# Trephination in Penetrating Keratoplasty



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**Core Messages**

- Donor and host trephination should be performed with the same system from the *epithelial side*
- A horizontal position of the limbal plane is essential
- The graft size should be adjusted individually ("as large as possible, and as small as necessary")
- Limbal centration is to be preferred over pupil centration (especially in keratoconus!)
- Avoid excessive graft over- or undersize
- Intraoperative adjustment is required of double running suture
- Nonmechanical excimer laser trephination results in:
  - Lower astigmatism
  - Higher regularity of topography
  - Better visual acuity – especially in young patients with keratoconus
- In unstable corneas (e.g., after RK, iatrogenic keratectasia after LASIK, descemetocele, perforated ulcer), laser application makes trephination feasible
- New nut-and-bolt type variants for potentially self-sealing donor/host appositions are on the horizon ("no-stitch keratoplasty")
- Femtosecond laser application may be the "excitement of tomorrow" in microsurgery of the cornea

## 10.1 Introduction

Zirm in 1905 was the first surgeon to perform a successful homologous penetrating keratoplasty (PKP) in a human patient [84]. The operation became more successful with the development of more delicate instruments, use of the operating microscope, and the availability of antibiotics, antivirals and corticosteroids. Today, still unsolved problems include: (1) high/irregular astigmatism, (2) trephination of unstable cornea, (3) surface pathologies, (4) immunologic graft rejection, (5) secondary glaucomas, (6) chronic endothelial cell loss of the transplant, (7) recurrences of the disease, and (8) a lack of donor tissue.

With the improved understanding and management of immunologic problems during past few decades, the microsurgeon's main attention in corneal transplantation has shifted from preserving a "clear graft" towards achieving a good refractive outcome. Thus, PKP today is no longer just a "curative" but has also become a sort of "refractive" procedure. Today, a crystal clear corneal graft after PKP with high and/or irregular astigmatism – especially if in association with high anisometropia – can no longer be considered "successful" in normal-risk keratoplasties. Deluded by advertisements of refractive surgery, patients expect an optimal visual acuity preferably without spectacles. Many patients consider the necessity of wearing contact lens as representing a partial failure of the intervention. Especially older PKP patients cannot cope with contact lenses manually and/or mentally. Additional "dysfunctional tear syndrome" and blepharitis further promote contact lens intolerance in this age group. Persisting corneal hypesthesia after PKP for many years can delay recognition of contact lens induced damage to the cornea.

It has been debated whether cutting or suturing is more important for the regularity of the transplant curvature. We have always stressed that: (1) early postoperative astigmatism *with sutures in place* should be differentiated from (2) late persisting postoperative astigmatism *without sutures* [59].

**Summary for the Clinician**

**Two major types of post-PKP astigmatism need to be distinguished:**

1. **Early postoperatively with sutures in place predominantly depending on:**
   - **Symmetry of suture positions**
   - **Depth of suture track in graft and recipient**
   - **Homogeneity of suture tension**
   - **Microsurgeon's "hand writing"**
2. **Late postoperatively persisting without sutures predominantly depending on:**
   - **Cut quality**
   - **Wound configuration (horizontal/vertical)**
   - **Symmetry of graft placement**
   - **Wound healing**

## 10.2 Astigmatism and Keratoplasty

### 10.2.1 Definition of Post-keratoplasty Astigmatism

The cornea contributes about two-thirds of the refractive power of a human eye. Surgical procedures on the cornea may therefore influence the state of refraction considerably. Corneal astigmatism is an optical aberration, resulting from unequal refraction of entering light in different meridians of the corneal surface. Astigmatism after PKP is often *irregular*, i.e., two or more meridians are separated from each other by an angle not equal to 90°. Two or more steep hemimeridians are not located opposite to each other. The same may be true for the flat hemimeridians. In addition, the refractive power of corresponding hemimeridians may differ. Especially with sutures in place, patients accept much less subjective cylinder than indicated by objective measures such as keratometry or topography analysis [20]. In cases of highly irregular astigmatism, good visual acuity can only be achieved by hard contact lenses (Table 10.1).

**Table 10.1.** Assessment of astigmatism and visual acuity after keratoplasty (SRI, surface regularity index; SAI, surface asymmetry index; PVA, potential visual acuity)

1. Uncorrected visual acuity
2. Keratometry
   a) Absolute values
   b) Angle of steep and flat meridian separately (Δ≠90°)
   c) Classification of irregularity [59, 62]
3. Topography analysis
   a) Meridians
   b) Hemimeridians
   c) Irregularity (SRI, SAI)
   d) Semiquantitative classification [29]
4. Objective refractometry/retinoscopy
5. Subjective refractometry and spectacle-corrected visual acuity
6. Pinhole
7. Diagnostic contact lens

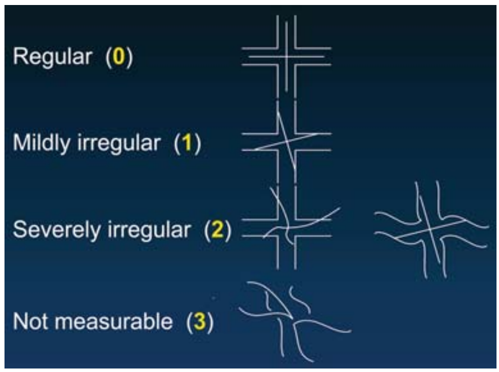


**Fig. 10.1.** Semiquantitative classification of regularity of keratometry mires (ophthalmometer, type H, 190071, Zeiss, Jena, Germany) (0, regular; 1, mildly irregular; 2, severely irregular; 3, not measurable) [59, 62, 83]

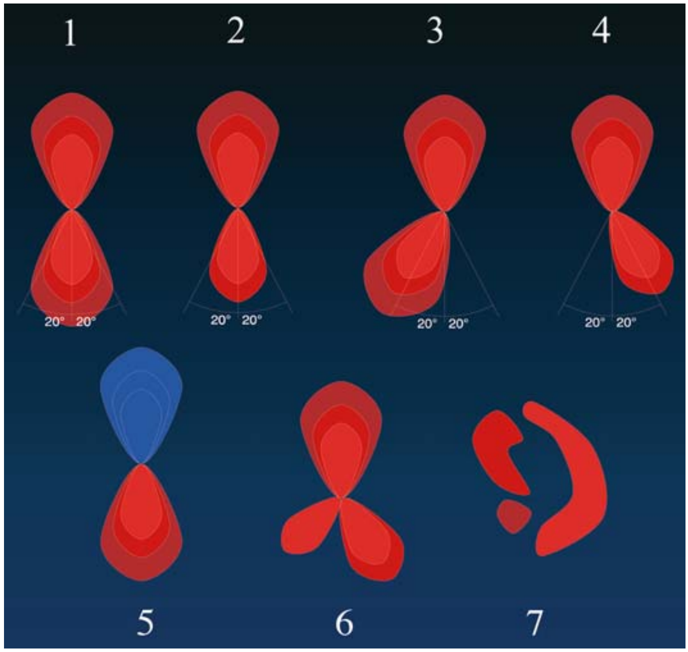


**Fig. 10.2.** Semiquantitative classification of corneal topography after PKP [29]: *1*, orthogonal symmetric (i.e., difference of maximal powers of opposing hemimeridians is less than 2 diopters and deviation of axis of opposing hemimeridians is less than 20°); *2*, orthogonal non-symmetric; *3*, non-orthogonal symmetric; *4*, non-orthogonal non-symmetric; *5*, keratoconus-like (a steep sector is opposing a flat sector at the apex, difference between steep and flat hemimeridian at least 2 diopters); *6*, polyaxigonal (at least three steep/flat sectors can be recognized, at least 2 diopters of power difference between steep and flat hemimeridians); *7*, irregular

After PKP we recommend documenting the keratometric refractive power separately in the steep and in the flat meridian with individual axis notation and assessment of the degree of "keratometric irregularity" (Fig. 10.1). Instead of "42.0+4.5/0°," we suggest writing "42.0/0° (irreg. 1); 46.5/70° (irreg. 2)" [62].

Besides keratometry, topography analysis is indispensable for mapping the corneal power over the entire graft. Refractive powers and individual axes of the four hemimeridians are complemented by system specific indices, e.g., SRI (surface regularity index) and SAI (surface asymmetry index) of the TMS-1 topography system. In addition, we suggest a semiquantitative classification of post-keratoplasty topography in seven groups (Fig. 10.2).

