. *Perpendicular* wound surfaces facilitate accurate approximation of the wound margins. The vectors created during suturing cannot cause tangential shifting of the wound margins. Only perpendicular shifts are possible, but these are easily recognized because they create a steplike incongruity which, even if slight, is plainly visible by the interruption of the surface reflex. *Oblique* wound surfaces are more difficult to approximate precisely because the edges can easily shift relative to each other (Fig. 5.36b). Also, it is more difficult to detect faulty apposition due to the angulation of the wound edges.

Lamellar deflection. Incisions made at an angle to the plane of the lamellae tend to undergo deflection, with a corresponding loss of precision.

Tissue resistance upon entering the globe. The lower the tissue resistance in the critical phase of the incision (last step before entry into the eye), the less force is required, and the less the danger of inadvertent damage to intraocular structures. This resistance depends on the thickness of the tissue layer that must be divided in the last phase of the incision.

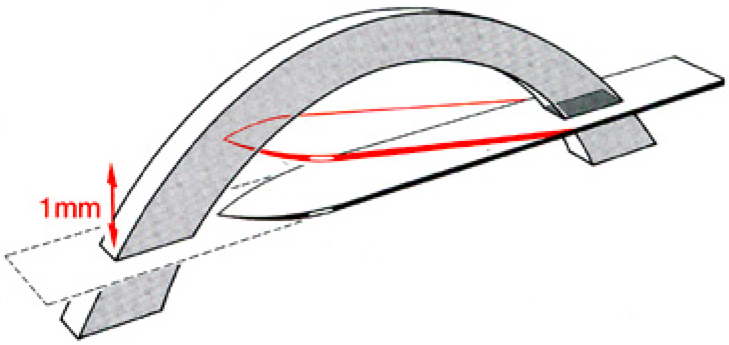
Technical complexity. The technical complexity of the incision, and thus the time required to complete the incision, increase with the number of direction changes involved in making the incision.

5.4 Methods of Opening the Anterior Chamber

The critical moment at which the blade reaches the anterior chamber is easily recognized: A polished surface that appears mat while still in the corneal stroma becomes bright again on entering the anterior chamber. Once inside the chamber, instruments appear displaced from their true position because of the higher refractive index of the cornea and aqueous fluid (Fig. 5.37). This is not a problem as long as the instruments are used entirely within the chamber, since all objects are viewed under the same optical conditions. But if it is necessary to make a counterincision from inside the chamber, allowance must be made for the apparent upward deflection by aiming the point of the blade higher than the planned site of emergence on the outer corneal surface.

If aqueous escapes when the anterior chamber is entered, this will affect not only spatial tactics but also tissue tactics due to the consequent fall of intraocular pressure and loss of tissue tension. Initially sharp *blades* will suddenly behave as if dull, and *fixation instruments* that initially fixed the entire globe will exert only a local action and deform the tissue. The effects on the conduct of the section are so profound that it is useful to distinguish between methods whose success depends on *avoiding aqueous loss* and methods in which *aqueous loss is acceptable* and due allowance is made for the fall of intraocular pressure.

Fig. 5.37. **Visual control in the anterior chamber**. The surface of polished instruments appears mat when between the corneal wound surfaces but becomes bright on entering the aqueous humor. Instruments in the anterior chamber appear to be bent upward, the degree of this effect varying with the viewing angle.[20] In reality the tip is lower in the chamber than it appears when viewed from the outside. If the tip is to emerge at the limbus, for example, the surgeon should aim for a point about 1 mm higher on the outer corneal surface (*red*). If he aims directly for the limbus, the counterpuncture will be too low



---

[19] The margin of watertightness determines closure not just at the end of surgery but also in the postoperative period during cicatrization. Therefore, the risks of early suture removal decrease when wounds have a large margin of watertightness.

Example: When correction of astigmatism by early suture removal is planned, incisions with a large margin of watertightness are preferred.

[20] Distortion is minimal from an overhead perspective (e.g. a coaxial microscope) and more pronounced with an oblique view.

back to index

‹ ›

5.4.1 Keratome Section

Keratomes have a wedge-shaped blade whose preferential path lies on one plane.[21] The shape of the cutting edge determines the vector components created when the blade is advanced (Figs. 5.38, 5.39).

Owing to the wedge shape of the keratome blade, the incision remains *watertight* as long as the blade is advanced. The intraocular pressure does not fall, the tissue remains sectile, and the diaphragm remains stationary until the point of the blade reaches the opposite chamber angle. The *length of the incision* that can be made under these optimal conditions is determined by the width of the keratome blade (Fig. 5.40). However, the geometry of the blade will cause the wound to open if the slightest error is made, i.e., if the blade is raised, lowered, or tilted to any degree. This excludes any possibility of corrections during the keratome incision (Fig. 5.42), for the diaphragm will bulge forward as soon as aqueous escapes. The section must be completed without delay, therefore.

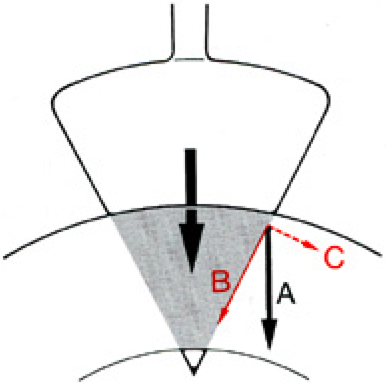


Fig. 5.38. **Force vectors of a keratome.** Advancing the keratome (*A*) creates a thrust component (*C*) that enlarges the incision and also a pull-through component (*B*) that improves the cutting efficiency of the blade

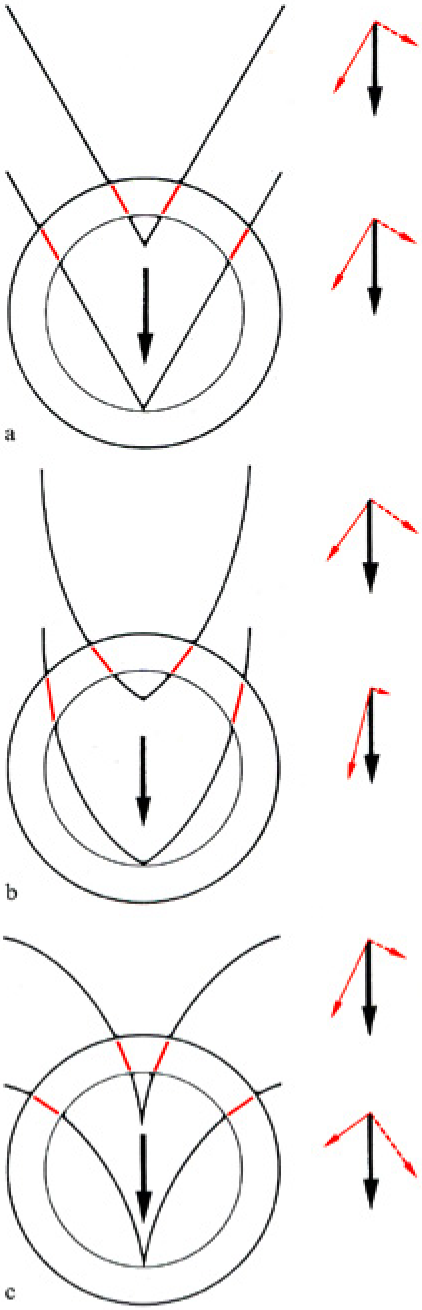


Fig. 5.39. **Cutting properties of various keratomes** ►

a In keratomes with straight cutting edges, the relation between the thrust and pull-through vectors remains fairly constant throughout the incision. However the length of the tissue segment to be divided increases and, with it, the resistance.

b In keratomes with convex cutting edges, the pull-through vector predominates so that the cutting ability of the blade steadily increases.

c In keratomes with concave edges, the thrust vector predominates so that cutting ability decreases as the incision proceeds. The resulting incision differs from that in **b** by the position of the hinge axis; in **b** it facilitates closure, whereas here it facilitates opening

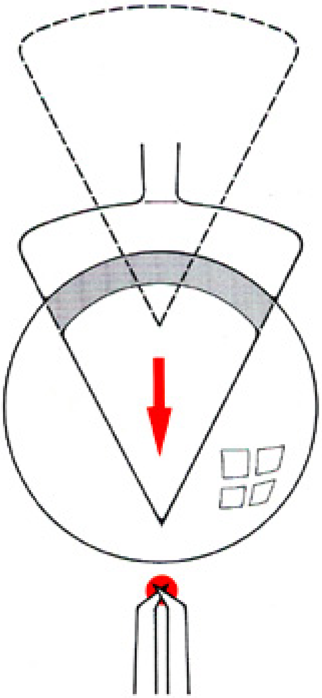


Fig. 5.40. **Advancing the keratome.** The tip is directed toward the fixation forceps (see also Fig. 3.19)

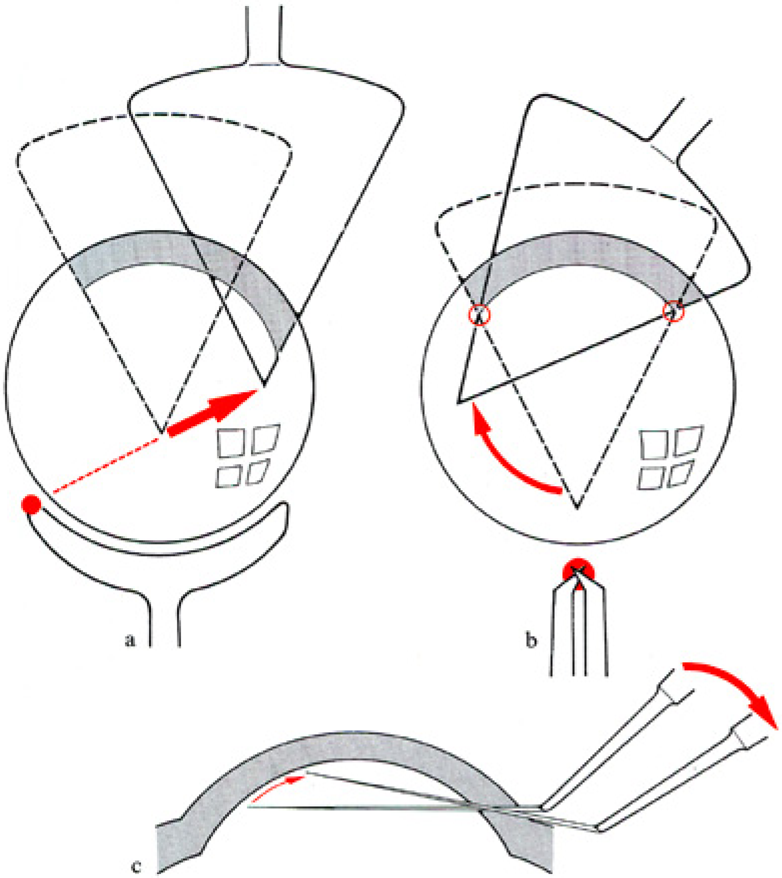
When the keratome is *withdrawn*, the point is first removed from the pupil region to avoid injury to the lens, which now moves forward to a more anterior position. This is done by raising the point of the keratome while simultaneously moving it toward the side (Fig. 5.41c). The section can still be extended at this time. If this is done in a smooth *rotary motion*, aqueous loss can be prevented and tissue sectility preserved (Fig. 5.41b). But if the keratome is moved *laterally* as it is withdrawn, aqueous will escape. Although this makes the tissue more difficult to cut, the section can proceed by utilizing the pull-through vector component of the cutting edge (Fig. 5.41a).

---

[21] If the two cutting edges are asymmetrically ground so that their preferential paths are on different planes, the incision will deviate as shown in Fig. 5.42. So the blade, especially if large, must be ground with extreme precision as to symmetry.

back to index

‹ ›



5.41

Fig. 5.41. **Withdrawing the keratome**

a Lateral blade movement to enlarge the incision: On withdrawal the keratome tip is moved laterally to remove it from the pupil region. The section can be simultaneously extended by adding a pull-through motion of the blade. A broad fixation forceps aids the lateral motion by offering resistance to lateral vectors.

b Rotation of the keratome to extend the section: The ends of the incision (*red circles*) can be sealed during this maneuver by keeping the cutting edges in firm contact with them. A small fixation forceps aids compensatory counterrotation of the globe.

c To avoid injury to the bulging diaphragm when the anterior chamber empties, the keratome tip is raised (handle is lowered) during withdrawal

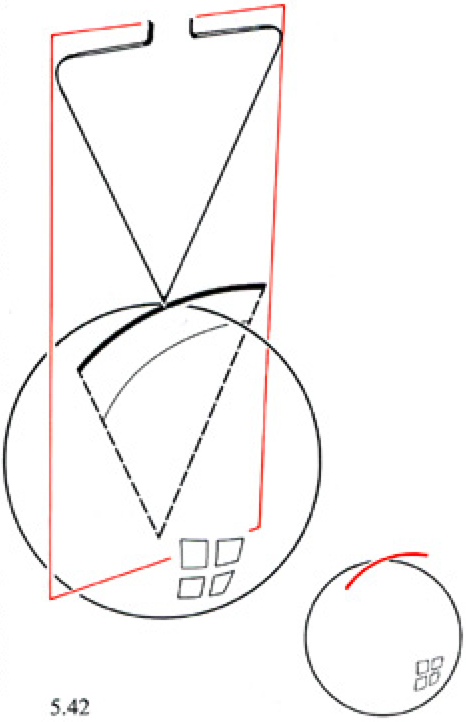


Fig. 5.42. **If the guidance path of the keratome** is not parallel to the limbal plane, the incision may transgress the limbus and enter the sclera. Any attempt to correct the position of the blade will allow loss of aqueous

5.42

5.4.2 Cataract Knife Section

Cataract knives have a narrow, pointed blade that is used first to *puncture* the chamber and then to *section* it from within (Fig. 5.43). The various types of cataract knife differ chiefly in the shape of the point, which determines whether the blade will deviate from the guidance direction when advanced through tissue (Fig. 5.44).