**Summary for the Clinician**

**Studies intending to compare the corneal curvatures after different trephination or suturing techniques for PKP should include the following:**

- **Subjective cylinder *and* keratometric/ topographic astigmatism**
- **Portion of irregular/not measurable astigmatism**
- **Astigmatism with "all-sutures-out" and vector-corrected astigmatism**

### 10.2.2 Reasons for Astigmatism After Keratoplasty

(Table 10.2)

Each of the multiple steps from donor selection, intraoperative trephination and suturing technique to type and quality of postoperative care can determine not only the clarity of the graft but also its final refractive result.

Besides intrinsic factors of donor and recipient, the *short-term astigmatism with sutures in place* seems to depend more on the symmetry of the sutures including methods of intra- and postoperative suture adjustments. After suture removal corneal curvature typically becomes more regular [35, 62], but the amount of net astigmatism may increase considerably [36, 38].

Thus, it has been concluded that factors directly or indirectly related to the quality of the wound geometry have a predominant influence on the *long-term residual astigmatism after suture removal* [59].

**Table 10.2.** Potential causative factors of high and/or irregular astigmatism after keratoplasty [59]

1. Preoperative factors
   a) Age of donor (infant!)
   b) Size of recipient cornea
      i) Keratoconus >Fuchs' dystrophy [60]
      ii) Microcornea
   c) Topography of donor
   d) Topography of recipient
   e) Disharmony between donor and recipient topography
   f) Pathologic properties of recipient
      i) Peripheral thinning or ectasia
      ii) Focal edema/focal scar
      iii) Defects in Bowman's layer
      iv) Vascularization
      v) Preceding keratoplasty (especially decentered)
   g) Aphakia
2. Intraoperative factors
   a) Decentration of donor excision and/or recipient bed
   b) "Vertical tilt" due to discrepancies of wound configuration [42]
      i) Application of different trephine systems for donor and recipient
      ii) Trephine tilt (i.e., not parallel to optical axis)
      iii) Limbal plane not horizontal
      iv) "Shifting" of trephine during cutting
      v) Too high/low intraocular pressure
   c) "Horizontal torsion" [42]
      i) Asymmetric placement of second cardinal suture ($\Delta \neq 180°$)
      ii) Mismatch of donor and recipient due to form incongruence
      iii) Focal overlap or dehiscence of donor button in recipient bed
   d) Excessive over-/undersize of donor
   e) Distortion and squeezing of cornea (e.g., due to dull trephine)
   f) Traumatizing the cornea with instruments
   g) Suture-related factors
      i) Suture material
      ii) Suture technique (interrupted, single running, double running, combinations)
      iii) Length of stitch
      iv) Depth of stitch
      v) Angle of stitch towards graft-host apposition
      vi) Suture tension
      vii) "Depth disparity"
   h) Simultaneous intraocular surgery (e.g., triple procedure, IOL exchange)
   i) Fixation rings and lid specula
   j) **Surgeon's experience**
3. Postoperative factors
   a) Suture-related factors
      i) "Cheese wiring" of sutures
      ii) Suture loosening
      iii) Suture adjustment/selective suture removal
      iv) Time point of suture removal
   b) Wound healing processes
      i) Wound dehiscence
      ii) Retrocorneal membrane
      iii) Incarceration of overlapping tissue
      iv) Focal vascularization
   c) Medication (e.g., corticosteroids)
   d) Postoperative trauma

#### 10.2.2.1
#### Preoperative Determinants

Infant corneas have high refractive power (>50 diopters) and tend to steepen further after transplantation due to the biomechanical instability of the tissue. Thus, Pfister and Breaud suggested using infant corneas to compensate for aphakia. However, the refractive outcome varied considerably and was not predictable [49]. Thus, we do not recommend the use of infant donor corneas for grafting.

Today, donor topography is still rarely performed. The higher the immanent preoperative astigmatism of donor and recipient, the more probable it is that dysharmony between donor and recipient topography results in high astigmatism after suture removal [10, 15, 56]. Especially high congenital astigmatism, keratoconus and previous corneal refractive surgery must be ruled out in potential donors.

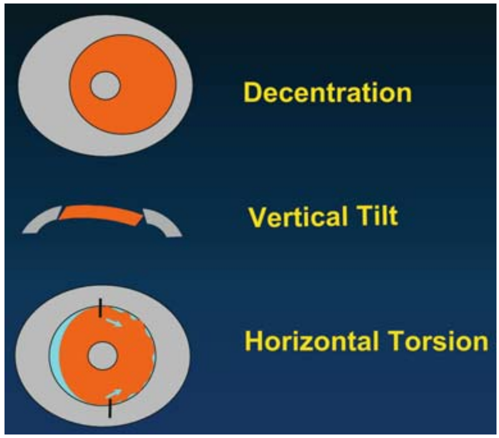


**Fig. 10.3.** Main reasons for high post-keratoplasty astigmatism: *top* decentration of donor and/or recipient trephination; *middle* "vertical tilt" due to incongruent cut angles; *bottom* "horizontal torsion" due to asymmetric suturing (modified from [42])

#### 10.2.2.2
#### Intraoperative Determinants (Fig. 10.3)

Asymmetrically placed fixation rings (e.g., Flieringa or McNeill-Goldmann) may induce an astigmatism of up to 10 diopters [45]. Thus, post-PKP astigmatism is typically higher in aphakic than in phakic or pseudophakic PKP [48]. Even simple lid specula may be responsible for 3 diopters of with-the-rule astigmatism [45].

**Decentration.** Besides a higher incidence of immunologic graft reactions due to proximity to the limbal vessels, decentration of host trephination (>1 mm) may result in higher astigmatism. The flat axis of astigmatism points towards the direction of decentration [30, 75]. Due to the thickness gradient from the center to the periphery, donor decentration may also have a minor impact on post-PKP astigmatism [61].

**"Vertical Tilt."** The amount of persisting post-PKP astigmatism after suture removal depends significantly on the incongruences ("mismatches") of shape and cut angles of donor and recipient wounds [50, 74, 75]. Theoretically, a trephine tilt of 5° (10°) can induce 1.6 (5.9) diopters of astigmatism with an 8-mm-diameter graft [22]. Especially tilted hand-held trephines and neglecting the *horizontal position of the limbal plane* are reasons for the "vertical tilt" phenomenon. In addition, application of different trephine systems and different trephination directions (e.g., punching the donor from the endothelial side) in donor and host are crucial factors.

**"Horizontal Torsion."** One of the major predispositions for regular all-suture-out curvature after PKP is the 360° symmetric apposition of the donor button in the recipient bed. Especially the correct positioning of the *second cardinal suture* opposite to the first one is crucial. Asymmetric placement of the second cardinal suture results in a tissue deficit on one side which needs to be compensated by forced suture adaptation. In the case of long shallow suture bites, a regional flattening may result. In the case of short and deep suture bites, a central steepening may result, in analogy to sutured wedge resections. On the other side a tissue surplus may result in peripheral donor tissue compression with peripheral steepening and consecutive central flattening [74].

An analogous situation arises when the recipient bed is cut asymmetrically elliptical [34, 46, 78]. This may result from asymmetric bulging of the unstable cornea into the trephine opening or even by using an obturator in the case of keratoconus [21]. Mechanical trephines, such as hand-held or motor trephines, may result in oval-shaped host beds even if a circular round excision was intended [9].

Likewise, in donor trephination a trephine tilt of 20° may induce a difference of about 0.5 mm between the maximal and minimal diameter, resulting in an elliptical donor button [45]. Suturing of such an elliptical donor button in a round bed will result in a peripheral steepening in the major axis due to tissue compression and – consequently – a central flattening in this (hemi-)meridian [8]. A wound disparity of 0.1 mm is supposed to create an astigmatism of about 1 diopter [45, 74].

Undoubtedly, the technique for adequate graft-host adaptation by means of four to eight cardinal sutures is determined – at least in part – by the experience of the microsurgeon. The same holds true for the correct performance, interpretation and consequences of intraoperative keratoscopy. However, even if adequate suture distribution and tension as well as intra-/postoperative suture adjustments compensate for the fundamental intraoperative determinants of post-PKP astigmatism in the early stage, suture removal – even after years – may result in major changes of topography and a dramatic increase in astigmatism [36, 38].

**Summary for the Clinician**

**Major intraoperative determinants for high/irregular astigmatism after suture removal include [42]:**

- **Decentration (donor and/or recipient trephination)**
- **"Vertical tilt" (incongruent cut angles between donor and host)**
- **"Horizontal torsion" (horizontal discrepancy of donor and host shape or asymmetric suturing – second cardinal suture!)**

#### 10.2.2.3 Postoperative Determinants

Postoperative suture adjustment or selective removal of single sutures may have a favorable impact on the early post-PKP astigmatism. However, changes of corneal curvature are unpredictable after suture removal [36, 38]. At this time there is still no reliable indicator available to the microsurgeon instructing him about the amount and direction of impending astigmatism changes of the graft after suture removal. There is some evidence that a high coincidence of the axes of refractive, keratometric and topographic astigmatism with the suture in place speaks in favor of decreasing astigmatism to be expected after suture removal [54]. Thus, in the case of intact sutures, lack of vascularization, a low amount of astigmatism, and high topographic regularity resulting in good spectacle-corrected visual acuity, microsurgeons will tend to leave the suture in place for a longer period of time under regular controls and adequate counseling of a compliant patient. However, it must be considered an illusion that keeping the sutures in place for a longer time would help to preserve a favorable topography after final suture removal [11, 14, 36, 38, 70]. Especially step formations after suture removal – often after inadequate trauma – will result in a flat hemimeridian and irregular high astigmatism. For this reason, such steps at the graft-host junction need immediate surgical repair to preserve a good long-term refractive result even if the anterior chamber is not opened [18].

**Summary for the Clinician**

**The pathomechanism of astigmatism increase after suture removal may be as follows:**

- **A low quality of trephination wound and geometric incongruences (horizontal and vertical) require a higher suture tension to guarantee:**
  - **Watertight wound closure**
  - **A pseudo-optimal topography early postoperatively**
- **Asymmetric regional forces between donor and host may cause inhomogeneous wound healing**

- **Removal of sutures liberates forces due to: (1) geometric incongruences and (2) inhomogeneous wound healing**
- **Thus: horizontal, vertical and topographic discrepancies between donor and host *intraoperatively* are responsible for an increase in astigmatism *after* suture removal**

### 10.2.3 Prevention/Prophylaxis of Astigmatism After Keratoplasty

The large number of treatment options for astigmatism after PKP leads to the conclusion that none of the methods is really convincing. Therefore, prophylaxis of high and/or irregular astigmatism is preferred over treatment [59].

#### 10.2.3.1 Alternatives "Without Sutures"

Alternatives "without sutures" include *phototherapeutic keratectomy* (PTK) in the case of superficial corneal diseases. PTK yields good results especially with recurrences of corneal dystrophies after PKP. In order to avoid sutures involving Bowman's layer, potentially self-sealing nut-bolt variants of donor-recipient apposition have been investigated. One approach is *divergent cut angles* that may be created using lasers [57]. The increased contact area reduces the probability of wound dehiscence, the smaller diameter at the level of Bowman's layer increases the distance from the limbal vessels with favorable effects concerning immunologic graft reactions, and the larger diameter at the level of Descemet's membrane increases the amount of transplanted endothelial cells with favorable effects in Fuchs' dystrophy and aphakic/pseudophakic bullous keratopathy. It has been shown that the stability of the graft in the recipient bed increases with increasing divergence of the cut angles [57]. Additional application of tissue glue, a temporary therapeutic contact lens or an intrastromal suture may further increase the stability of the graft-host junction.

An analogous approach was followed by introducing an *inverse mushroom-shaped trephination* with the larger diameter of the graft at the level of Descemet's membrane [7, 67].

In order to leave the architecture of the central cornea untouched, endothelial cell transplantation has been investigated and *posterior lamellar keratoplasty* (PLKP) has been introduced into clinical routine by Melles [37] in Europe in 1998 and later modified by Terry in the United States [71] in cases of sole endothelial failure.

#### 10.2.3.2 Ten Precautions During Surgery

1. Donor topography should be attempted for exclusion of previous refractive surgery, keratoconus/high astigmatism, and "harmonization" of donor and recipient topography [16, 56, 59].
2. Donor and recipient trephination should be performed from the epithelial side with the same system, which – from our point of view – predisposes to congruent cut surfaces and angles in donor and recipient. For this purpose an artificial anterior chamber is used for donor trephination although the whole globe would yield even better results [27].
3. Orientation structures in donor and host facilitate the correct placement of the first four cardinal sutures to avoid horizontal torsion [2].
4. A measurable improvement seems possible using the Krumeich guided trephine system (GTS) [4], the second generation Hanna trephine [81] and our technique of nonmechanical trephination with the excimer laser [58, 66].
5. Horizontal positioning of head and limbal plane is indispensable for state-of-the-art PKP surgery in order to avoid decentration, vertical tilt and horizontal torsion [59].
6. Graft size should be adjusted individually ("as large as possible, as small as necessary") [60, 62].

7. Limbal centration should be preferred over pupil centration (especially in keratoconus – "optical displacement of pupil") [31].
8. Excessive graft over- or undersize should be avoided to prevent stretching or compression of peripheral donor tissue [19, 47, 82].
9. As long as Bowman's layer is intact, a double running cross-stitch suture (according to Hoffmann [17]) is preferred since it results in greater topographic regularity, earlier visual rehabilitation and less loosening of sutures, with suture replacement only rarely required.
10. Intraoperative keratoscopy should be applied *after* removal of lid specula and fixation sutures. Unstable donor epithelium would be better removed to allow for reproducible results. Adjustment of double running sutures or replacement of single sutures may be indicated [3].

### Summary for the Clinician

**Requirements for *"the optimal trephination"* include:**

- **Full visual control**
- **No contact**
- **Optimal donor and host centration**
- **Identical shape of donor and host (typically circular)**
- **Congruent cut angles**
- **360° symmetric donor host alignment**
- **No necessity to complete trephination by scissors**
- **No damage to intraocular tissues**
- **Future: self-sealing donor/host apposition**

**Table 10.3.** Principal indications for keratoplasty (modified from [40])

1. Optical
   a) Opacities
   b) Pathologic curvature
2. Curative
   a) Deep keratitis (e.g., herpetic keratitis with granulomatous reaction to Descemet's membrane or *Acanthamoeba* keratitis)
   b) Endothelial diseases (primary or secondary)
   c) Perforated corneal ulcer
3. Tectonic
   a) Traumatic corneal defects
   b) Infectious corneal defects
   c) Postoperative fistula after cataract extraction or antiglaucomatous surgery
   d) After "block excision" [44]
      i) Uveal tumors
      ii) Localized epithelial downgrowth (cysts)
   e) Reconstruction of the anterior segment

## 10.3 Trephination Techniques

The principal indications for keratoplasty include optical, curative and tectonic factors (Table 10.3). Overlaps between the different categories may occur. But corneal transplants may also be classified according to the type of donor material, the vertical shape of the graft, the horizontal shape of the graft and the location of the graft within the host (Table 10.4) [40].

A few general technical details concerning PKP need to be mentioned [40, 42]:

1. *General anesthesia* has advantages over local anesthesia. The arterial blood pressure should be kept low as the eye is opened ("controlled arterial hypotension").
2. To protect the crystalline lens in phakic keratoplasty, usually the *pupil is constricted*.
3. Before recipient trephination, a stab-like *paracentesis at the limbus* is performed.
4. The *limbal plane* must be *horizontal* during trephination.
5. An *iridotomy* prevents pupillary block and acute angle closure glaucoma (so-called Urrets-Zavalia syndrome in the case of dilated pupil with iris sphincter necrosis [43]).
6. The *second cardinal suture* is crucial for graft alignment.