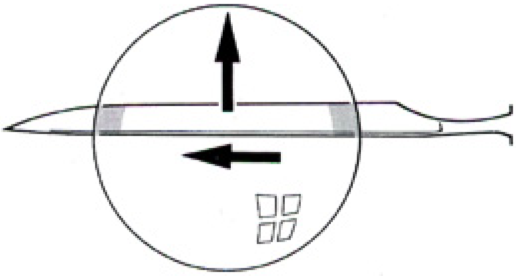


Fig. 5.43. **Force vectors in the cataract knife section.** The vector for making the puncture and counterpuncture and that for performing the section are separate from each other and are mutually perpendicular

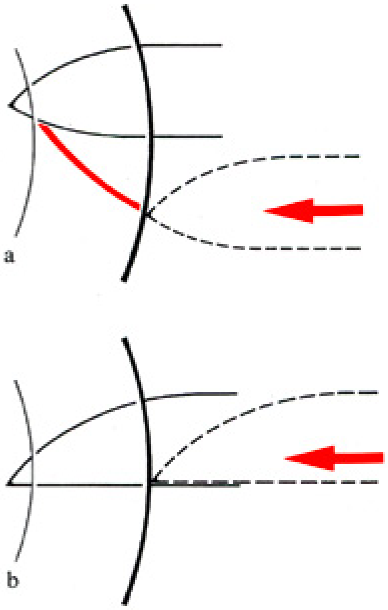


Fig. 5.44. **Cutting properties of the cataract knife tip**

a Knives with a curved back deviate in the direction of the cutting edge when thrust straight into the tissue.

b Knives with a straight back do not deviate from the guidance direction

back to index

‹ ›

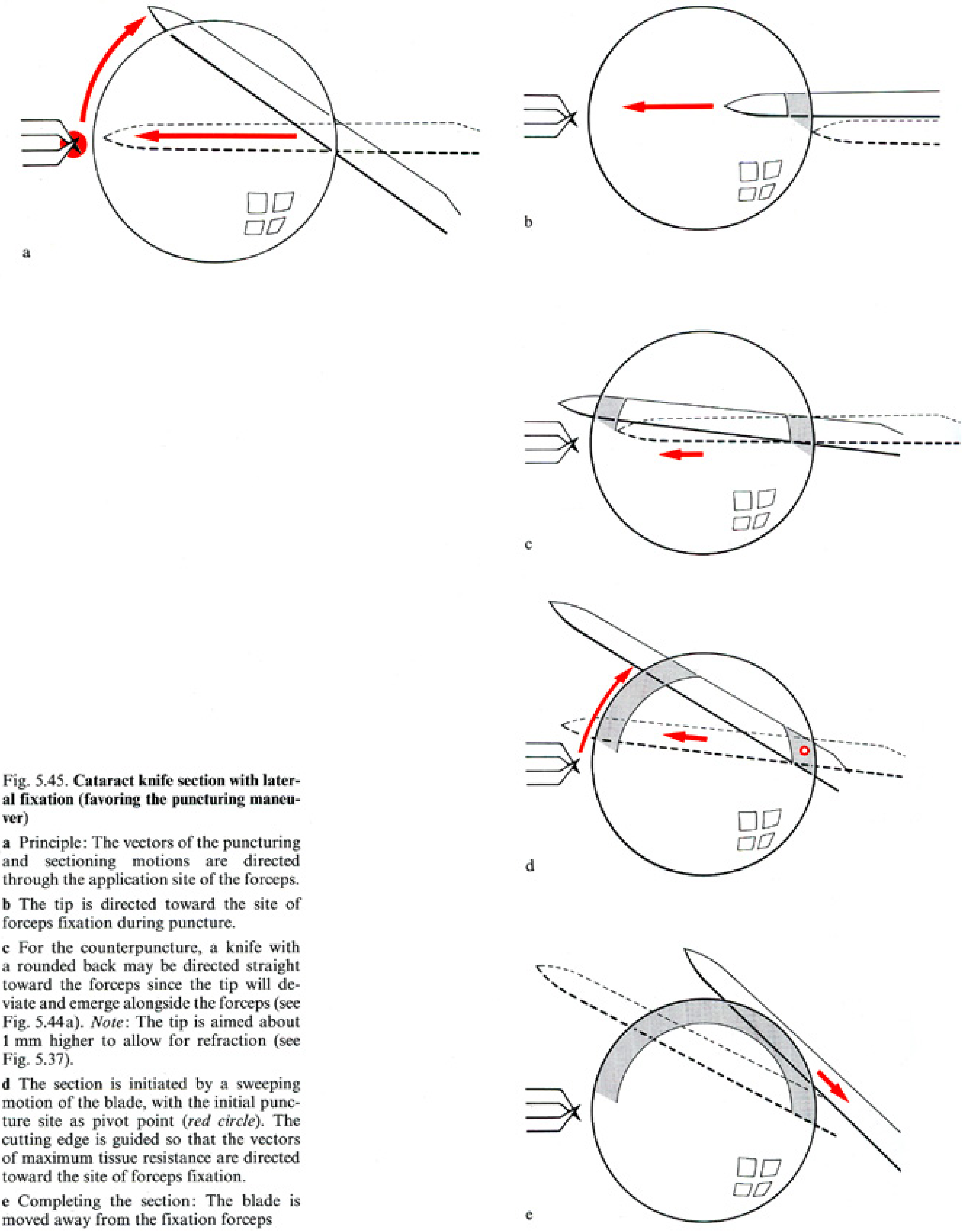


Fig. 5.45. **Cataract knife section with lateral fixation (favoring the puncturing maneuver)**

a Principle: The vectors of the puncturing and sectioning motions are directed through the application site of the forceps.

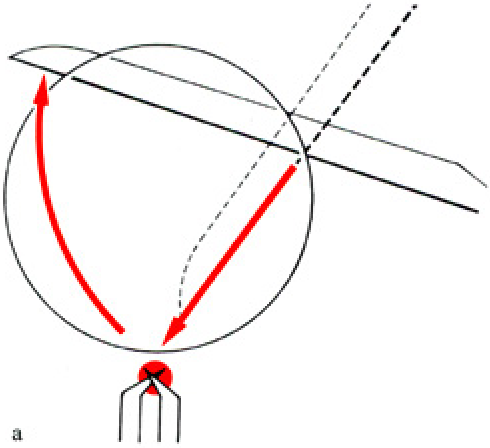
b The tip is directed toward the site of forceps fixation during puncture.

c For the counterpuncture, a knife with a rounded back may be directed straight toward the forceps since the tip will deviate and emerge alongside the forceps (see Fig. 5.44a). *Note*: The tip is aimed about 1 mm higher to allow for refraction (see Fig. 5.37).

d The section is initiated by a sweeping motion of the blade, with the initial puncture site as pivot point (*red circle*). The cutting edge is guided so that the vectors of maximum tissue resistance are directed toward the site of forceps fixation.

e Completing the section: The blade is moved away from the fixation forceps

back to index



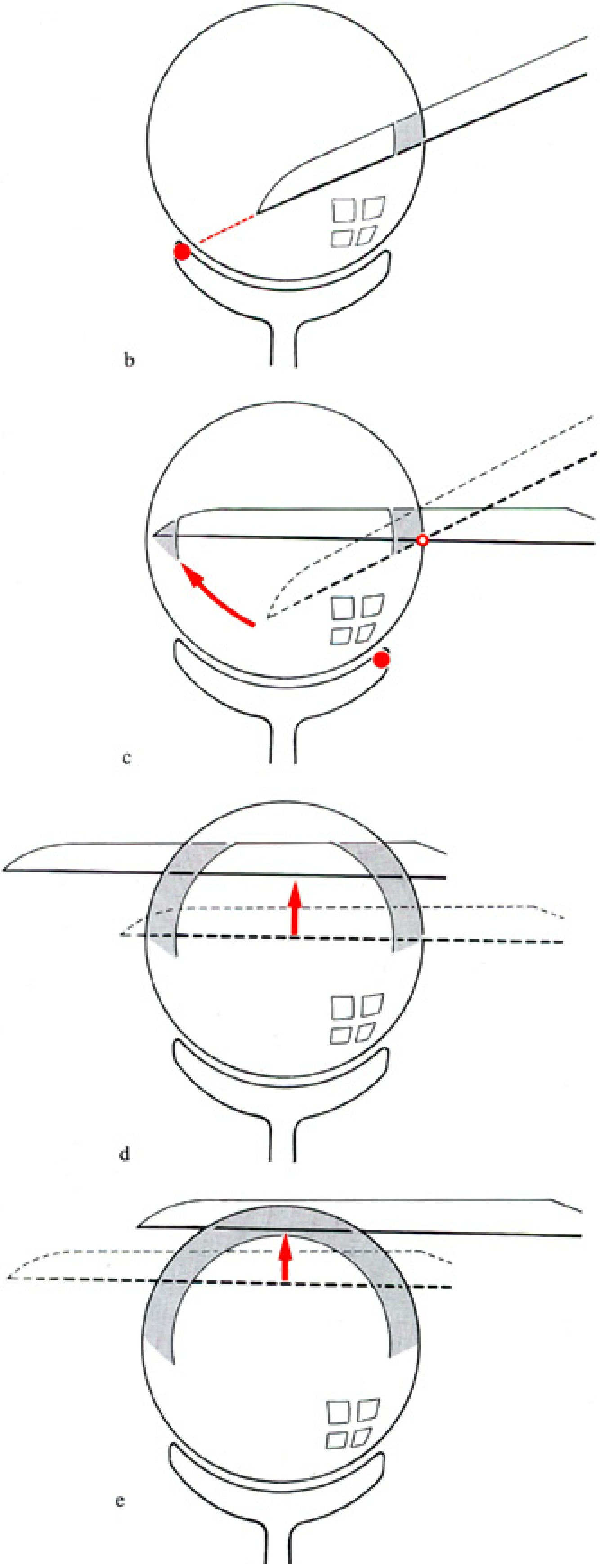


Fig. 5.46. **Cataract knife section with fixation from below (favoring the sectioning maneuver)**

a Principle: The vectors of puncture and counterpuncture are directed through the application site of the forceps.

b The puncture is directed toward the fixation instrument. Knives with a straight back make it easier to maintain the initial direction of insertion (see Fig. 5.44b). If broad fixation forceps are used, the tip is directed toward the far end (*red dot*).

c Counterpuncture is initiated with a sweeping motion so that the vector resisting the tip motion passes through the site of forceps application. The wider the forceps jaws, the smaller the necessary angle of the sweep, so the guidance of the knife approximates that for lateral fixation.

d, **e** Section is completed by a to-and-fro motion of the blade

back to index

‹ ›

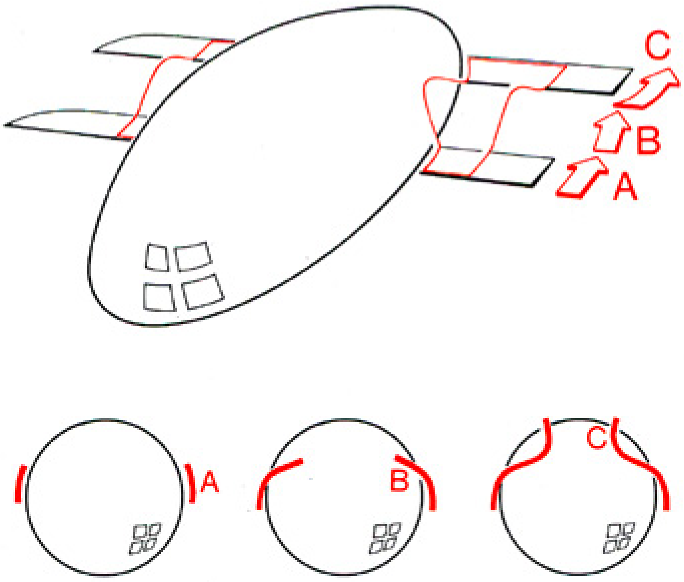


Fig. 5.47. **Corrective movements of the cataract knife.** The shape of the incision depends on the geometric intersection of the guidance path with the corneal dome. If the blade is not directed parallel to the iris (*A*), the incision will turn inward if the plane of the blade is raised (*B*) or outward if it is lowered (*C*)

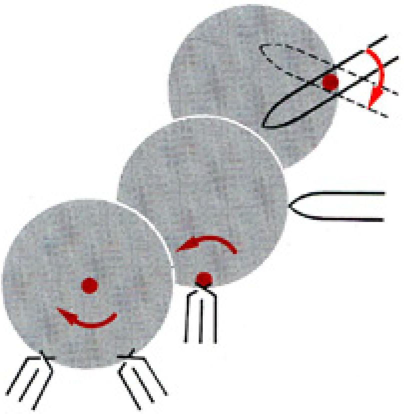


Fig. 5.48. **Centers of rotation for actions associated with the cataract knife section.** The center of rotation for corrective movements of the fixation forceps (see Fig. 3.21 a) is at the center of the globe (*bottom*). Movements of the knife (see Fig. 3.21 b) rotate the globe about the application site of the forceps (*center*). Swiveling movements of the knife (see Figs. 5.45 d and 5.46 c) should pivot at the puncture site to prevent the escape of aqueous (*top*)

Since the puncturing and sectioning maneuvers are separate with this instrument, both vectors cannot be simultaneously opposed by a single *fixation*. Therefore the surgeon must decide whether main resistance should be given to the puncturing vector or the sectioning vector. This will determine whether the fixation instrument is applied opposite the puncture site or opposite the end of the incision (Figs. 5.45, 5.46).

Broad fixation forceps allow greater freedom in this regard. However, they can also cause tissue distortion (very critical in this technique) unless they are held exactly in the position predefined by the shape of the grasping surfaces.[22]

Loss of aqueous can be prevented only during the puncture and counterpuncture. As soon as the section is begun, the incision is made under more demanding conditions, i.e., with lax tissue, decreased sharpness, and a protruding diaphragm. To avoid iris injury, the surgeon should pass the knife beyond the pupil margin immediately after making the counterpuncture, while the chamber still has sufficient depth. He must avoid any corrective maneuvers prior to this, because any tilting, raising, dipping, or withdrawal of the blade will allow premature aqueous escape. Only after the knife has passed the pupillary margin the direction of the cut may be revised. It should be noted, however, that any *direction change* in the incision will also change the *width* of the opening (Fig. 5.47).

The cataract knife section requires considerable skill, because the movements of the fixation forceps, knife, and the relative movements between them have *different centers of rotation* (Fig. 5.48). A good result is obtained only if these movements are perfectly coordinated at all times. This is made difficult by the requirement that all movements be performed swiftly and smoothly in the initial phase, i.e., before the blade passes the pupil margin.

5.4.3 Cutting with a "Point" Cutting Edge

Keratomes, cataract knives, and other broad-bladed knives are designed for making incisions in a *single plane*. To produce more *complex* incisions, techniques are required that immerse only a very small blade width in the tissue (see Fig. 2.74). The blade will then behave more or less as a "point" cutting edge and can be directed as needed to produce incisions of any shape desired (Fig. 5.49; see also Fig. 2.66).

---

[22] Deformation by wide grasping forceps as illustrated in Fig. 3.20 b is a particular problem when the anterior chamber has emptied and the now "blunt" cataract knife tends to push the tissue aside rather than cut it.

back to index

❮

❯

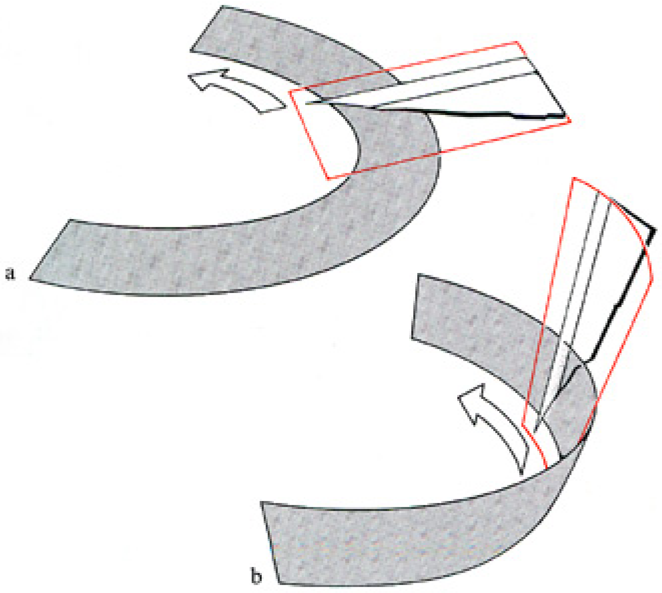


Fig. 5.49. **Opening the anterior chamber with a razor blade**. The technique of holding and guiding the blade determines the profile of the resulting incision.

a Coronal incision is made by guiding the blade on one plane, imitating a cataract knife or keratome section (preparation for continuing the section with scissors as in Fig. 5.55a).

b Perpendicular incision is made by holding the blade upright and guiding it along a conical surface (preparation for scissor section as in Fig. 5.55b)