**Table 10.4.** Terminology of various types of keratoplasty (modified from [40])

| Donor cornea | Vertical shape of graft | Horizontal shape of graft | Location within the host |
|---|---|---|---|
| Autologous (autograft)<br>Homologous (allograft)<br>Heterologous (xenograft)<br>Alloplastic (keratoprosthesis) | Lamellar (anterior vs. posterior)<br>Penetrating<br>Mushroom<br>Inverse mushroom [67] | Circular<br>Elliptical<br>Semilunar<br>Rectangular<br>Triangular<br>Ring-shaped | Central<br>Eccentric<br>Marginal |

## 10.3.1 Principal Considerations

### 10.3.1.1 Donor Trephination

From a 16-mm corneoscleral button as provided by the Eye Bank, the transplant can be created in two principal ways:

1. The original method used is for the donor button to be punched *from the endothelial side* against a firm surface (such as a paraffin or Teflon block) using special trephines (*Lochpfeifentrepan*) [6, 80]. Care must be taken to ensure a proper alignment when cutting since a beveled cut will result if the blade is not perpendicular to the cutting block. This risk may be decreased by the use of "guided donor trephine" systems (e.g., "guillotines") (Fig. 10.4).
   On histological evaluation, the cut surfaces without consideration of the cut angles seem to be almost "perfect." However, deviation of the cut direction outwards results in *convergent cut angles* due to a smaller diameter at the level of Descemet's membrane and a larger diameter at the level of Bowman's layer ("*undercut*") (Fig. 10.4 D) [76].
2. Since the development of "*artificial anterior chambers*" [23], microsurgeons have had the opportunity to perform donor trephination from the epithelial side, which is the same direction as in the host. If pressure in the artificial anterior chamber is kept normal (e.g., 22 mmHg), the advantages with respect to cut angles are obvious [55]. However, fixing the corneoscleral button in an artificial anterior chamber may induce a considerable amount of astigmatism. This problem can be overcome by using an artificial anterior chamber with a larger central opening, leaving the limbus untouched during fixation for trephination from the epithelial side. In this setting the corneoscleral limbus seems to have a protective effect concerning the central corneal topography of the fixated cornea [27].

**Summary for the Clinician**

- **Trephination of the donor button should preferably be performed *from the epithelial side* using an artificial anterior chamber with a large central opening**
- **Punching the donor *from the endothelial side* results in an undercut at the level of Descemet's membrane with convergent cut angles**

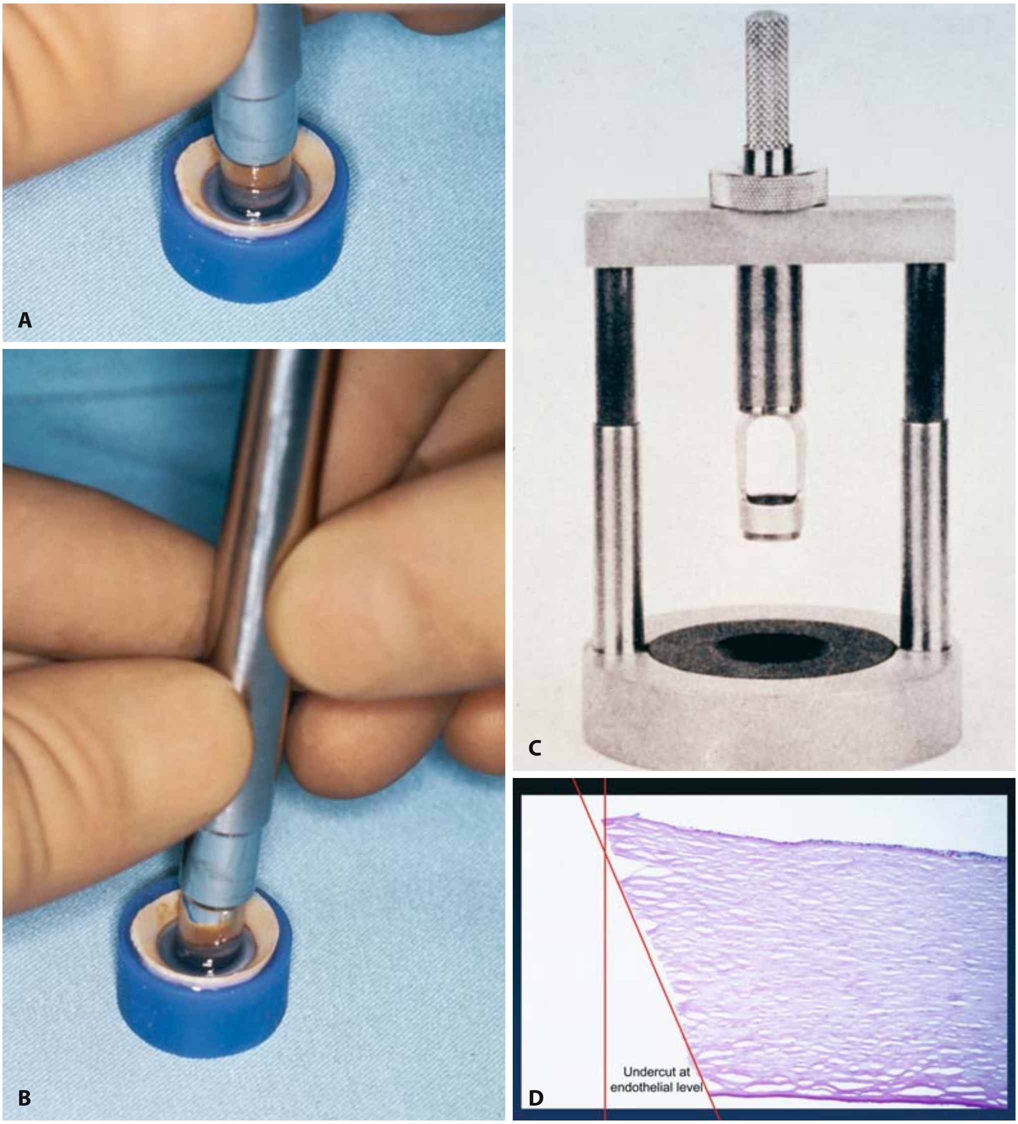


**Fig. 10.4 A–D.** Donor trephination *from the endothelial side*. **A** Correct position of hand-held trephine; **B** tilted trephine; **C** "guillotine" to avoid trephine tilt; **D** smooth cut surface but "undercut" at the level of Descemet's membrane

### 10.3.1.2 Recipient Trephination

For recipient trephination, the horizontal position of the head and especially the limbal plane is indispensable. To increase the overview and reduce *vis à tergo*, the Lieberman speculum is preferred. Any viscoelastic agent may be used to stabilize the anterior chamber during trephination. A Flieringa ring is not necessary for PKP or the triple procedure, but is helpful in cases of aphakic eyes, especially if a secondary sclera-fixated IOL is inserted. The ring can be sutured temporarily onto the globe using 6-0 Vicryl sutures through the conjunctiva and episclera.

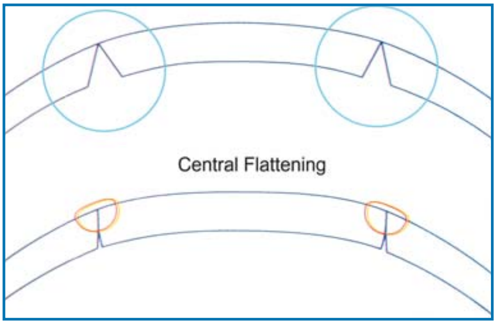


**Fig. 10.5.** Combination of donor trephined *from the endothelial side* (convergent cut angle) and mechanically trephined recipient (divergent cut angle) results in a triangular-shaped tissue deficit at the level of Descemet's membrane which has to be compensated by suture tension resulting in central flattening and vertical tilt

Investigations by Van Rij and Waring demonstrated that in recipient trephination all trephine systems result in an opening larger than the trephine size. In addition, the diameter is larger at the level of Descemet's membrane, resulting in *divergent cut angles* [76]. This can be explained by the "ballooning" of the cornea to be excised into the trephine opening due to the pressure executed. The higher the intraocular pressure, the more divergent the angles to be expected [55]. This phenomenon of "ballooning" is one of the major drawbacks of a mechanical trephine and can be prohibited – at least in part – by the use of an "obturator." However, Kaufman stresses that the use of an obturator in keratoconus may result in other than round host openings such as pear-shaped holes [21].

The combination of a donor punched from the endothelial side with convergent cut angles and a host opening with divergent cut angles will result in a triangular-shaped tissue defect at the level of Descemet's membrane that has to be compensated for with increased suture tension and – consequently – vertical tilt (Fig. 10.5).