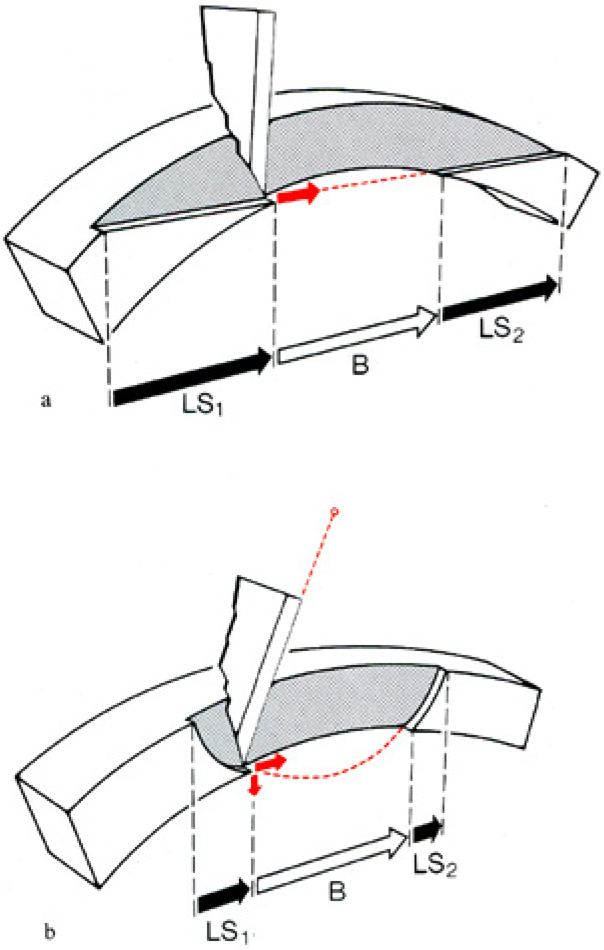


Fig. 5.50. **Avoiding centripetal vectors on opening the anterior chamber with a long incision using a razor blade fragment**

a An interior opening of specified length (*B*) can be made by a purely tangential blade motion. The cut is started some distance from *B* so that the blade first passes through an intramural "lead segment" (*LS*) before incising the deep surface of the cornea. As a result, the external opening is longer than the internal opening.

b If the incision is started closer to *B* (shorter *LS*) to reduce the length of the external opening, the blade motion will inevitably produce centripetal vector components

back to index

‹ ›

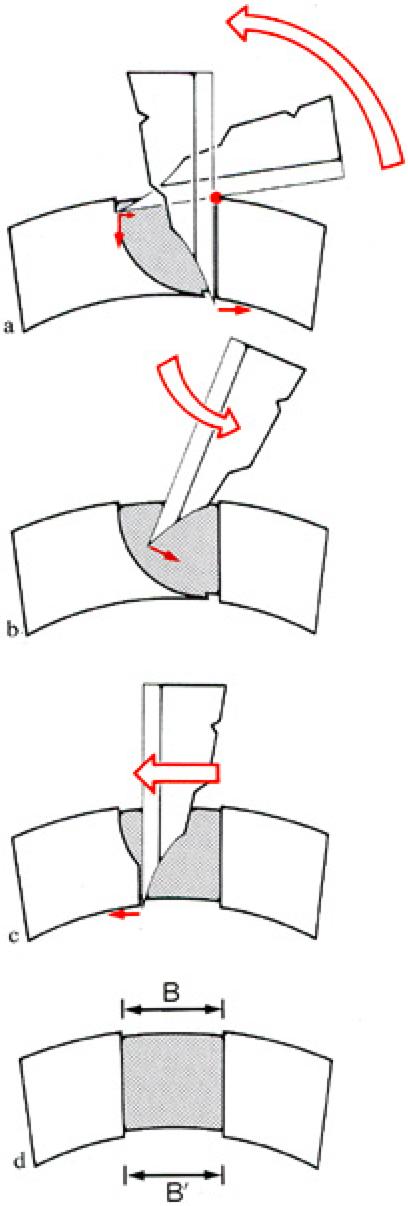


Fig. 5.51. **Avoiding centripetal vectors on opening the anterior chamber with a short incision using a razor blade fragment**

a When the intent is to make an incision that has equal external and internal lengths, centripetal vector components can be reduced by rotation of the blade. Centripetal vectors then exist only as long as the blade is within the tissue. The moment the chamber is entered, only tangential vector components are operative.

b For extending the incision the blade is removed, turned 180°, and reintroduced into the wound with the blunt edge leading.

c Then the blade is moved tangentially until the deep wound length matches the superficial wound length.

d Result: $B = B'$; no lead segment

However, a blade used in this fashion cannot seal the incised opening, and most of the incision must be made with the chamber opened, and thus with decreased tissue sectility. This places very high demands on the cutting ability of the instrument. Even with a very sharp blade, though, only a short chamber opening can be made unless the tissue resistance is extremely low.[23]

Because the anterior chamber can empty, blade movements with centripetal vector components (i.e., directed toward the chamber) are hazardous in this technique. These components are avoided by guiding the blade *strictly in a tangential direction* (Figs. 5.50a, 5.51c).

5.4.4 Scissor Section

Scissors can accurately cut tissues of low sectility, so they are used to *complete the cut* after the anterior chamber has been opened with another instrument. Scissors also allow a *safe section* because the "danger zone" (see Fig. 2.81b) is precisely defined, and its size can be reduced by taking small bites with the scissors.

An important safety factor is the *tangential movement* of the cutting point during the section (Fig. 5.52b).

Real danger exists only during **insertion of the scissor blades** into the anterior chamber, when *centripetal* vectors are unavoidable (Fig. 5.52a). That is why, in corneal scissors, the end of the inserted blade is rounded to prevent inadvertent tissue lesions (Fig. 5.53a). Also, the rounded blade is longer so that it will not slip out of the chamber when the scissors is closed (Fig. 5.53b). An incision of constant profile is obtained by cutting in opposite directions with *two scissors*, each a mirror image of the other (Fig. 5.54).

---

[23] E.g., the incision of a deep precut groove, where only a very thin layer remains to be divided before entering the chamber.

back to index

‹ ›

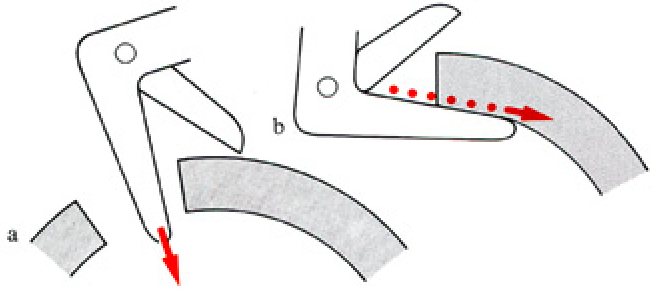


Fig. 5.52. **Force vectors produced by scissors**

a Centripetal vectors occur when the blade is introduced into an opening.

b During the scissor section, the vector of the cutting point motion is parallel to the surface

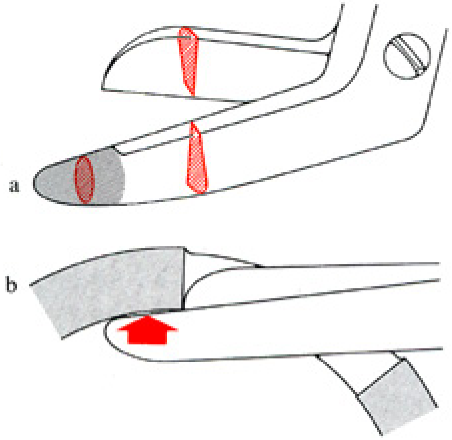


Fig. 5.53. **Special design features of corneal scissors: Blade tips**

a If the blade inserted into the chamber is blunt-tipped and well rounded, it forms a kind of spatula (*gray*) that projects past the ground edges of the blades. *Red*: Cross-sections of the cutting and blunt blades.

b The longer inner blade keeps the scissors from slipping out of the eye upon closure

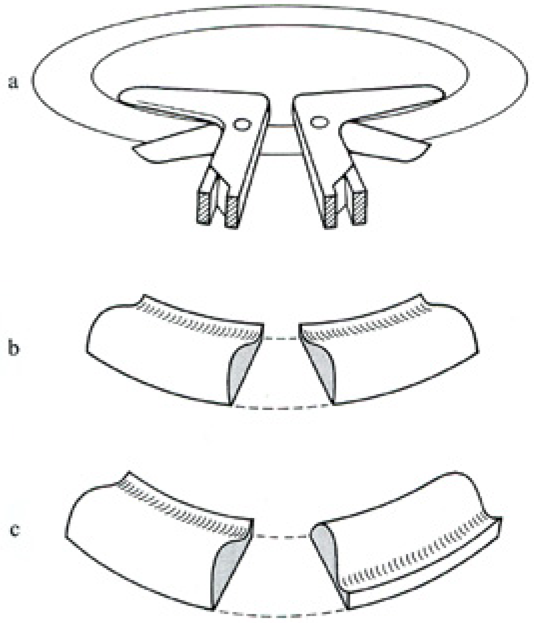


Fig. 5.54. **Special design features of corneal scissors: Arrangement of blades.** Identical, S-shaped cut profiles are obtained by cutting in opposite directions with two scissors, each a mirror image of the other.

a Mirror-image scissors for bidirectional cutting.

b Continuous profile (see also Fig. 2.79) obtained with mirror-image scissors.

c Discontinuous profile made by using a single scissors to cut in both directions

back to index

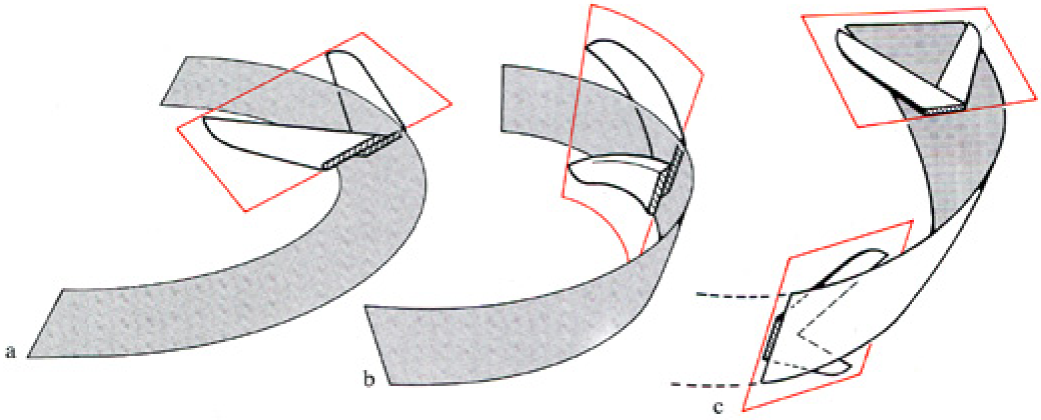


Fig. 5.55. **Relation between the shape of the scissor blades and the shape of the resulting cut.** If the blade shape is consistent with the desired shape of the cut (i.e., the guidance path is congruent with the cut surface), the cut can be completed by simple closure of the blades.

a Straight blades are suited for making flat cuts parallel to the iris.

b Perpendicular cuts are made with blades whose curvature conforms to the conical surface of the cut.

c The plane of the cut can be varied by changing the inclination of the scissors. In this example the ends of the incision are rotated 90° relative to each other. This facilitates opening the wound through rotation of a flap because hinge formation can occur without intramural alignment, i.e., with minimum distortion of surrounding tissue (see Fig. 1.51c)

The **curvature of the scissor blades** should conform to the shape of the planned incision (Fig. 5.55). If this is the case, the section can be completed with a minimum of swiveling movements (Fig. 5.56c). The main concern in the scissor section is to keep the *iris* away from the interblade "danger" zone. Thus, the blades are opened only slightly when initiating the cut to ensure that the enclosed corneal tissue will obstruct access to this zone (Fig. 5.56a). The depth of insertion can be limited by bracing the outside blade against the corneal surface. The inside blade is pressed firmly against the inner corneal surface to prevent incarceration of underlying tissues (Fig. 5.56b).

Safety can be enhanced by introducing *viscoelastic material* to displace the iris backward before enlarging the incision with the scissors; this creates additional room for inserting the scissor blade and for the following maneuvres.

The safety of the iris can be checked directly by watching the blades or indirectly by watching for concomitant pupillary motion (Fig. 5.57).

Disadvantages of the scissor section are the high cutting resistance and the complicated profile of the section. Both correlate with the tissue thickness, however, and are minimized by *preliminary thinning of the tissue layer* (see Fig. 2.80d).

back to index

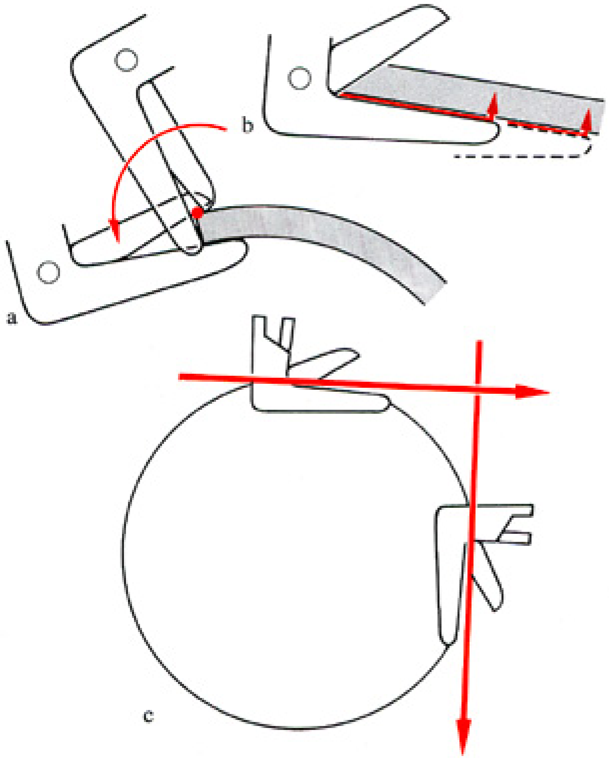


Fig. 5.56. **The scissor section**

a Introducing the scissors: The blades are nearly closed when introduced to avoid injury to intraocular structures. An aperture just large enough to accommodate the corneal thickness will safely obstruct access to the interblade area. The outside blade is braced against the outer corneal surface to prevent inadvertent deep entry into the chamber. Then the instrument is rotated about the outer blade tip into the chamber (*red dot*: Pivot point).

b Extending the cut: The inner blade is apposed firmly to the deep corneal surface to guard against iris incarceration.

c Guiding the scissors: To keep the cutting point moving tangentially to the limbus at all times, a 90° direction change is required through each quadrant. If this is not guaranteed by the blade curvature, the handle must be moved in a wide arc during the section

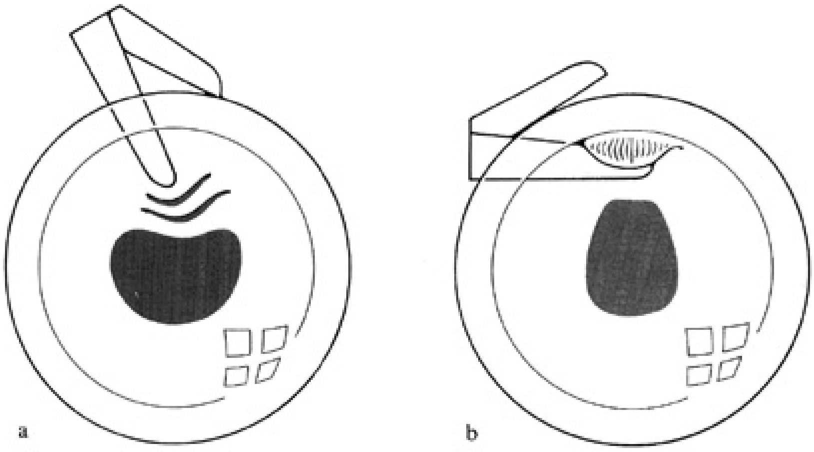


Fig. 5.57. **Monitoring the iris during the scissor section.** Distortion of the pupil is a sign that the iris has been caught by the blades.