**Summary for the Clinician**

- **Horizontal positioning of limbal plane is indispensable**
- **Flieringa ring is only necessary in aphakic eyes**
- **The higher the intraocular pressure (iatrogenic!) the more divergent are the cut angles to be expected [55]**

### 10.3.1.3 Graft Size and "Oversize"

**Graft Size.** In a quantitative study we found that the corneal diameter of keratoconus patients was larger than that of Fuchs' patients (mean horizontal diameter of 11.8 mm in keratoconus patients and 11.3 mm in Fuchs' patients) [60]. *In general, a good optical performance requires a larger graft, whereas a low rate of immunologic graft reactions tends to be seen with smaller grafts.* Therefore, the graft should be "as large as possible, but as small as necessary." For many eyes with keratoconus an 8.0-mm diameter and in many eyes with Fuchs' dystrophy a 7.5-mm diameter prove to be good options as a prerequisite for obtaining tissue from the Eye Bank. Today, graft diameters of 5.5–7.0 mm are only rarely required and justified.

It has been supposed that smaller grafts might be associated with a higher post-keratoplasty astigmatism. In a recent study we found [62]:

1. A flatter curvature with smaller grafts
2. A higher topographic irregularity with smaller grafts
3. A higher proportion of unmeasurable keratometry mires with smaller grafts
4. A tendency towards regularization of topography after suture removal
5. No difference concerning the amount of net astigmatism between different graft sizes either with or without sutures

The major reason for the flatter and more irregular graft with smaller diameters seems to be the closer position of the proximal suture ends in relation to the optical center of the graft. This will be pronounced in particular with wider suture bites. After suture removal the potentially topography disturbing circular scar at the graft-host junction is located closer to the line of sight with smaller grafts. This may explain that overall the regularity of graft topography increases with suture removal but that major differences between various graft sizes do persist.

Larger sizes may be considered for eccentric tectonic corneoscleral grafts (e.g., after the block excision of tumors of the anterior uvea or cystic epithelial downgrowth [44]) and in buphthalmos [73]. But we do not recommend graft sizes over 8.5 mm in buphthalmos for immunologic reasons [52].

Recent studies indicate that the rate of chronic endothelial cell loss after PKP depends on the initial diagnosis [32, 53]. Endothelial migration from donor to recipient in pseudophakic bullous keratopathy along a density gradient is thought to be the reason for this phenomenon. Therefore, eyes with bullous keratopathy may require a larger graft not just to improve the optical performance but rather to transplant as many endothelial cells as possible. Nevertheless, *graft size has to be judged by the surgeon individually in every single case before recipient trephination* to achieve the best compromise between immunologic purposes and optical quality [59, 60]. A slit lamp with a measuring device (scale), e.g., a Haag-Streit slit lamp, or calipers for intraoperative application may be helpful. Prior removal of vascularized pannus (in contrast to vascularized stromal scars) may render a larger "individual optimal graft size" possible for transplantation of more endothelial cells and better graft topography.

**Graft "Oversize."** In mechanical trephination, the diameter of the recipient bed tends to be larger and the diameter of the donor button, punched from the endothelial side, tends to be smaller than the trephine diameter, which may affect the resulting spherical equivalent [76]. Thus, "oversizing" the donor button by 0.25–0.50 mm is commonly done to compensate for refractive effects and to reduce crowding of the chamber angle and therefore postoperative "glaucoma" [47]. An oversize of 0.25 mm compared to one of 0 mm or 0.5 mm may account for a difference in keratometric readings of 1.5 diopters after suture removal. Javadi et al. found no difference in astigmatism in comparing 0.25 mm and 0.50 mm graft oversize [19]. However, Perl et al. stressed that oversizing the graft by 0.5 mm (punched from the endothelial side) may result in significantly increased corneal astigmatism [47]. In keratoconus, same size donors were found to reduce resulting myopia. We do not recommend undersizing of a graft!

In contrast, with guided trephines and laser trephination (donor from the epithelial side), attempted diameters are indeed achieved with congruent cut angles. Thus, donor oversize is not necessary.

### Summary for the Clinician

- **Typically, keratoconus corneas are larger than Fuchs' dystrophy corneas**
- **Graft size has to be judged by the microsurgeon individually in every single case *before* recipient trephination to achieve the best compromise between immunologic purposes and optical quality**
- **Donor trephination from the endothelial side results in a smaller donor button than trephine size and convergent cut angles ("undercut")**
- **Recipient trephination results in larger openings than trephine size and divergent cut angles**
- **This discrepancy makes a donor "oversize" of ≥0.25 mm necessary**
- **Same size grafts are feasible if the donor is created by means of an artificial anterior chamber from the epithelial side**
- **Undersizing the graft for simultaneous correction of myopia in keratoconus is *not* recommended (watertight wound! irregular astigmatism!)**

### 10.3.1.4 Pupil Versus Limbal Centration

Centration is crucial with respect to immunologic graft reaction and post-PKP astigmatism. Typically a compromise between limbal and pupil centration is attempted in the case of non-traumatized pupils. However, limbal centration is preferred especially in keratoconus, scars after trauma or irregular astigmatism of other origins. In such eyes the center of the visible ("entrance") pupil may be dislocated from that of the real anatomic pupil [31].

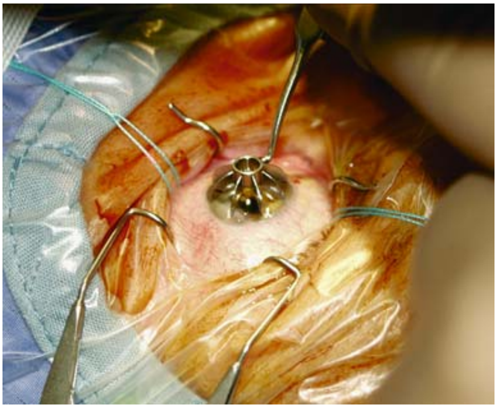

**Fig. 10.6.** An eight-line radial keratotomy marker (colored with methylene blue) may be used to facilitate limbal centration

An eight-line radial keratotomy marker may be used to ensure centration (Fig. 10.6). An additional central dot-like mark may be helpful for certain trephine systems (e.g., Hessburg-Baron).

If the broadening of the superior limbus due to a vascularized pannus is neglected intraoperatively, an inferior decentration may be recognized on the next day at the slit-lamp.

**Summary for the Clinician**

- **In doubt, limbal centration is preferred over pupil centration**

#### 10.3.1.5 "Harmonization" of Donor and Patient Corneal Topography

Keratometric readings of the donor cornea are still usually neglected. However, it might be better to consider them to improve predictability of the final refractive outcome after PKP [10, 16, 56]. This may help to avoid transplantation of corneas with unusual or abnormal curvatures. In addition, it may allow a more accurate selection of intraocular lens power in triple procedures.

The vertical difference at the graft-host junction due to the different curvatures of donor and recipient must be compensated intraoperatively by suture tension to avoid a step formation. The resulting forces may be co-responsible for the amount of relative change in curvature after suture removal. Therefore, "*harmonization*" of donor and recipient topography should allow for minimization of the residual astigmatism for a given pair of donor and recipient [56]. The use of an artificial anterior chamber enables donor topography analysis and allows the "contour line" of the trephination edges in both donor and recipient to be calculated. A computerized simulation of graft rotation in the recipient bed may help to find an angle of graft rotation at which topographical misalignment is minimal.

Grütters et al. have proposed "astigmatism-oriented perforating keratoplasty", i.e., matching the flat axis of the donor with the steep axis of the host cornea [16].

**Summary for the Clinician**

**Consideration of donor topography may:**

- **Eliminate the use of donors with abnormal or unusual curvatures (such as high astigmatism, keratoconus, previous refractive surgery)**
- **Allow for "harmonization" of donor and recipient topography**

#### 10.3.1.6 The Vascularized Cornea

Excessive bleeding after trephination of vascularized corneas with blood clots left in the anterior chamber may result in increased risk of immunologic graft reaction and peripheral anterior synechiae due to contraction. Thus, the following precautions should be taken:

Before trephination the microsurgeon should differentiate between vascularized pannus tissue ("plus") and vascularized scars ("minus"). Vascularized fibrous tissue between the epithelium and Bowman's layer or the superficial stroma in the case of defective Bowman's layer can be removed easily with a hockey knife. Typically, bleeding stops after a few minutes without additional measures. In contrast, distinct "feeder vessels" of vascularized scars may be incised with a pointed scalpel at the limbus. Pillai et al. have proposed sophisticated kauterization techniques for coagulation of afferent and efferent vessels [51]. In the case of diffusely capillarized scars, ice-cold balanced salt solution (BSS) or topical alpha-mimetic vasoconstringent drops (such as naphazoline nitrate) may help to reduce bleeding during trephination.