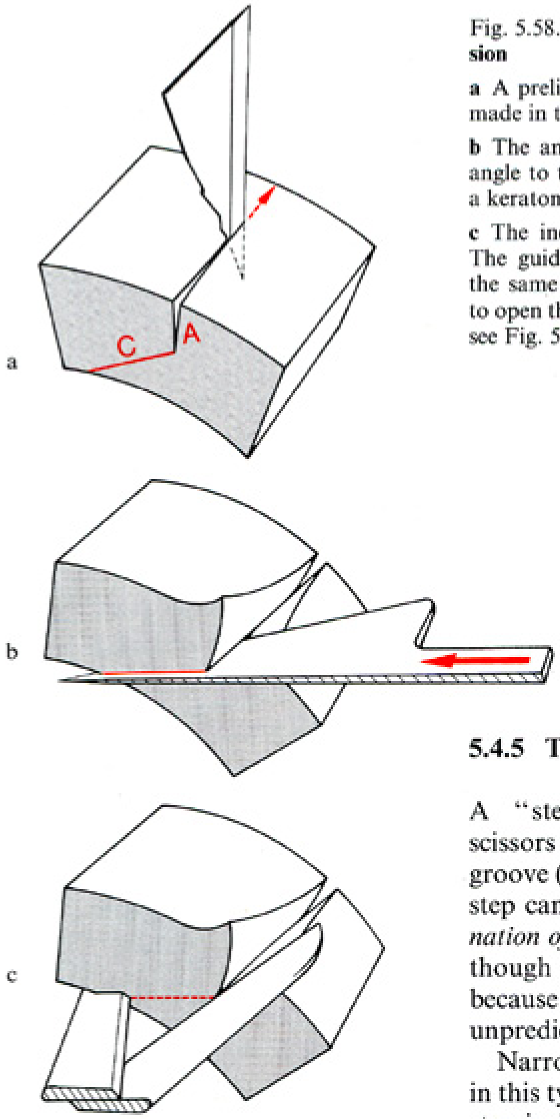
a Inward displacement of the iris on insertion of the inner blade (→ iridodialysis).

b Outward movement of the pupillary margin indicates incarceration of iris between the blade and cornea (→ iridectomy)

back to index

❮

❯



5.58

Fig. 5.58. **Technique of the two-step incision**

a A preliminary perpendicular incision is made in the sclera (*A*) (cf. Fig. 5.4).

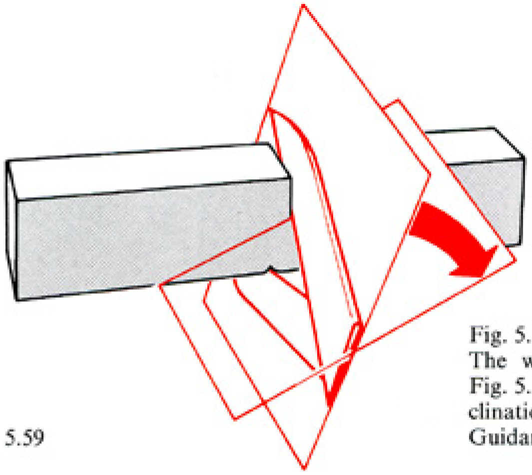
b The anterior chamber is entered at an angle to the precut groove (*C*) (here with a keratome).

c The incision is enlarged with scissors. The guidance path of the scissors is on the same plane as that of the knife used to open the chamber (**b**) (here: Horizontal, see Fig. 5.55a)

5.4.5 Two-Plane Stepped Incision

A "step" is created whenever scissors are used to enlarge a precut groove (Fig. 5.58). The width of the step can be controlled by the *inclination of the scissors* (Fig. 5.59), although this control lacks precision because the tissue tends to shift in unpredictable ways.

Narrow steps cause few problems in this type of incision. But if a wide step is desired, the tissue resistance will rise with increasing step width (see Fig. 5.36c).[24]



5.59

Fig. 5.59. **Changing the width of the step.** The width of the step (segment *C* in Fig. 5.58) is controlled by changing the inclination of the cutting instrument (*red*: Guidance path of the blades)

5.4.6 Three-Plane Stepped Incision

In this incision the resistance to entering the anterior chamber is independent of the step width. The intralamellar portion of the steps is formed in a separate phase (Fig. 5.60). It can be made as wide as desired and placed at any depth.[25]

When the chamber itself is entered, perpendicular vectors (directed toward the eye interior) can be avoided by tenting the inner lamella with forceps (Fig. 5.60c) and then sectioning it with a purely "tangential" guidance motion.

The width of the step is controlled by varying the guidance direction (Fig. 5.61), not by the inclination of the cutting instrument as in the two-plane incision. Therefore cutting can always be done on a vertical, where tissue resistance is lowest.

Corrections are easily made as the three-plane incision is carried out. Small irregularities (Fig. 5.62) usually cause no harm. A serration in the course of the surface groove can even provide a helpful landmark for approximating the wound margins. Variations in the step width also cause few problems. Associated changes in the margin of watertightness can be compensated by appropriate suture placement according to the hinge rule (see Fig. 5.28).

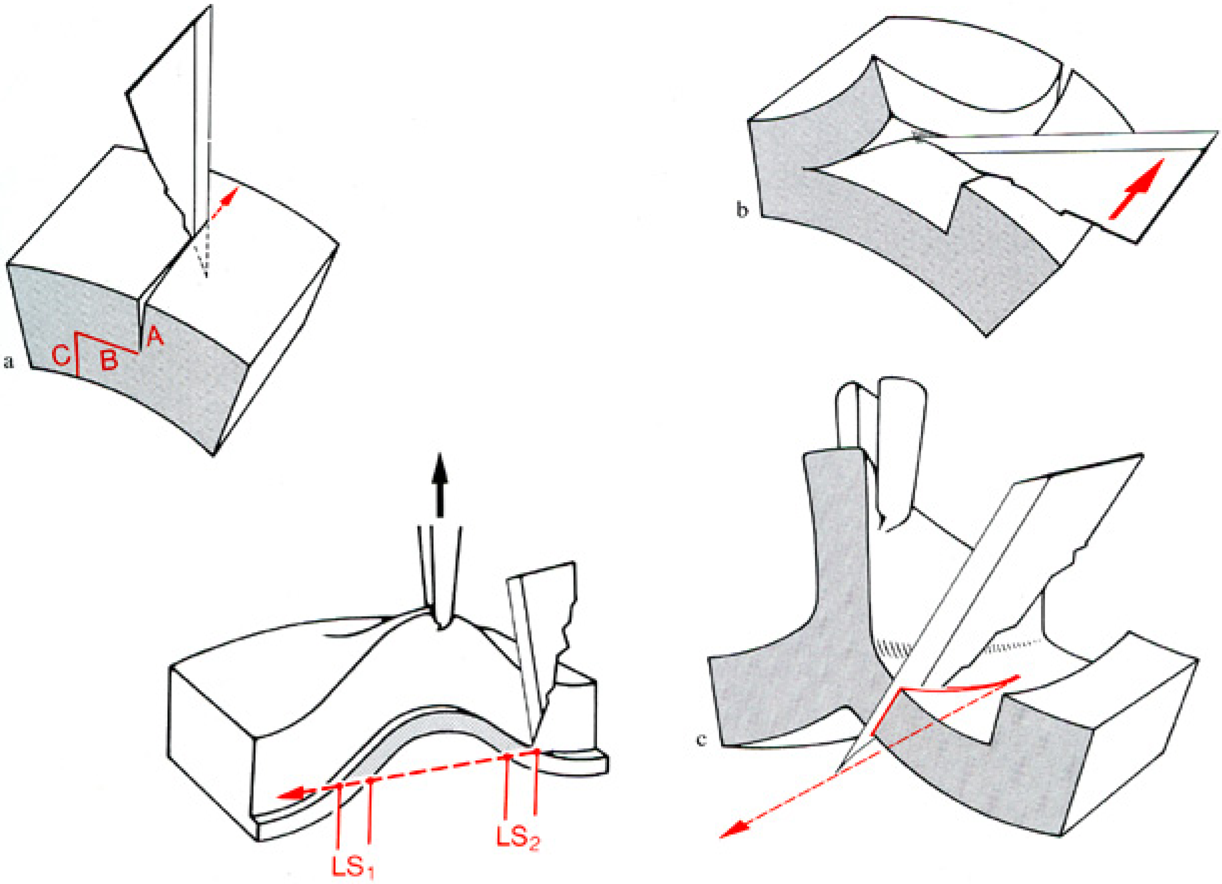
The mutual independence of the outer and inner wound margins in the three-step incision (cf. Fig. 5.35b) can be utilized to achieve specific goals. For example, the outer wound margin can be configured for optimum closure while the inner wound margin is adapted to anatomic conditions (Fig. 5.63).

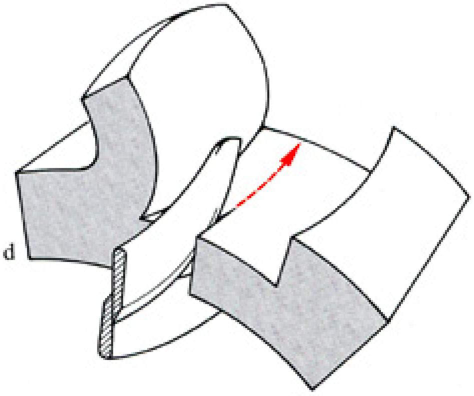
---

[24] *Note*: Scissors held at an oblique angle carry a risk of desquamating the corneal endothelium and Descemet's membrane.

[25] The step may be placed so deep that the inner lamella is transparent and affords a direct view into the chamber periphery.

back to index





5.60

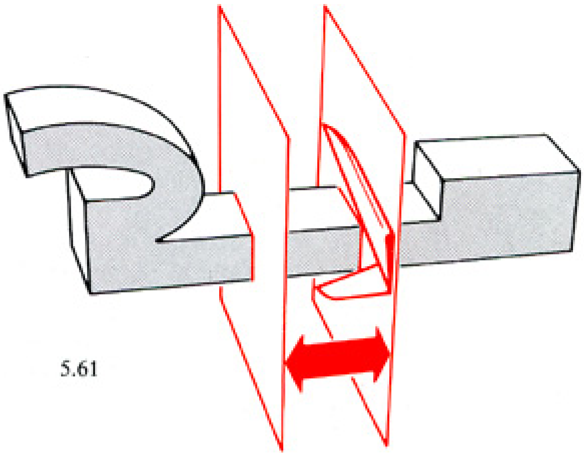
Fig. 5.60. **Technique of the three-step incision**

a A preliminary perpendicular incision (*A*) is made to the desired depth in the sclera.

b The intralamellar part of the step is dissected back to the desired width (*B*) (see Figs. 5.8–5.10).

c The anterior chamber is entered on a perpendicular plane (*C*). Tangential guidance of the blades is facilitated by tenting the inner lamella with fixation forceps. *Left*: A lead segment *LS* is still necessary but is smaller than in Fig. 5.50 due to the preliminary thinning of the cornea.

d The incision is enlarged with scissors. Their guidance path is perpendicular (see Fig. 5.55 b)



5.61

Fig. 5.61. **Controlling the step width**. The step width is changed by shifting the cutting instrument laterally, i.e., toward the limbus or toward the corneal center as needed (*red*: Guidance path of the cutting edge)

back to index

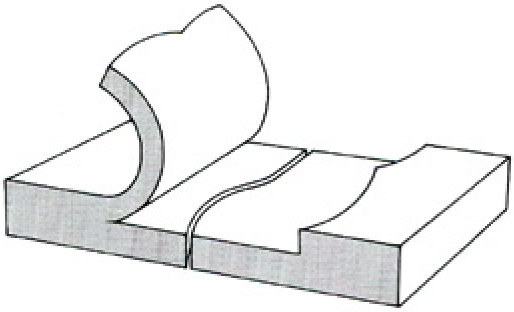


Fig. 5.62. **Irregularities in the stepped incision.** Irregularities in the course of the incision do not hamper wound closure as long as the valvular mechanism remains intact

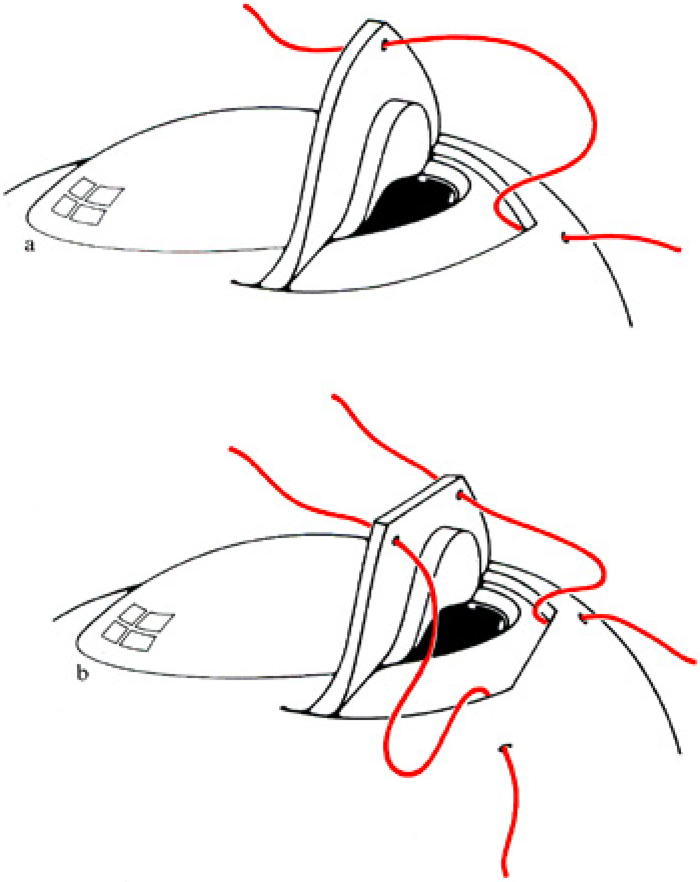


Fig. 5.63. **Disparities in the shapes of the external and internal wound margins ("gothic arch" incision)**

a The *external* wound margin consists of two intersecting segments of great circles and can be closed with one suture at the apex (see Fig. 5.31d and e). The *internal* wound margin parallels the limbus to respect the local anatomy.

b Incision with a truncated apex: The external wound margin consists of three smaller segments, all of which are closed with only two preplaced sutures. This type of incision allows the insertion of instruments or implants through one segment while the others remain safely closed

5.4.7 Trephine Incisions

Trephines are circular blades (Fig. 5.64) that excise round tissue pieces of precisely defined *diameter* and edge *profile*. In theory, a given trephine should excise perfectly congruent disks from different eyes,[26] but in reality trephine incisions show individual variations, and specimens cut from different eyes do not have identical shapes. The *discrepancies* are caused by tissue displacements that stem from asymmetrical resistances. Yet the greatest discrepancies occur when the incision is started with a trephine and completed with a different instrument.

If the anterior chamber empties the moment it is opened, the iris and lens will move forward against the cutting edge of the trephine, making it necessary to discontinue the trephination. Continued use of the trephine after opening the anterior chamber requires means to prevent the escape of aqueous. A *no-outflow system* is established either by using a self-sealing instrument design (Fig. 5.65d) or by first replacing the aqueous with viscoelastic material (see Fig. 1.4c).

---

[26] Absolute congruity is essential for optimum corneal grafting, because discrepancies between donor and recipient are a source of irreversible astigmatism.

back to index

‹ ›

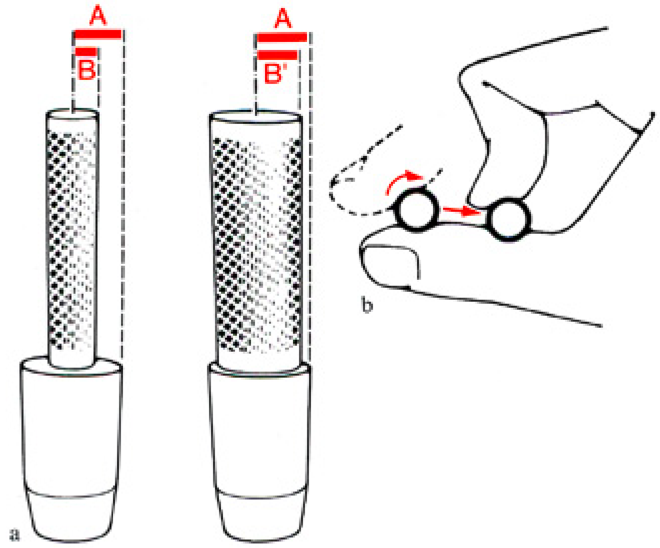


Fig. 5.64. **Manual trephines**

a Effect of handle diameter on cutting excursion. The handle circumference determines the number of revolutions made by the trephine when rolled between the fingers. The two trephines shown have the same cutting diameter (*A*), but the trephine with the smaller handle radius (*B*) completes more turns (= greater pull-through action) when rolled than the thick-handled instrument.

b When rotated, the trephine is rolled along the fingers. Its position is unstable, since the trephine has a tendency to travel, but this instability is partially compensated by the high lateral resistance of the blade

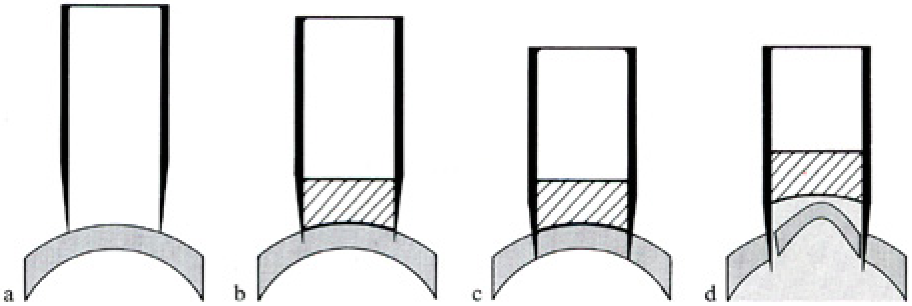


Fig. 5.65. **Open trephines and trephines with a central plunger**

a Open trephine with no depth stop. The operative field is visible through the opening.

b Trephine with an inner plunger. The plunger acts as a stop to limit the depth of the cut (e.g. for lamellar keratoplasty).

c In a penetrating keratoplasty, the stop prevents the cutting edge from passing too deeply.

d The stop serves to seal the aqueous space and prevents emptying of the anterior chamber when trephining an irregularly arched cornea

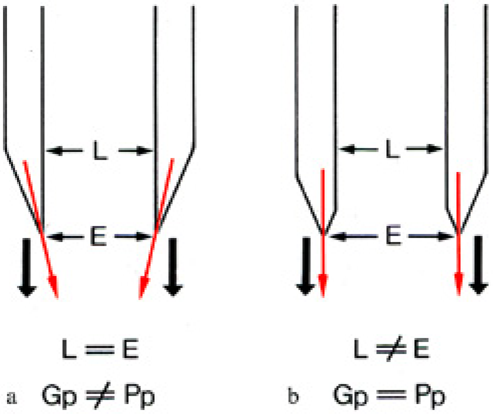


Fig. 5.66. **Bevel of the cutting edge**. The bevel angles of the trephine blade are critical for blades of finite thickness because any discrepancies between the preferential path (*red arrows*) and guidance path (*black arrows*) result from the instrument design and cannot be corrected by manual guidance.

a Bevel only on the outside edge. Inside, the diameter of the bore (*L*) equals the diameter at the cutting edge (*E*). The preferential path (the line bisecting the cutting edge, see Fig. 2.73) does not coincide with the guidance path, so an asymmetric lateral resistance develops.

b Counterbevel on the inside edge. The preferential path and guidance path coincide. The inside diameter at the cutting edge is slightly greater than the bore diameter, so tissue entering the hollow of the instrument is slightly compressed.

P_p: Preferential path
G_p: Guidance path

back to index

❮ ❯

Cylindrical Trephines

Open cylindrical trephines (Fig. 5.65a) allow *visual monitoring* of the trephined disk through the hollow of the trephine. But the cutting edge itself cannot be seen at one time around the whole circumference of the blade due to the cylindrical shape. Open trephines cannot prevent aqueous leakage.

Trephines with a central plunger. A plunger provides an adjustable stop for controlling the depth of penetration (Fig. 5.65b)[27] and can produce a watertight seal.[28]

The **trephining motion** can be divided into two vector components: one perpendicular to the tissue surface (thrust) and one parallel to the tissue surface (rotation). The *thrust vectors* deepen the cut. The *rotation vectors* create a pull-through action that enhances the "sharpness" of the cutting process (Fig. 5.70). The *resistance* to trephining depends on which parts of the trephine come in contact with the tissue, and changes with the depth of penetration (Figs. 5.67–5.69). The interplay of forces and resistances is such that the action of the trephine on the disk and on the surrounding cornea is different. Also, the different forces and resistances vary in the phases *before* and *after* the anterior chamber is entered.

In the initial **phase before the chamber is entered** (i.e., during division of the parenchyma), resistances are distributed evenly along the circumference of the blade. Ini-

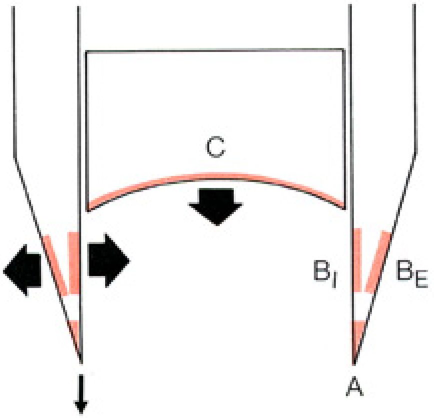


Fig. 5.67. **Design-related sources of resistance in trephines**

A Cutting resistance develops at the sharp cutting edge. The main component acts in the direction of thrust.

B Lateral resistance develops at the lateral surfaces of the cutting edge. Its effects depend on tissue displacement and hence are greater outside the hollow (B_E) than inside (B_I).

C Additional resistance develops if the central plunger meets the corneal surface. This resistance affects only the trephine disk

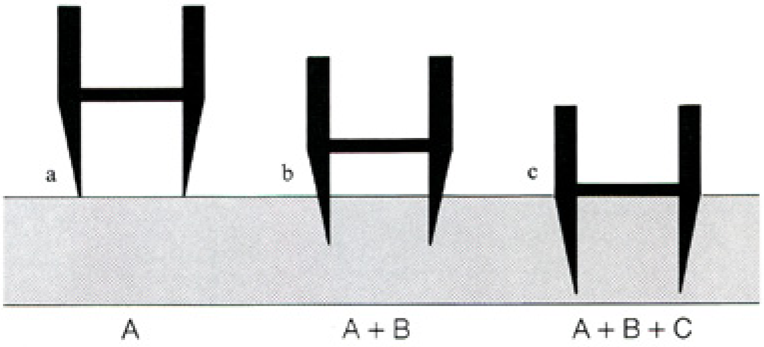


Fig. 5.68. **Effect of penetration depth on resistance prior to entering the anterior chamber**

a Application of the trephine. Only the cutting resistance (*A*) is operative at this stage.

b Penetration of the parenchyma. Lateral resistance (*B*) becomes an increasing factor with increasing depth of penetration.

c Maximum penetration. Contact between the plunger and cornea creates an additional resistance (*C*)

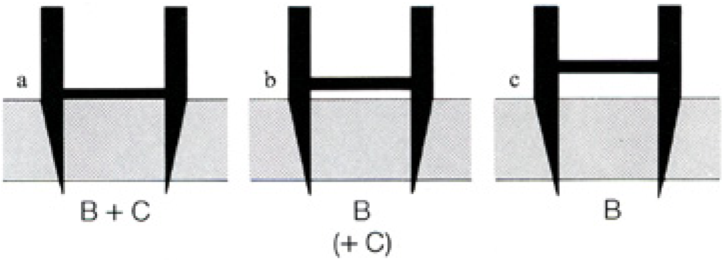


Fig. 5.69. **Effect of plunger position following entry into the anterior chamber.** Once the cutting edge enters the chamber, cutting resistance (*A*) is no longer a factor.

a Depth of plunger set exactly at corneal thickness: When the chamber is entered, the plunger resistance at the disk (*C*) is added to the lateral resistance (*B*).

b Plunger set slightly deeper than corneal thickness: The moment the chamber is entered, the plunger has no contact with the cornea. Concomitant rotation of the corneal disk is determined only by lateral resistance. Fluid pooling beneath the plunger acts as a lubricant; it may transmit some rotation of the plunger to the cornea, depending on its rheological properties.

c Plunger set much deeper than the corneal thickness: There is space over the cornea to allow for folding of the disk

---

[27] Visual monitoring of the disk is possible only from inside the eye using an endoscope. Experimental endoscopic studies form the basis for the following analysis of the trephining process.

[28] The seal must not be airtight, however, because if air is trapped between the blade and cornea, penetration becomes impossible. To avoid airtightness, the bore must be dry before the trephine is applied to the cornea. Otherwise fluid residue may obstruct air outflow.

back to index

❮ ❯

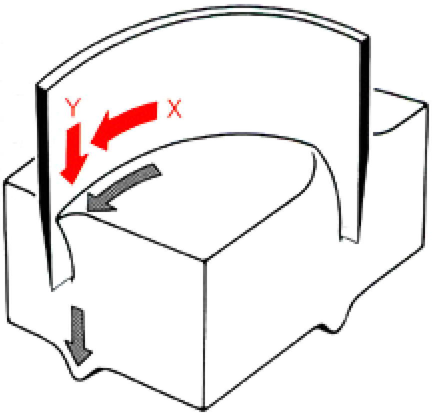


Fig. 5.70. **Vector components of the trephine section.** The perpendicular components (*Y*) cause the cut to progress in depth. They also shift the tissue toward the anterior chamber. The components parallel to the surface (*X*) cut the tissue by an ("infinite") pull-through action. They also cause concomitant tissue motion in the direction of blade rotation

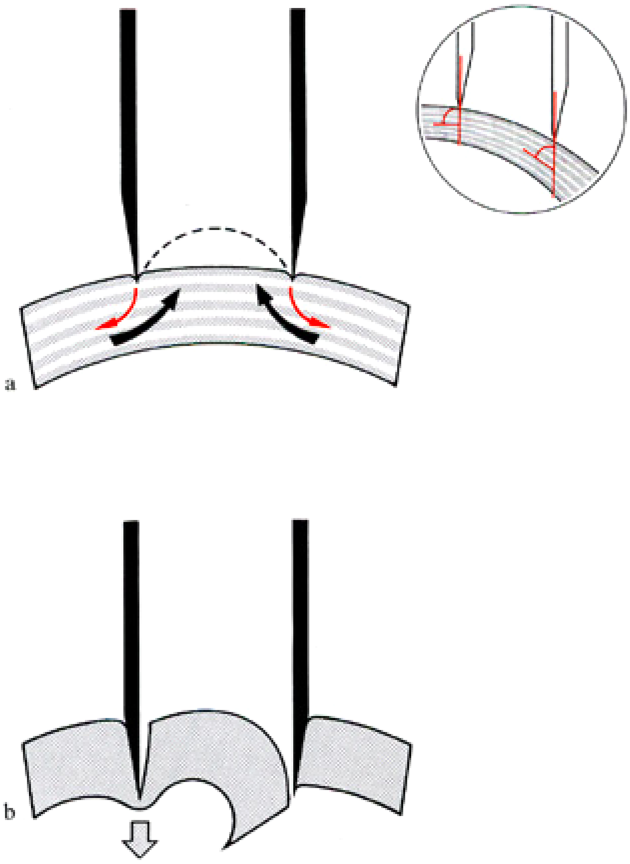


Fig. 5.71. **Tissue motion accompanying blade thrust**

a In the phase before the anterior chamber is entered, the cut may deviate as a result of lamellar deflection. The extent depends on the bevel of the cutting edge (i.e., the direction of the preferential path; see Fig. 5.66) and the angle of attack on the lamellar surfaces (which in turn depends on the site of application on the corneal dome, i.e., the diameter of the trephine; see *inset*).

b In the phase after the chamber is entered, the trephine blade tends to push ahead the still unsectioned tissue. Because these tissue layers have become lax and less sectile, it is difficult to divide them with the trephine

tial resistance to the trephining depends on the resistance to the cutting edge. As the cut deepens, lateral resistance increases and helps to *stabilize the guidance* of the trephine. Thus, the precision of the trephine incision improves as the blade penetrates deeper into the tissue, and the amplitude of the cutting motion may be gradually increased as the incision proceeds. Even manual trephines (Fig. 5.64) can be guided with precision owing to the high lateral resistance that develops. Due to the high lateral resistance, the operator cannot redirect the incision once the cut has been initiated, so the result depends entirely on the inherent *cutting characteristics of the instrument* (Fig. 5.66).[29] In the thrusting mode lateral resistances are asymmetrical, and *lamellar deflection* may shift tissue toward the trephine opening (Fig. 5.71 a).[30] This deflection can be minimized by reducing the thrust vector (applying gentle pressure) and making the cut chiefly by rotation of the trephine.

The rotation induces an entrainment of the tissue in the *direction of rotation* of the trephine. Fixation of the globe with forceps will eliminate this concomitant tissue motion outside the trephine, but it has no effect inside the trephine, where *shear effects* develop in the tissue between the outer cornea and the trephined disk (Fig. 5.72). These shear forces can shift tissue ahead of the blade and create irregularities in the lateral surface of the disk.[31]

In the second phase, **after the anterior chamber is entered,**[32] the situation changes drastically: The tissue becomes less sectile, and the

---

[29] That is why the same trephine should be used to obtain congruent disks from different eyes.

[30] The extent of the deflection depends on the intraocular pressure and is greater at low pressures (= low tissue sectility). Therefore donor and recipient eyes should be trephined at equal intraocular pressures to obtain congruent disks.

[31] Shear effects can be reduced by applying a friction-reducing lubricant, i.e., by moistening the corneal surface. But note: The fluid should be applied to the corneal surface *after* the trephining is started. Otherwise it will enter the hollow of the trephine and trap air (see footnote [28], p. 178).

[32] *Note*: The second phase requires a no-outflow system, that means trephination with a watertight plunger or visco-elastic stabilisation of the anterior chamber.

back to index

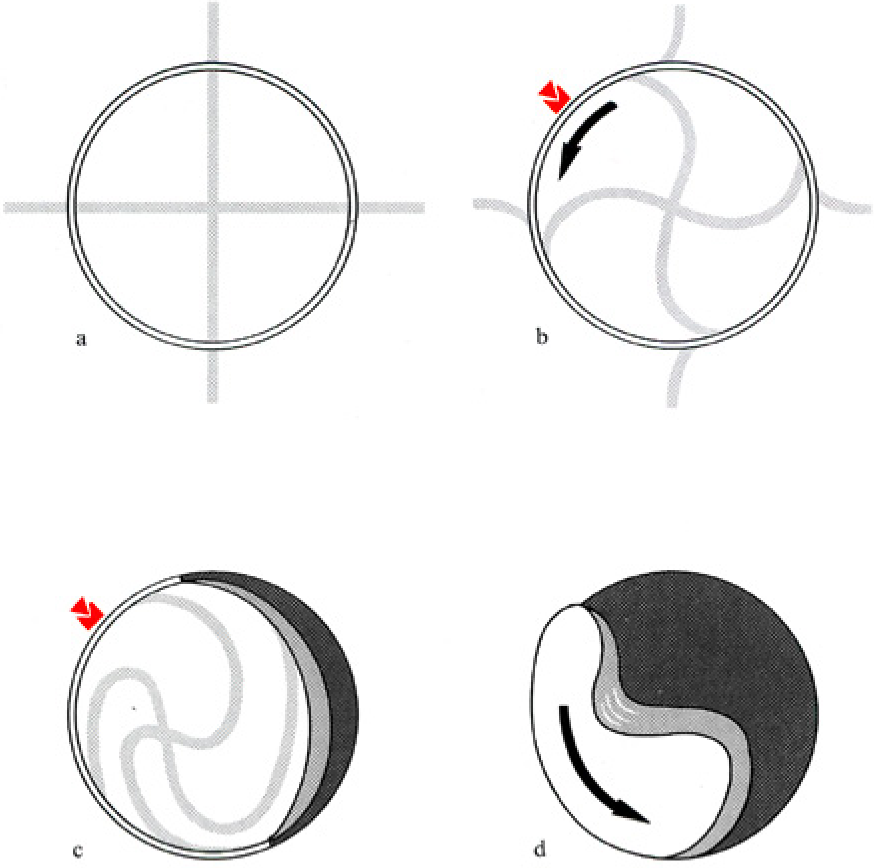


Fig. 5.72. **Tissue motion accompanying blade rotation**

a The drawing shows the position of the corneal disk in the resting state (i.e., at the moment the stationary trephine is applied). This position is marked by imaginary cross-hairs to allow comparison with later drawings.

b During penetration of the parenchyma, the tissue is entrained by the rotating blade. If the peripheral cornea is fixed by forceps at this stage, only the tissue inside the trephine will be twisted. This creates shearing motions between the lamellae in the (superficial) part of the disk already divided and the (deep) portions of the cornea not yet divided.

c After the anterior chamber is entered, the divided part of the disk becomes more mobile and is driven toward the portion still attached.

d When more than half the disk has been excised, it may become folded if there is sufficient space in the hollow of the trephine.