**Summary for the Clinician**

- **Removal of vascularized pannus tissue may help to increase the "individually optimal graft size"**
- **Incision or kauterization of distinct "feeder vessels" of scars at the limbus may reduce bleeding during trephination**

#### 10.3.1.7 Keratoconus and Disabling High Astigmatism of a Graft

**Keratoconus.** In keratoconus, a central round PKP is indicated as soon as hard contact lenses are no longer tolerated. Excessively steep corneas before surgery do not have less favorable outcome than less deformed corneas after PKP using the excimer laser for nonmechanical trephination [83].

Keratoconus eyes have larger corneas than normal eyes and other dystrophies allowing for larger graft diameters (typically 8.0 mm) [60]. A larger graft diameter in keratoconus patients may help to preserve a sufficiently thick cornea at the trephination margin in the patient since the "cone" can be excised almost completely. Kauterization of the cone has been suggested to avoid divergent cut angles, but its effect may not be reproducible. Thus, we do *not* advocate kauterization of the cone. Kaufman has suggested not using obturators in the case of keratoconus to prevent unintended creation of elliptical or pear-shaped openings [21].

We do *not* advocate centering the trephination on the cone, thereby typically decentering the trephination with respect to the limbus. In addition, pupil centration may be misleading due to "optical displacement" of the visible pupil because of irregular refraction of incoming rays of light by the irregularly curved corneal surface in keratoconus [31]. We do *not* advocate undersizing of the donor to reduce myopia, since irregular astigmatism is to be expected.

Due to inhomogeneous corneal thickness, an early perforation at the site of the thinned cornea is to be expected. This has to be taken into account with conventional trephines to avoid inadvertent injury of the iris or even the lens.

*Peripheral thinning* of the host cornea, e.g., with keratotorus (= pellucid marginal degeneration) or Fuchs-Terrien marginal degeneration, is very rare but difficult to treat. Treatment options include an eccentric semilunar lamellar/penetrating graft or an overdimensioned preferably elliptical eccentric through-and-through graft.

**Disabling High Astigmatism of a Graft.** Eyes with high disabling astigmatism after PKP are often – but not always – associated with small and/or decentered grafts. The re-graft should be well centered and large enough to cut out the previous graft entirely. However, in some cases the previous graft-host junction cannot be excised in toto (cf. Sect. 10.3.1.3, "Graft Size" and "Oversize"), leaving a "wedge" of the first donor tissue in situ.

After second suture removal, astigmatism may increase again and may no longer be significantly different in comparison to the preoperative values [70].

Our own results suggest a potentially important role of the remaining second running suture in keeping corneal astigmatism values low and topographic regularity high after repeat PKP in patients with high and/or irregular post-keratoplasty astigmatism. After removal of the last suture, the curvature may change in an unpredictable and often unfavorable manner. The presumed original instability of the host rim, which on final suture removal may be transferred to the center of the graft ("memory effect"), is probably responsible for the increase in astigmatism and the increase in irregularity of the corneal surface. In addition, the host rim instability may be exacerbated by incomplete excision of the previous graft-host junction in severely decentered first grafts. However, the exact role of any such residual tissue has yet to be clarified.

The long-term value of so-called "intracorneal rings" inside the graft-host junction with respect to stabilization of the topography in such eyes has yet to be determined [13, 24].

**Summary for the Clinician**

- **With keratoconus a large excision should be centered at the limbus (not the "cone") and non-contact laser trephination is preferred to prevent "other-than-round" recipient openings**
- **Where repeat PKP is performed in eyes with high and/or irregular astigmatism in clear grafts, visual rehabilitation may be limited by an increase in astigmatism and topographic surface irregularity after removal of the last running suture**
- **In such eyes it may be advantageous to postpone final suture removal for as long as possible**

#### 10.3.1.8 The Unstable Cornea

Unstable corneas include:

1. Corneal perforations or descemtoceles typically arising from ulcerative necrotizing stromal keratitis of herpetic or bacterial origin
2. Eyes after unfavorable keratorefractive surgery such as after radial keratotomy and iatrogenic keratectasia after laser in-situ keratomileusis (LASIK)

In the "open eye" situation mechanical trephines may lead to compression and distortion of the cornea although a high-viscosity viscoelastic agent is used to stabilize the anterior chamber. Especially with large perforations the trephine can only be used to mark the excision, the keratotomy has to be deepened with a diamond knife and the excision is completed with scissors. Nonmechanical laser trephination has been advocated since it may allow non-contact round and elliptical trephinations (Fig. 10.7) [26]. One suggestion has been to insert a trimmed part of a soft contact lens via large paracentesis, unrolling it inside the anterior chamber and thus achieving a stable eye for trephination after pressurizing the globe by insertion of viscoelastic agent via paracentesis ("valve"). A larger than usual graft oversize (e.g., 0.5 mm) is recommended to avoid peripheral synechiae in eccentric or even peripheral grafts.

In the case of excisions involving the limbus, the *scleral spur* has to be preserved during (partly lamellar) trephination. In the case of peripheral small perforations, an eccentric mini-keratoplasty may have immunologic advantages. Wide limbus-parallel perforations – typical of rheumatoid origin – may best be treated with a crescent graft. For this partly "freehand" procedure, an outer segmental trephination with a smaller diameter (e.g., 10 mm) is combined with an inner segmental trephination with a larger diameter (e.g., 16 mm). Adequate preparation of the slightly oversized graft is best achieved from an intact donor globe but is quite difficult using a corneoscleral button from the Eye Bank (protection of endothelium!).

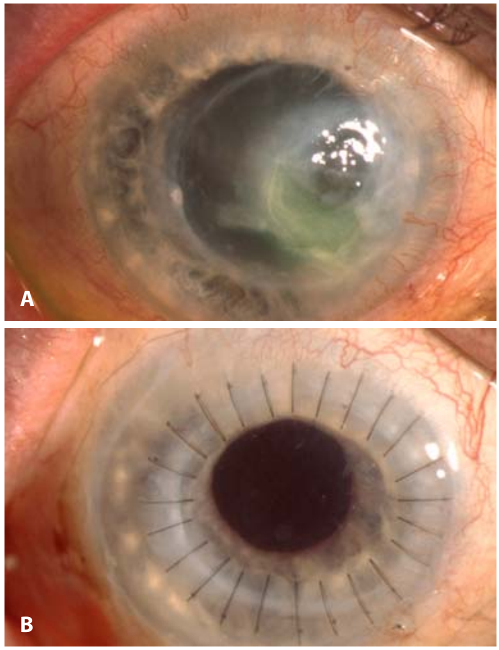


**Fig. 10.7. A** Descemetocele after ipsilateral autologous keratoplasty for localized central herpetic scar; **B** eccentric elliptical triple procedure *à chaud* (7.0×8.0 mm/7.1/8.1 mm, excimer laser trephination)

After excessive *radial keratotomies* resulting in irregular astigmatism and glare/halos due to scars in the optical field, deep epithelial plugs are typically present inside the original radial cuts for years. Instability leads to opening of these plugs during mechanical trephination. Certain types of circular sutures have been proposed before trephination. However, non-contact laser trephination seems to be the method of choice for such eyes. In analogy, iatrogenic keratectasia after LASIK is prone to opening of the lamellar interface between the stromal bed and flap during conventional contact trephination. This may result in oval host wounds and different sizes of the excised button at the flap and bed levels [64]. Again, non-contact laser trephination seems to be the method of choice for such eyes, the incidence of which is supposed to increase over the next few decades.