➤ site of forceps application

thrusting motion of the blade tends to push the still undivided corneal lamellae ahead, preventing a full-thickness excision (Fig. 5.71 b). Moreover, the distribution of resistances along the circumference of the blade becomes unequal, and with rotation of the blade the divided, mobile portion of the disk tends to rotate toward the portion that is still attached. This results in a folding of the partially excised disk, and the cutting process continues in deformed tissue (Fig. 5.72 c, d). Yet, as the undivided portion becomes twisted and stiffened, its sectility is restored, and a full-thickness trephine incision may be completed. At that point the corneal disk flattens out again within the hollow of the trephine because the resistances along the circumference of the blade again become uniform. But though apparently the disk has been excised smoothly with one precise cut, it does not have the ideal cylindrical shape because of the tissue distortions occurring in the final phase of the cut.[33]

Trephines with a Pointed Blade

Constant, complete *visual monitoring* of the trephination is possible only with the use of a *cone-shaped* instrument. The basic design requires a pointed blade that travels along a conical outer sleeve (Fig. 5.73).

Small blades are extremely mobile owing to their low lateral resistance and can easily deviate from the intended path. It is more difficult to achieve a circular incision than with a cylindrical trephine, because the low lateral resistance cannot adequately stabilize the instrument. The cut may deviate laterally whenever the blade encounters a site of increased tissue resistance (Fig. 5.74). To avoid this, the trephine and cornea must be apposed so securely that the resistance to lateral deviation is greater than the force inducing the deviation.

---

[33] These deformations are unnoticed by the surgeon because they are hidden by the plunger. The degree of these distortions depends on *friction*, i.e., on the area of contact between the trephine and tissue, and is greatest when the plunger of the trephine touches the corneal surface (see Fig. 5.69 a). The friction is reduced by fluid escaping from the chamber and pooling beneath the plunger (Fig. 5.69 b). Thus, if the chamber has been filled with viscous or viscoelastic material prior to trephining, their rheologic properties can be exploited for lubrication. However, these materials can transmit rotary motion from the plunger to the corneal disk, depending on their maximum viscosity at low shear rates (see Fig. 2.17). If *empty space* exists below the plunger the moment the anterior chamber is entered (Fig. 5.69 c), there will be no plunger friction, but deformation of the disk is facilitated because the dead space makes room for folding or even inversion of the disk (Fig. 5.72 d).

back to index

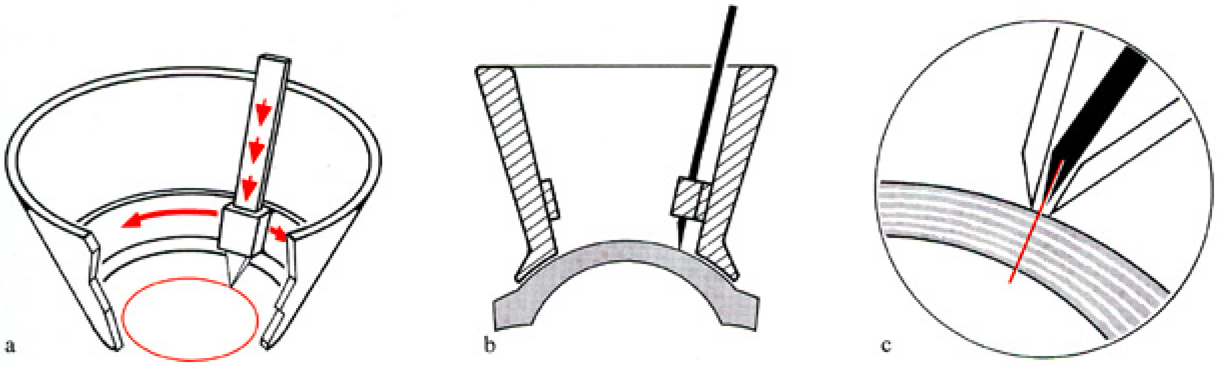


Fig. 5.73. **Trephine with a pointed blade**

a The point of the blade travels along a conical carrier as it is advanced more deeply. Both motions require precise mechanical control.

b Cross-section through the cone and blade.

c With cones of varying inclination, various angles of attack at the tissue can be selected

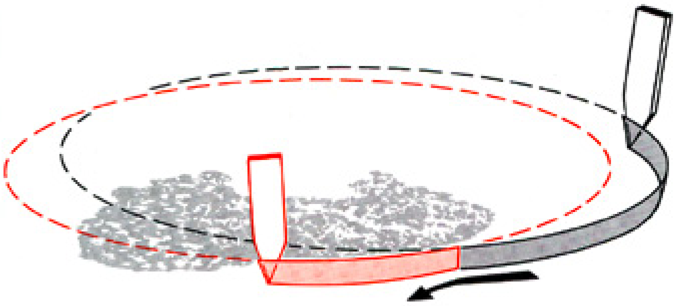


Fig. 5.74. **Lateral shifting tendency of the trephine.** The blade tends to bypass areas of increased resistance within the cornea, e.g. scars (*gray*). The carrier may shift relative to the corneal surface, or the globe may shift relative to the cone if the resistance to this shift is smaller than its force. In contrast to cylindrical trephines, then, the cut may deviate laterally (*red*) from the intended circular path (*black*)

Completion of the Trephine Section

Once the anterior chamber has been entered, trephining can be continued only as long as the chamber retains sufficient *depth*. If the corneal disk cannot be excised with the trephine alone, the section must be completed with a *scissors* or *ultrasharp blade*. But changing to a different instrument also changes the profile of the incision, and a ledge may be formed. Because this is a major source of *incongruity* between different disks, it is important to keep these **ledges** as small as possible. This is achieved by guiding a cutting edge precisely along the cut surface already established (Figs. 5.75, 5.76) and by minimizing tissue deformation in front of the cutting edge. *Scissors* (Fig. 5.77) are applied so that they distort only tissue that will subsequently be discarded (i.e., the residual cornea in the donor eye, and the disk in the recipient cornea). *Fixation instruments* are applied in a way that avoids traction that could deform or displace tissue in front of the cutting edge (Fig. 5.78).

If we analyze the trephining process, we find that the major obstacle to obtaining perfectly congruent disks is the tendency of the blade to *entrain or push aside the tissue*. This tendency results from the resistances that invariably develop along trephine blades of finite thickness. Thus, the key to improving precision with these instruments is to immobilize the peripheral cornea and corneal disk with methods that allow perfect fixation.

Best are "no touch" techniques that divide tissue without resistance, i.e., surgical lasers.

back to index

❮

❯

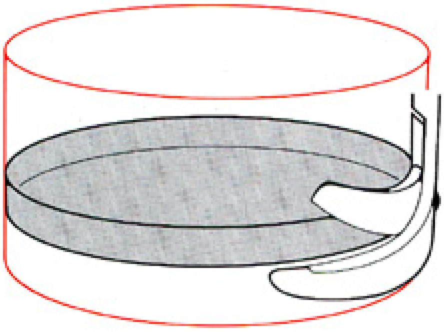


Fig. 5.75. **Completing the trephine section with scissors**. If the radius of blade curvature equals the radius of the trephine, the cutting point will follow the trephine incision on closure of the blades. Thus the blades make no swiveling motions in the anterior chamber

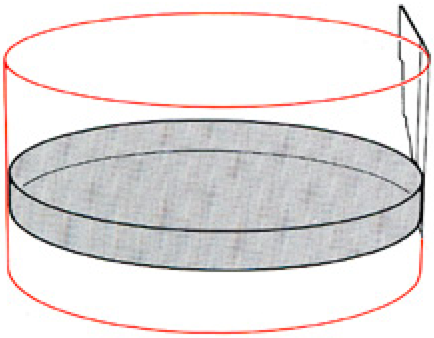


Fig. 5.76. **Completing the trephine section with a sharp-pointed blade**. The cutting edge of the blade is guided carefully along the edge of the corneal disk. It is held in the same plane as the trephine cylinder (i.e., vertically) and precisely follows the circular line of the trephine incision

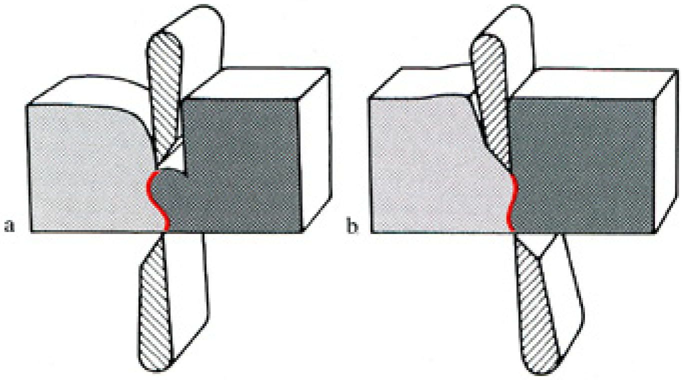


Fig. 5.77. **Completing the trephine incision with scissors** creates a step whose location is determined by the placement of the scissor blades. *Light gray*: Trephine disk, *dark gray*: Peripheral cornea.

a When the edge of the blade in the incision faces from the peripheral cornea toward the disk, the step forms in the peripheral cornea.

b When the cutting edge faces away from the disk, the step is formed in the disk

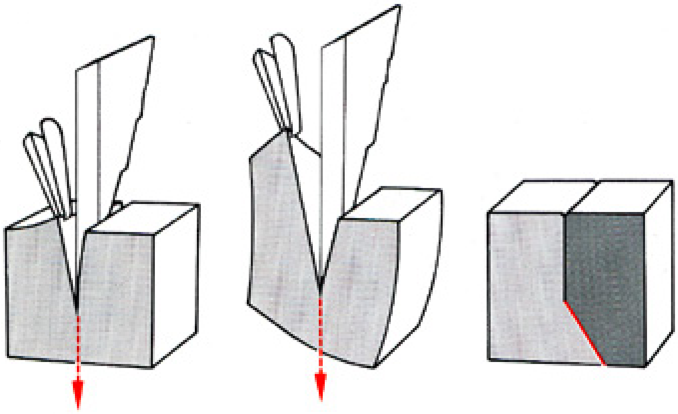


Fig. 5.78. **Step formation by traction with a grasping instrument**. If the forceps does not significantly deform the disk prior to cutting, the blade can make an almost step-free incision (*left*). But if the disk is stretched upward (*center*), an inverse step (= defect) may form in the peripheral cornea (*right*)

5.5 Suturing the Cornea and Sclera

5.5.1 Suture Technique

Due to the unyielding nature of the tissue, extreme precision is required in the placement of corneal and scleral sutures.

The **needle track** is cut in lamellar tissue, so the *lamellar rule* applies. This means that the greatest accuracy is achieved when the needle tip is passed either parallel or perpendicular to the plane of the lamellae (Fig. 5.79) rather than obliquely (see also Fig. 5.2). This requirement is especially important in tissue with low sectility, which offers greater resistance to passage of the needle.

If tissue deformation is caused by the grasping forceps, it must be compensated for by appropriate countermovements during needle passage (Figs. 5.80–5.82).

back to index

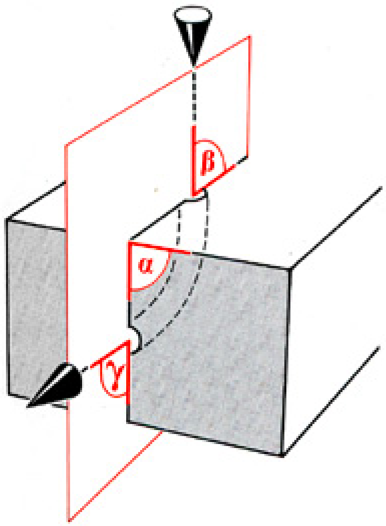


Fig. 5.79. **Suture characteristics.** A suture causes minimal shift of the wound surfaces when:

- the suture plane is perpendicular to the tissue surface ($\alpha = 90°$);
- the needle is inserted perpendicular to the tissue surface ($\beta = 90°$);
- the tip emerges perpendicular to the wound surface ($\gamma = 90°$)

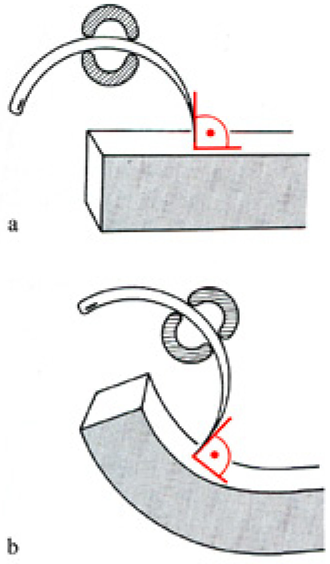


Fig. 5.80. **Inserting the needle perpendicular to the tissue surface**

a In an undeformed tissue surface, the needle shaft must be inclined well back to allow the tip to pierce the tissue at a right angle (note the position of the needleholder).

b If the tissue surface is picked up with a forceps, the needle position must be adjusted accordingly. The shaft may now be held in a more upright position

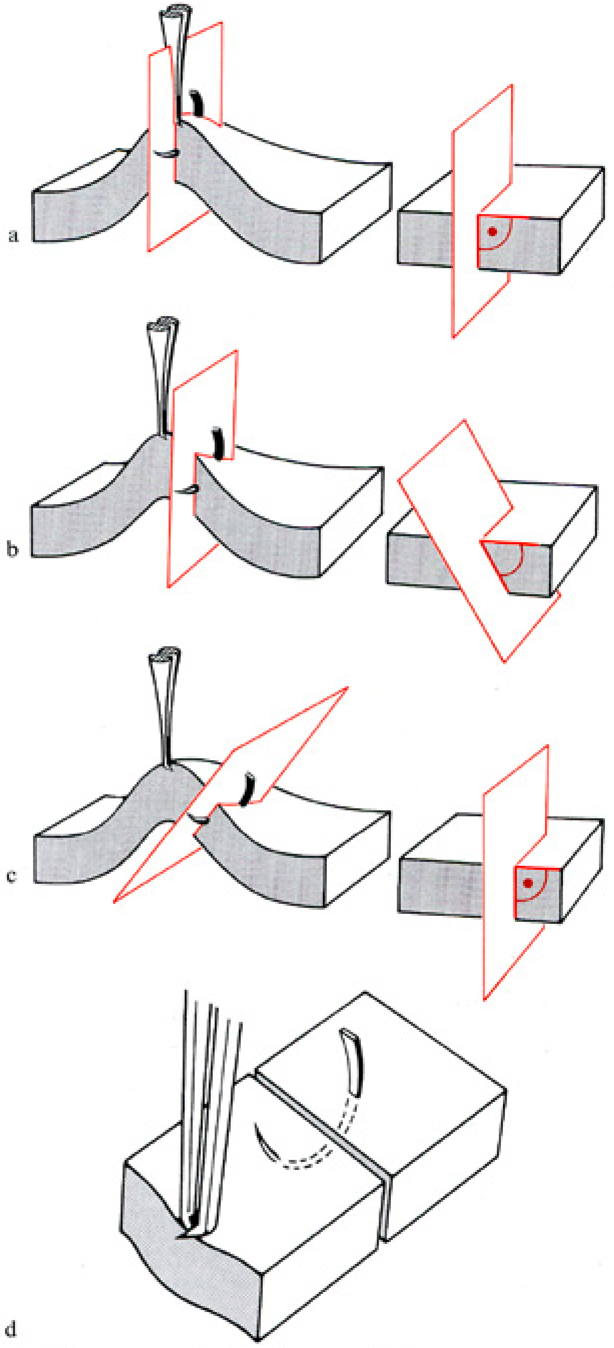


Fig. 5.81. **Obtaining a perpendicular suture plane**

Left: Tissue deformation by forceps.