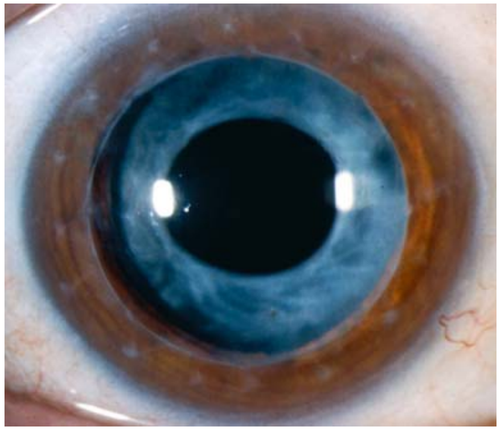

**Fig. 10.8.** Well centered (1) trephination, (2) capsulorhexis, and (3) posterior chamber lens inside the capsular bag after triple procedure in Fuchs' dystrophy (7.5/7.6 mm, excimer laser trephination with eight "orientation teeth/notches")

**Summary for the Clinician**

- **In the "open eye" situation conventional trephines typically only mark the host excision which has to be completed freehand with diamond knife and scissors**
- **With unstable corneas non-contact non-mechanical laser trephination has major advantages over conventional mechanical trephination**

### 10.3.1.9 The Triple Procedure

Since the introduction of the triple procedure [= simultaneous penetrating keratoplasty (PKP), extracapsular cataract extraction and implantation of a posterior chamber intraocular lens (PCIOL)] in the mid-1970s, there has been an ongoing discussion among corneal microsurgeons concerning the best approach (*simultaneous* or *sequential*) for combined corneal disease and cataract [65]. For the refractive results after the triple procedure, some intraoperative details are crucial: trephination of recipient and donor from the epithelial side without major oversize (guided trephine system or non-mechanical excimer laser trephination) should preserve the preoperative corneal curvature. Graft and the PCIOL placed in the bag after large continuous curvilinear capsulorhexis should be centered along the optical axis (Fig. 10.8). If possible, performing the capsulorhexis under controlled intraocular pressure conditions prior to trephination may help to minimize the risk of capsular ruptures. In the case of excessive corneal clouding, a capsulorhexis forceps is used via the "open sky" approach. Delivery of the nucleus is achieved via the "open sky" approach by means of manual irrigation, and removal of the lens cortex by automated irrigation-aspiration.

The major advantage of the triple procedure is the faster visual rehabilitation achieved and less effort required for the mostly elderly patients. In contrast, sequential cataract surgery has the potential for a simultaneous reduction of corneal astigmatism (appropriate location of the incision, simultaneous refractive keratotomies or implantation of a toric PCIOL). Disadvantages may include the loss of graft endothelial cells and the theoretically increased risk of immunologic allograft reactions. After the triple procedure, major deviations from target refraction have been reported. However, individual multiple regression analysis may help to minimize this problem with appropriate methods of trephination [77]. Since suture removal after PKP may result in major individual changes of the corneal curvature, IOL power calculation for the sequential approach requires all sutures to be removed at the time of cataract surgery. However, even after complete suture removal the abnormal proportions between anterior and posterior curvatures and/or the irregular topographies after PKP may be responsible for marked IOL power miscalculations in the individual eye [65].

**Summary for the Clinician**

- **The postulated better prediction of refraction after sequential keratoplasty and cataract surgery is opposed by a markedly delayed visual rehabilitation**
- **We consider the triple procedure including cataract extraction via "open sky" in general anesthesia as the method of choice for combined corneal and lens opacities**

#### 10.3.1.10 Impact of Trephination on Suturing

The trephination modality may have a major impact on the correct placement of the first four or eight cardinal sutures. The predominant purpose of the *cardinal sutures* is: (1) symmetric horizontal distribution of donor tissue in the recipient bed, (2) good adaptation of graft and host on Bowman's level (external steps are to be avoided, internal steps may be tolerated in the case of thin recipient corneas such as in pellucid marginal degeneration or herpetic scars), and (3) stabilization of the anterior chamber for further homogeneous suturing.

Unintentionally other than round host opening may create a challenge even for the experienced PKP surgeon concerning the correct placement of the *second cardinal suture*. After removal of the cardinal sutures the quality of the trephination and graft positioning are major determinants for watertight wound closure. The better the trephination, the smaller the final suture tension required for watertight wound closure after removal of the cardinal sutures. The smaller the final suture tension, the better the visual acuity as long as the sutures are in place. Generally, in cases where Bowman's layer is intact, a 16-bite double-running diagonal cross-stitch suture (10-0 nylon) according to Hoffmann (Fig. 10.9) is preferred. The more rapid

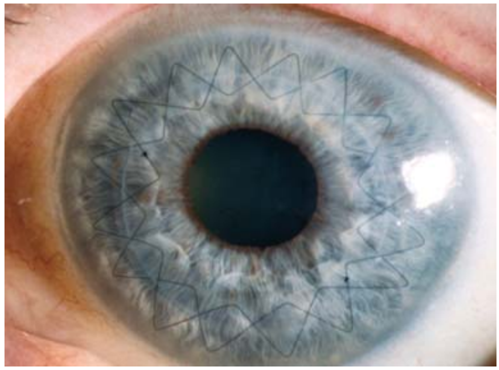

**Fig. 10.9.** Typical double running 10-0 nylon cross-stitch suture with 8 bites each (according to Hoffmann [17]) in keratoconus (8.0/8.1 mm, excimer laser trephination with eight "orientation teeth/notches")

visual rehabilitation with these sutures in place in contrast to single sutures is due to a more regular corneal topography avoiding cornea plana.

**Summary for the Clinician**

- **The better the trephination the easier watertight wound closure is achieved**
- **Inadequately high suture tension to achieve watertight wound closure may deteriorate the regularity of the topography after PKP and delay visual recovery**

### 10.3.2 Conventional Mechanical Trephines (Table 10.5)

In 1886 Arthur von Hippel was the first to use a mechanical clock-watch driven trephine (Fig. 10.10) for transplantation of a lamellar corneal graft from a rabbit to a human [79]. The same trephine was used by Eduard Zirm for his first successful PKP in a patient in 1905 [84].

Conventional mechanical trephination is associated with *deformation* of corneal tissue including a distortion of the cut margin with rough-cut edges as a consequence of *axial and radial forces* induced by the trephine. The cut angle deviates from the perpendicular and it may be different in donor and recipient, especially if the donor trephination is undertaken from the endothelial side. The fitting of the

**Table 10.5.** Characteristics of mechanical trephines

| Type | Geuder Micro-Keratron (discontinued) | Moria (Hanna) | GTS (Krumeich) | Hessburg-Barron | Asmotom (Gliem & Franke) |
|---|---|---|---|---|---|
| Motorized cutter | Yes | No | No | No | Yes |
| Vacuum fixation for recipient | No | Yes (limbus) | Yes (limbus) | Yes (cornea) | Double |
| Cutter feed | No | No | No | No | Yes |
| Depth adjustment | No | Yes | Yes | Limited | Yes |
| Auto-retract | No | No | No | No | Yes |
| Anterior chamber maintainer required for donor | Yes | Yes | Yes | Possible | No |
| Automation | No | No | No | No | Yes |

**Table 10.6.** Trephines used in Germany in the year 2002 for 4583 penetrating keratoplasties (German Keratoplasty Registry Erlangen) (122 institutions contributed) [5]

| | GTS | Manual | Barron | Motor trephine | Asmotom | Excimer laser | Unknown |
|---|---|---|---|---|---|---|---|
| Donor | 1555 | 1040 | 716 | 415 | 393 | 313 | 151 |
| % | 33.9 | 22.7 | 15.6 | 9.1 | 8.6 | 6.8 | 3.3 |
| Recipient | 1570 | 818 | 745 | 640 | 346 | 313 | 151 |
| % | 34.3 | 17.8 | 16.3 | 13.9 | 7.6 | 6.8 | 3.3 |


**Fig. 10.10 A, B.** Mechanical trephines. **A** Arthur von Hippel's clock-watch driven trephine. **B** "Modern" mechanical trephines (motor trephine, *Lochpfeiffentrepan*, hand-held trephine [39])

donor tissue into the malleable recipient cornea is extremely difficult to achieve in a perfectly symmetric fashion. After suturing the incongruent cut edges in order to achieve watertight wound closure, wound healing may cause marked distortion of the surface topography after suture removal due to this "vertical tilt." In addition, asymmetric cardinal suture placement may result in unequal donor tissue distribution in the host wound, particularly if the second cardinal suture is not placed exactly opposite to the first ("horizontal torsion") [42].