Right: Position of suture plane after forceps release.

a–c The wound margin is picked up with a forceps to create resistance for suturing.

a If the needle is passed on the perpendicular plane directly beneath the forceps, the suture plane also will be perpendicular on release.

b The same maneuver performed at some distance from the forceps yields an oblique suture plane upon release.

c Compensatory slanting of the needle is necessary when the suture is passed at some distance from the forceps.

d An ultrasharp needle can be passed with very little fixation of the wound margins, so the forceps need not grasp (and deform) the tissue but merely touches its surfaces at the needle exit (see Fig. 2.40c). This eliminates the tissue deformation problems in **a–c**

back to index

‹ ›

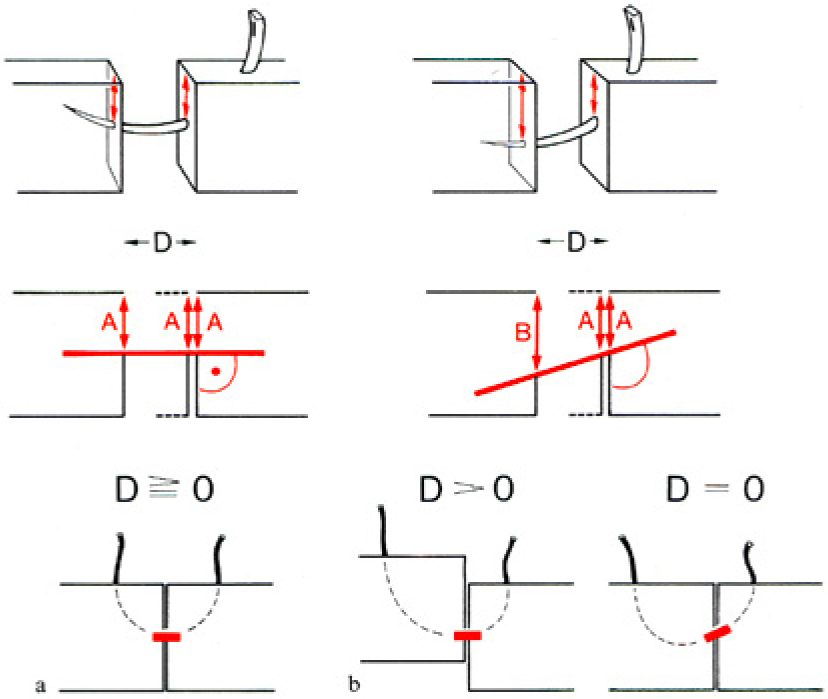


Fig. 5.82. **Effect of the direction of needle passage on wound apposition**

a Passing the needle parallel to the tissue surface results in equal suture depths in the two wound surfaces (*A*) regardless of the gap between them (*D*) at the time of suturing.

b Passing the needle obliquely results in different suture depths (*A* does not equal *B*), an effect that increases with the distance *D*. The degree of incongruity on tightening does not depend on the suture tension (*lower left*). If the wound margins are pressed together during oblique passage of the needle (*D* = *O*), the suture depths are equal (*A* = *B*), but the stitch is asymmetrical (*lower right*). The wound surfaces will remain apposed at low suture tension but will become incongruent when tension is increased

Loose sutures such as simple **apposition sutures** pose few problems because they do not alter the tissue topography. But *tight sutures* such as **compression sutures** shorten the suture track and cause deformations that may interfere with wound closure. The nature of the deformation can be inferred from the *rule of suture tightening* (see Fig. 2.100). In perpendicular incisions, the deep wound edges begin to gape when suture tension is increased (Fig. 5.83). In single-plane oblique incisions, the wound edges shift relative to each other and override (Fig. 5.84). In stepped incisions, superficial apposition is preserved but the valve mechanism is destroyed in the deeper portion of the wound (Fig. 5.85).

It should be noted that a *single deforming suture* can disrupt closure for the full length of the wound due to the rigidity of the tissue (Fig. 5.86, see also Fig. 5.94). This situation is best corrected by *removing* the offending suture. Any attempt to produce a countertension with "corrective sutures" would cause additional distortion that may restore watertightness, but at the cost of significant astigmatism.

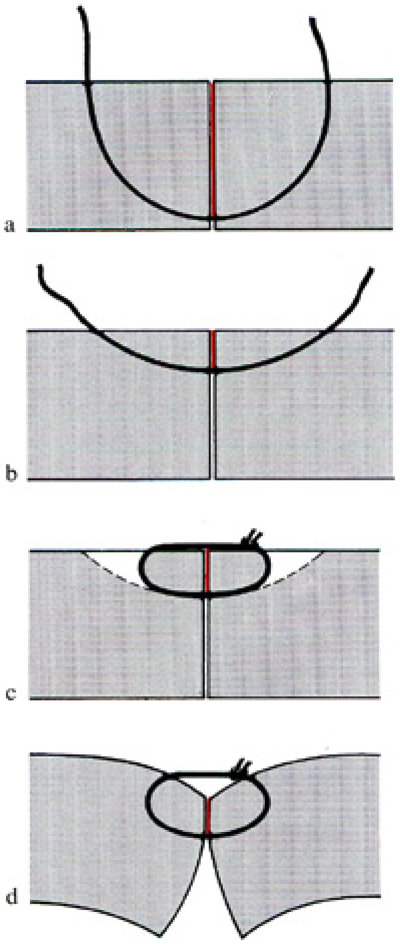


Fig. 5.83. **Suture problems in the perpendicular incision**. Comparison of sutures that enter and emerge at points equidistant from the wound line.

a A deep semicircular stitch produces a large compression zone. The depth of placement is limited by the tissue compatibility of the suture material (inflammatory canal, see Fig. 2.123).

b A superficial stitch compresses only a small part of the wound surface. Apposition in the deep (uncompressed) zone is maintained only if the suture track has not been shortened by tightening of the thread.

c The thin surface layer may tear when the suture is tightened. This places the suture closer to the wound line than planned.

d If the tissue does not tear, deep gaping occurs when the suture is tightened. Aqueous may rise to the suture track. Contrary to expectations, the more the suture is tightened, the greater the risk of fistula formation

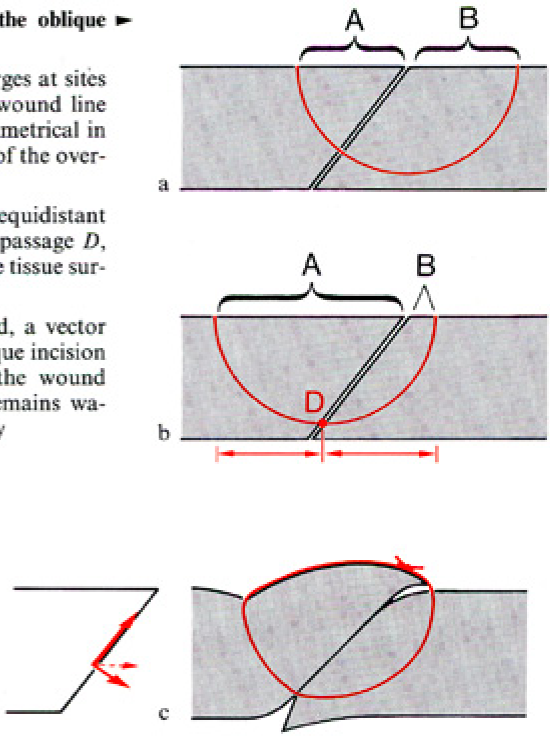
back to index

Fig. 5.84. **Suture problems in the oblique incision** ►

a If the suture enters and emerges at sites equidistant from the external wound line (*A* = *B*), the stitch will be asymmetrical in the tissue and encompass little of the overriding wound margin.

b If the entry and exit sites are equidistant from the point of deep suture passage *D*, they will be asymmetrical on the tissue surface (*A* > *B*).

c When the suture is tightened, a vector component acts along the oblique incision to cause relative shifting of the wound margins (*inset*). The wound remains watertight, but apposition is faulty



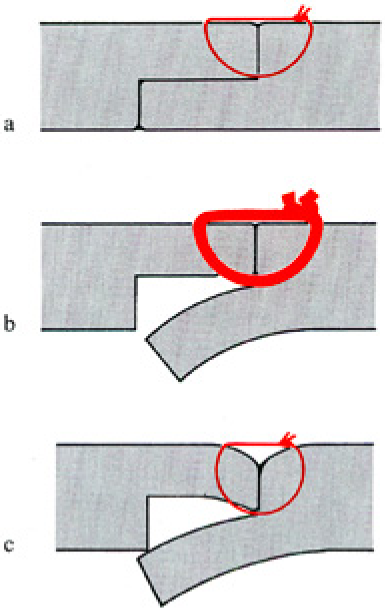


Fig. 5.85. **Suture problems in the step incision** ►

a The outer step is fixed by a superficial apposition suture and maintains the valve function.

b The valve mechanism is impaired by a thick thread in the interlamellar layer.

c The valve mechanism is also compromised by excessive suture tension. The entire valve is deformed and may leak

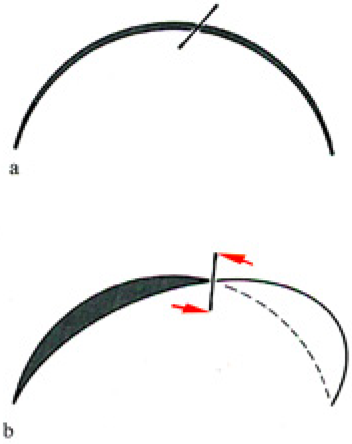


Fig. 5.86. **Tightening of obliquely placed sutures**

a When loose, an obliquely placed suture does not impair apposition.

b Tightening the suture causes the wound edges to shift, and leak occurs not just at the suture but along the entire wound line

5.5.2 Special Types of Suture

Given the difficulties that invariably occur when tight sutures are used in rigid tissue, it is best to avoid incisions that require compression sutures for effective closure (perpendicular incisions) in favor of incisions that can be made watertight with simple apposition sutures (valvular incisions).[34] In that case the type of suture used is far less important than the suture *length* – for any suture whose length exactly equals the length of the needle track makes a satisfactory apposition suture (see Fig. 2.97).

If the surgeon must deal with a *traumatic or irregular wound* of predetermined shape, he should seek the best compromise on the basis of the valve rule, hinge rule, and the rule of suture tightening.

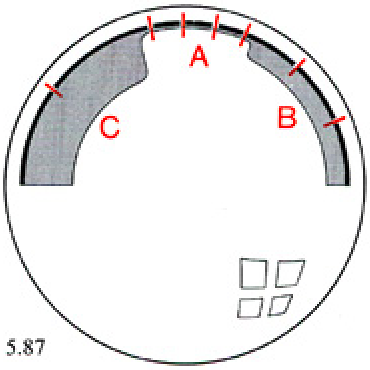
---

[34] Some very small valvular incisions can be made watertight simply by applying a contact lens.

back to index

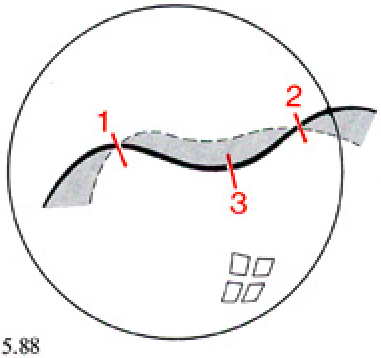
‹ ›

Fig. 5.87. **Wounds with a variable valve width.** Simple interrupted sutures are spaced according to the hinge rule. In segment *A* the wound surface is steepest (i.e., the valve is most narrow), so the sutures must be spaced closer together than in segment *C*, where the valve is very wide



5.87

Fig. 5.88. **Wound with valves facing multiple directions.** Simple interrupted sutures are placed at sites where the wound surfaces are perpendicular (*1* and *2*), subdividing the wound into segments whose valves face the same direction. These segments are managed according to the hinge rule (*3*)

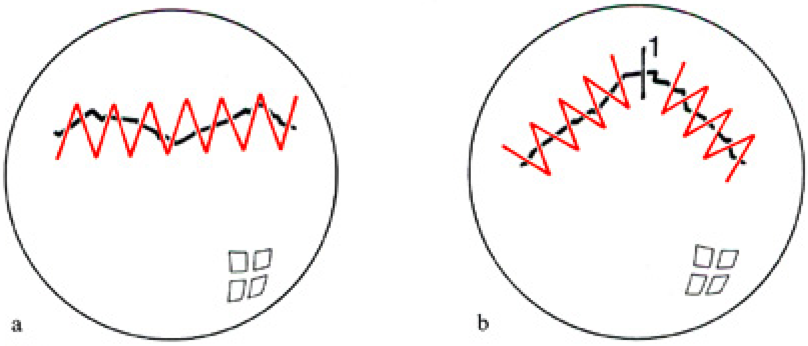


5.88

Fig. 5.89. **Continuous sutures on irregularly shaped wounds**

a Continuous sutures tend to linearize the encompassed area (see Fig. 2.103 b). Thus the suture does not follow the irregularities in the course of the wound, but produces a linear compression zone that incorporates the entire wound area.

b If the wound line is too irregular to permit this, one or more simple interrupted sutures (*1*) are used to subdivide the wound into segments, which are then managed in accordance with **a**. (*Note*: Strong suture tension tends to flatten the corneal dome; see Fig. 2.103 a)



a

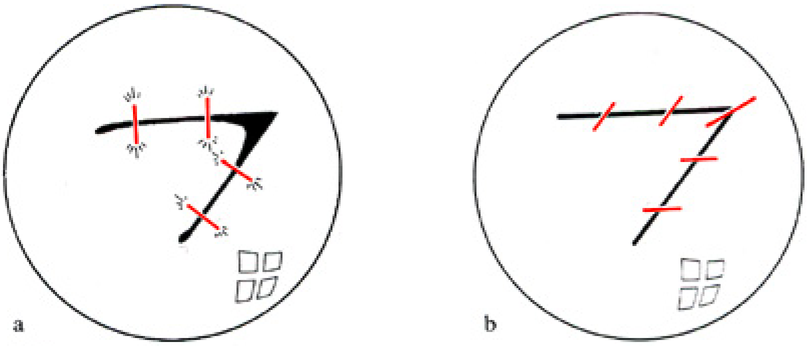
b

5.89

Fig. 5.90. **Suturing a triangular flap**

a Compression sutures on the lateral wound margins would cause the apex of the flap to retract.

b Solution: The apex is sutured first. This is done by direct suture if sufficient tissue is present, i.e., if the flap angle is sufficiently large. The lateral sutures are placed obliquely to relieve tension on the apex



a

b

5.90

In incisions that have a **nonuniform valve width** (Fig. 5.87)[35] more sutures must be placed per unit wound length in portions with a narrow wound surface than in places with a wider valve. If the **plane of the cut is twisted** so that the valves face various directions (Fig. 5.88),[36] interrupted sutures can be placed at the nodes of the twist (i.e., at sites where the wound surfaces are perpendicular), subdividing the wound into *segments* that have a single valve direction. These segments are then closed according to the hinge rule.

Wounds with **multiple fine serrations** are best managed by dividing them into *subsegments* that can be closed with straight, continuous suture lines (Fig. 5.89).

---

[35] This occurs when the angulation of the cutting instrument is varied during the corneal section. For example, segment A in Fig. 5.87 was made with the blade held upright, resulting in a narrow valve. The section was completed with scissors held less upright in segment B (moderately wide valve) and at a very low angle in segment C (very wide valve).

[36] This type of wound is made by flat, irregular missiles such as flying glass or a bursting shell.

back to index

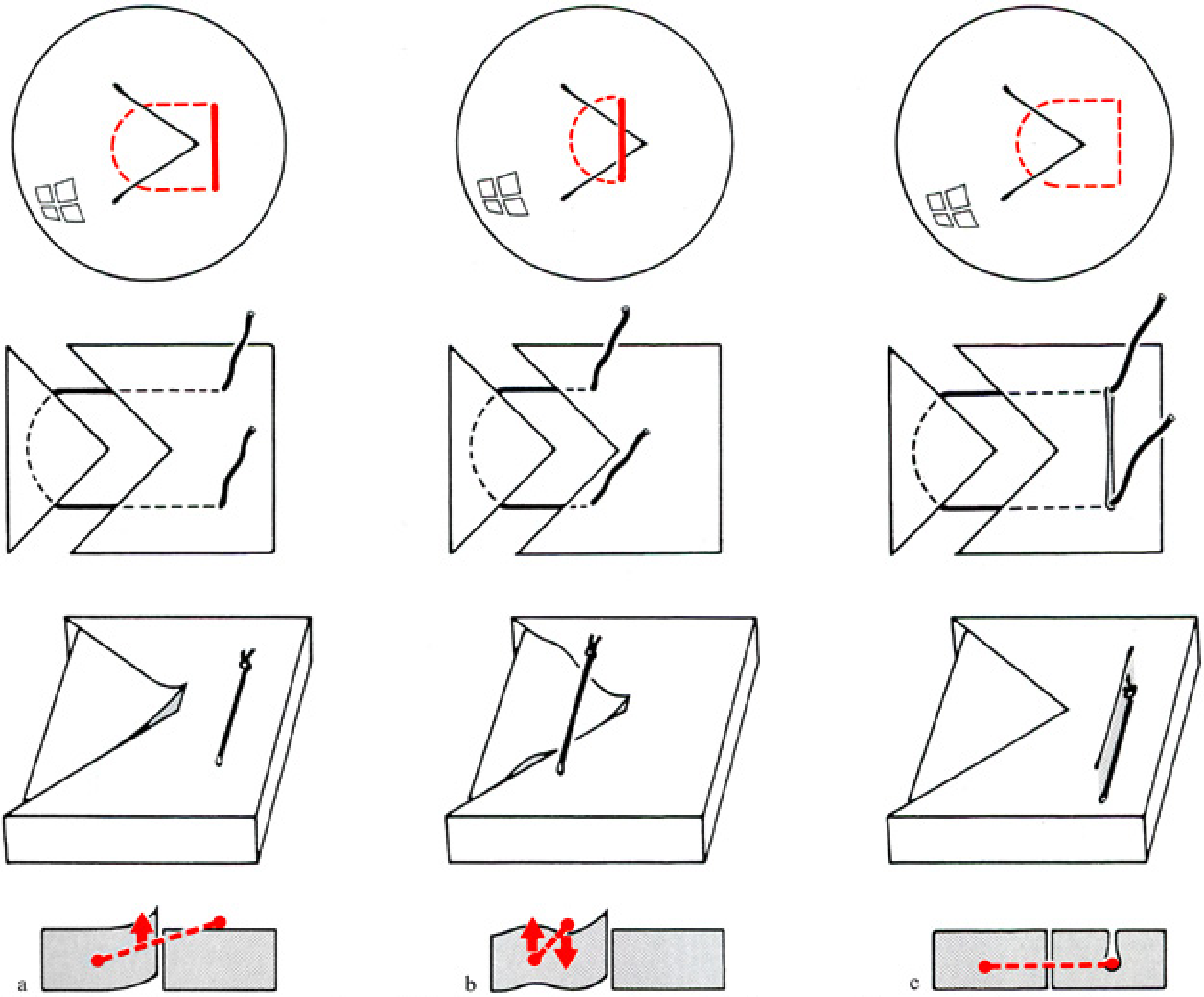


Fig. 5.91. **Closure of triangular wounds with intralamellar sutures.**
Top: View of the cornea from above.
Center: Semiperspective view of the loose and tightened suture.
Bottom: Cross-sectional view of the apical region.

a Partial intralamellar suture: The stitch is intralamellar in the flap and epicorneal distal to the flap. Tightening the loop creates vectors that evert the flap above the level of the cornea, forming a step.

b Passing the epicorneal part of the loop across the end of the flap (i.e., placing the suture less distally) creates vector components that press the flap downward and reduce eversion of the apex, although the surface of the flap is still somewhat irregular.

c For a purely intralamellar suture, the cornea is incised to the desired depth distal to the apex of the flap using an ultrasharp blade. The suture is passed from the base of this incision through the flap and back to the groove, affording a secure closure that keeps the flap flush with the surrounding cornea

The closure of **triangular and branched wounds** is especially challenging.[37] Compression of the side limbs causes immediate gaping of the apex (Fig. 5.90). The first step, then, is to *secure the apex*. If there is not enough tissue for a simple interrupted stitch, the apices can be apposed using *intralamellar sutures* (Figs. 5.91, 5.92). Sutures with a partial intralamellar placement have a tendency to evert the intralamellar portion of the wound (Fig. 5.91a, b). This is avoided by a total intralamellar suture placement (Fig. 5.91c).[38] When closing the *side limbs*, it is useful to place the sutures obliquely to direct additional traction toward the apex (Fig. 5.90b).

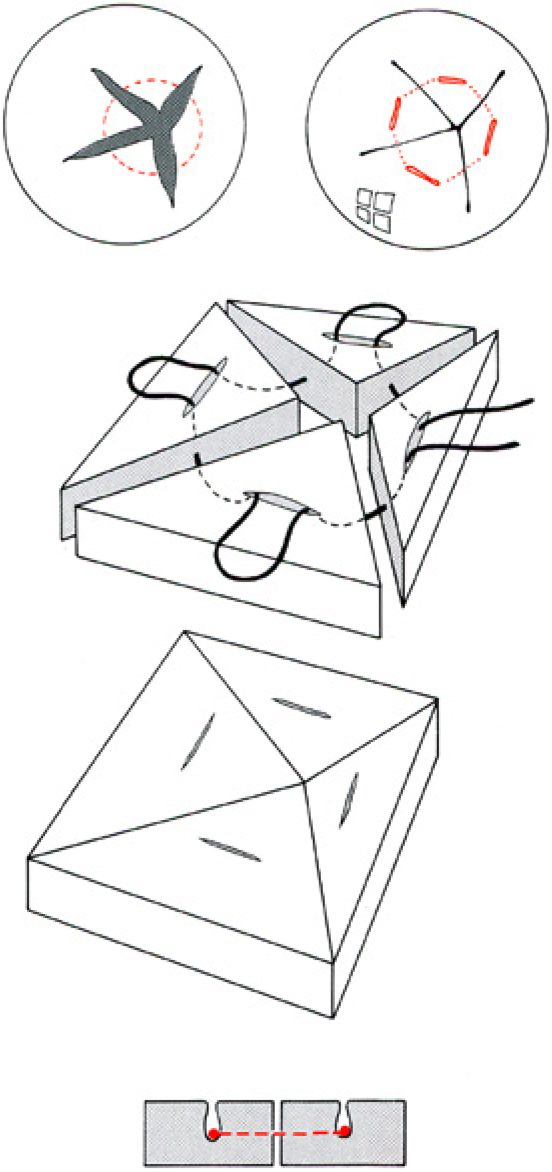
---

[37] This type of wound is produced by objects with multiple edges, such as fragments of thick glass.

[38] *Note*: The intralamellar threads have a greater tendency to cut through the tissue than "normal" threads placed perpendicular to the surface because they are not anchored by the rigid Bowman's membrane. These sutures must be placed an adequate distance from the apex, therefore.

back to index

Fig. 5.92. **Closure of a jagged wound with an intralamellar pursestring suture.** A partial-thickness corneal incision is made with an ultrasharp blade next to each flap, analogous to Fig. 5.91c. A pursestring suture is passed through these grooves and is tightened to approximate the apices of the flaps



In wounds involving a **tissue defect,**[39] closure often cannot be effected simply by reapproximating the wound margins with sutures. If the defect is small, *relaxing incisions* may mobilize the tissue sufficiently to allow watertight closure (Fig. 5.93). Larger defects require reconstruction with corneal or scleral grafts.[40]

The suturing of **corneal disks** basically follows the hinge rule. The *first hinge* is formed as soon as the disk is fixed with two sutures. Additional sutures serve to subdivide the wound into watertight segments. The number of segments is dictated by the *hinge rule* for flaps that open *inward* (see Fig. 5.32).[41] Thus, a disk with a small diameter requires more sutures per unit wound length (i.e., more closely spaced sutures) than a large disk. Also, more sutures are needed when placed superficially than when placed deeply (see Fig. 5.34).

Circular wounds are especially challenging in terms of achieving uniform tension along the wound line. Even a single suture placed too tightly can cause gaping along the whole circumference of the wound (Fig. 5.94). Continuous sutures distribute tension uniformly and in fact are ideal for suturing corneal disks, because the circular shape eliminates the inherent disadvantages of the running suture (Fig. 5.95).

---

[39] Such as an inveterated wound containing incarcerated foreign material (foreign body, iris prolapse, lens capsule, etc.). If a long interval passes from trauma to treatment, the wound margins will stiffen in a gaping position as a result of tissue organization, and removal of the incarcerated material will leave a defect. Similar problems can arise when an attempt is made to close an antiglaucomatous fistula secondarily.

[40] In some cases coverage of the wound area with a conjunctival flap may be necessary to improve watertightness.

[41] The standard rules of wound closure apply only if specific conditions are met: Closure by the valve mechanism is possible only if the wound surfaces are smooth and congruent; irregular wound surfaces require compression sutures to provide a contact area adequate for closure. The hinge rule applies only if there is sufficient tissue tension. In trephining, then, the primary task of sutures is to make the disk tense, the number of sutures depending on the inherent elasticity of the tissue. Once sufficient tension is achieved, the definitive number of sutures depends on the hinge rule.

back to index

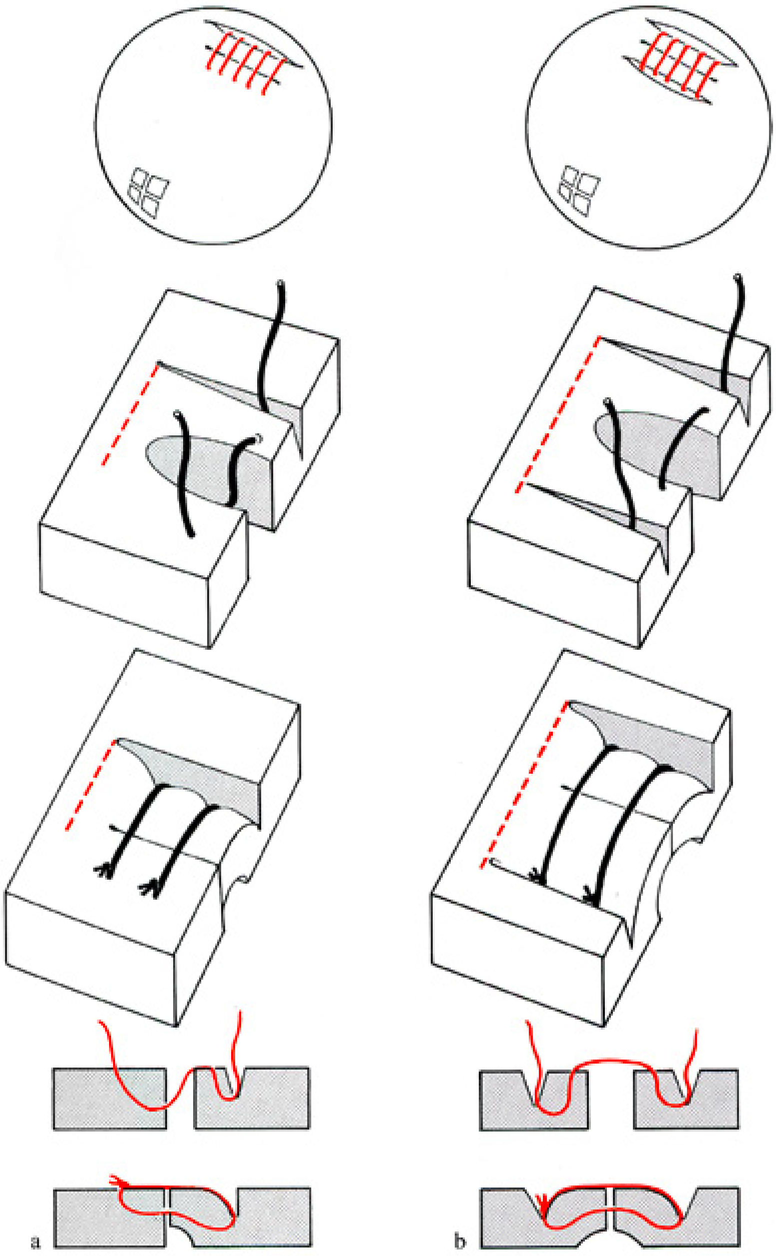


Fig. 5.93. **Repair of small tissue defects.** Use of relaxing incisions to obtain scleral or corneal sliding flaps. (*Note*: Corneal flaps must be de-epithelialized before use.)

a A partial-thickness incision made some distance from the wound margin mobilizes the superficial tissue layer, allowing it to be swung into the defect. *Note:* The relaxing incision must be longer than the defect to be repaired!

b Relaxing incisions may be used on both sides of the defect

back to index

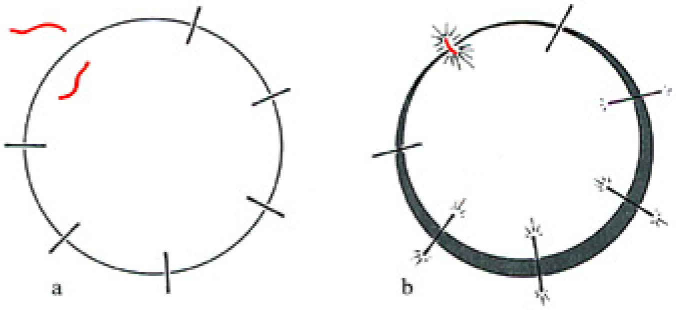


Fig. 5.94. **Simple interrupted sutures in corneal disks.** Tightening of sutures placed perpendicular to the wound margin.

a If suture tension is uniform, the wound edges are pressed together uniformly about their circumference.

b If even one suture is overtightened, the entire wound gapes

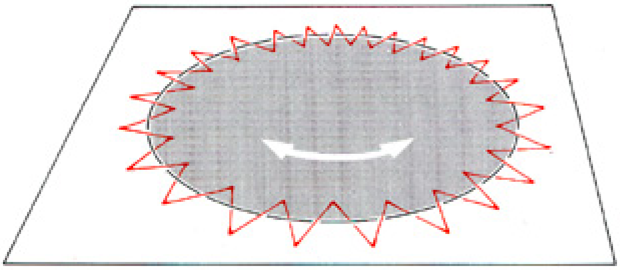


Fig. 5.95. **Continuous sutures in corneal disks.** In circular wounds the side effects of continuous sutures play a minor role. The tendency of continuous sutures to move onto one plane when tightened (see Fig. 2.103a) may not flatten the dome, because a circular wound is already on one plane. The lateral shifting tendency on suture tightening is of no consequence in a circular wound (see Fig. 2.111)

back to index