A questionnaire was sent to all German keratoplasty surgeons in 2002 asking for their preferred technique of trephination. As outlined in Table 10.6 for recipient trephination, most surgeons use the GTS (34.3 %), the hand-held trephine (17.8 %) or the Hessburg-Barron trephine (16.3 %). Motor trephines are used more rarely and the laser trephination has still not entered many operating theaters because it is bulky and expensive. As many as 12 % of all procedures were performed with different trephine systems for donor and recipient [5]!

#### 10.3.2.1 Freestanding Blade/Hand-Held Trephines

Hand-held trephines are available in a wide range of diameters from very small (e.g., 1.5 mm) to very large (e.g., 16.0 mm). Hand-held trephines may be dull with reduced visual control under the operating microscope despite recent improvements [39]. Thus, centration may be a problem. Typically, the donor is punched from the endothelial side (*Lochpfeiffentrepan*). Francheschetti-type freestanding blades (Fig. 10.11) seem to create more reproducible cuts than other hand-held trephines [72, 76].


**Fig. 10.11.** Francheschetti-type freestanding blades are available in a wide range of diameters

#### 10.3.2.2 Motor Trephines (Mikro-Keratron, Asmotom)

**Mikro-Keratron.** The *Geuder Micro-Keratron* trephine is a non-automated motor-driven trephine system for PKP. The depth of the cut is not preadjustable, so that this trephine system has no impact on lamellar keratoplasty. Rotation (variable speed) may be started and stopped by pressing down and releasing a foot pedal. Different blades mounted on the unit allow for a wide range of trephination diameters. To trephine the donor cornea from the epithelial side, the tissue has to be mounted into an artificial anterior chamber maintainer. Motor trephine rotation may lead to "shifting" of the trephine within the corneal stroma.

**Asmotom.** The *Asmotom ATS* is an automated trephine system for PKP. The trephination of patient and donor eyes as well as corneoscleral disks is performed with separate instrumentation sets. For non-perforating cuts the cutting depth is preadjustable with offset rings for the patient. The cutter sets provided by the distributors include five different diameters (6.0–8.2 mm). The ATS uses an innovative double fixation design. Vacuum is applied to both the central and the peripheral section of the cornea. The trephine rotates between the two concentric areas of fixation, using an automatic feed. Once the pre-set depth is reached, the cutter retracts back into its initial position, holding on to the separated central portion, until vacuum is released. The ATS marker facilitates the centering of the trephination cut to the cornea. The system does not require an artificial chamber maintainer for graft trephination.

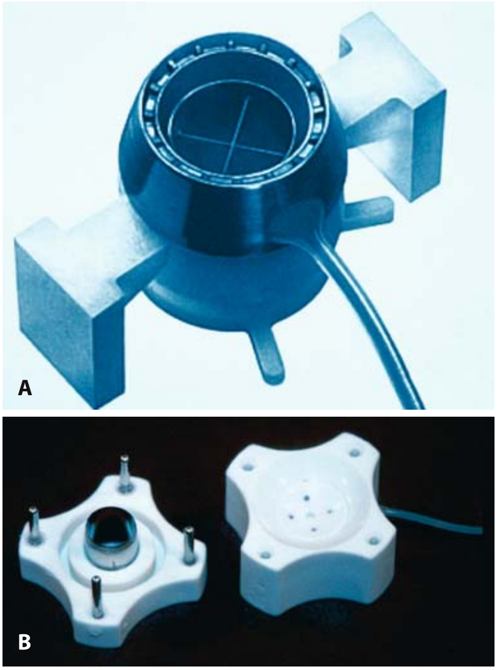


**Fig. 10.12 A, B.** Hessburg-Barron suction trephine. **A** Recipient trephine with cross-hairs for centration; **B** Donor trephination is performed from the endothelial side

### 10.3.2.3 Suction Trephines (Hessburg-Barron)

The classical *Hessburg-Barron trephine* (HBT) has been on the market for over 25 years. The HBT vacuum trephine is an easy to handle single-use product. The suction is applied to the peripheral cornea. The depth of the lamellar trephination can be predicted to a certain degree. One full rotation is presumed to achieve 250 µm of corneal depth. Perforation is typically limited to one-third to one-half of the circumference of the excision. The recipient trephine has cross-hairs for centration. No obturator is applied (Fig. 10.12 A). The Hessburg-Barron trephine leads to divergent cut angles and a larger diameter of the hole at the level of Descemet's membrane [72, 76].

In the classic version the donor is punched from the endothelial side with the aid of a suction device for fixating the donor epithelial side down. Tilt is avoided by four metal rods in the periphery of the blade-containing part and four corresponding peripheral holes in the suction-containing part (Fig. 10.12 B). In addition, four small holes inside the cut area which are colored before the corneoscleral button is placed inside give a reference with respect to the first four cardinal sutures. The donor is typically oversized by 0.25 mm [12].

Recently, a single-use artificial anterior chamber has been available, to create donor trephination from the epithelial side using the recipient trephine for donor trephination first.

### 10.3.2.4 Guided Trephines (GTS, Hanna)

The guided trephines result in the best cut qualities possible with mechanical trephines [72, 76]. These new generation suction trephines such as the Hanna trephine [80] and the Krumeich trephine ("guided trephine system," GTS) [4, 23] are preferred over the Hessburg-Barron trephine because they stabilize the globe by suction at the limbus – not the peripheral cornea. Thus – at least theoretically – the cut angles should be parallel to the optical axis, the dimensions for donor and recipient should be equal and, therefore, no graft oversize is required [50]. Overall, handling of both trephines requires a *special introduction* to the microsurgeon and the staff before application in patients.

**GTS** (Fig. 10.13). The *Krumeich guided trephine system* (GTS) is designed for PKP, lamellar keratoplasty, and circular keratotomy. The GTS can be used with and without an obturator preventing ballooning of the excised tissue into the trephine opening.

*Advantages* of the GTS include: (1) trephination of donor and recipient from the epithelial side using an artificial anterior chamber, (2) pre-defined depth of trephination, e.g., for lamellar procedures, and (3) in experienced hands through-and-through trephination without the necessity of cut completion with scissors can be achieved.

Potential *disadvantages* of the GTS include: (1) it is difficult to apply in patients with narrow lid fissure or deeply set eyes with prominent or-

**Fig. 10.13.** The Krumeich guided trephine system (GTS) is designed for PKP, lamellar keratoplasty, and circular keratotomy. In patients, the GTS can be used with and without an obturator preventing ballooning of the excised tissue into the trephine opening

bital bones (which is not an uncommon issue in keratoconus), preexisting filtering blebs or conjunctival chemosis, (2) centration is difficult due to the limited view, (3) injury if the iris and lens are not securely prohibited, and (4) eccentric mini-keratoplasty with a small diameter (e.g., 4 mm) cannot be accomplished.

**Hanna Trephine** (Fig. 10.14). The *Hanna (Moria) trephine system* is one of the most advanced trephines which is designed to create a proper donor/recipient match. The Hanna trephine attaches firmly to the eye through suction applied to the limbal conjunctiva. Uniform support over the whole cornea during trephination prevents corneal vaulting. From a fully retracted position, the blade rotates while descending to a preset depth, after which the blade rotates without further descent, cutting the displaced tissue and creating a uniform incision. The Hanna trephine in combination with the artificial anterior chamber allows the surgeon to trephine both the recipient and the donor cornea from the epithelial side, thus reducing shape disparity. In the original version the donor trephination was performed from the endothelial side [81].

**Fig. 10.14.** The Hanna (Moria) trephine system. In patients this trephine attaches firmly to the eye through suction applied to the limbal conjunctiva. The Hanna trephine in combination with the artificial anterior chamber allows the surgeon to trephine both the recipient and the donor cornea from the epithelial side

**Summary for the Clinician**

- **If conventional trephines are used it is recommended to use at least the same system with trephination of the donor from the epithelial side using an artificial anterior chamber for placement of the corneoscleral button from the Eye Bank**
- **The trephine should be as sharp as possible**

### 10.3.3 Nonmechanical Laser Trephination

Hypothesizing that the properties of the wound bed are much more important for the final "all-suture-out" astigmatism and the final optical performance of the graft than various types of suture techniques or methods of suture adjustment, we have developed and optimized the technique of *nonmechanical* corneal trephination since 1986.

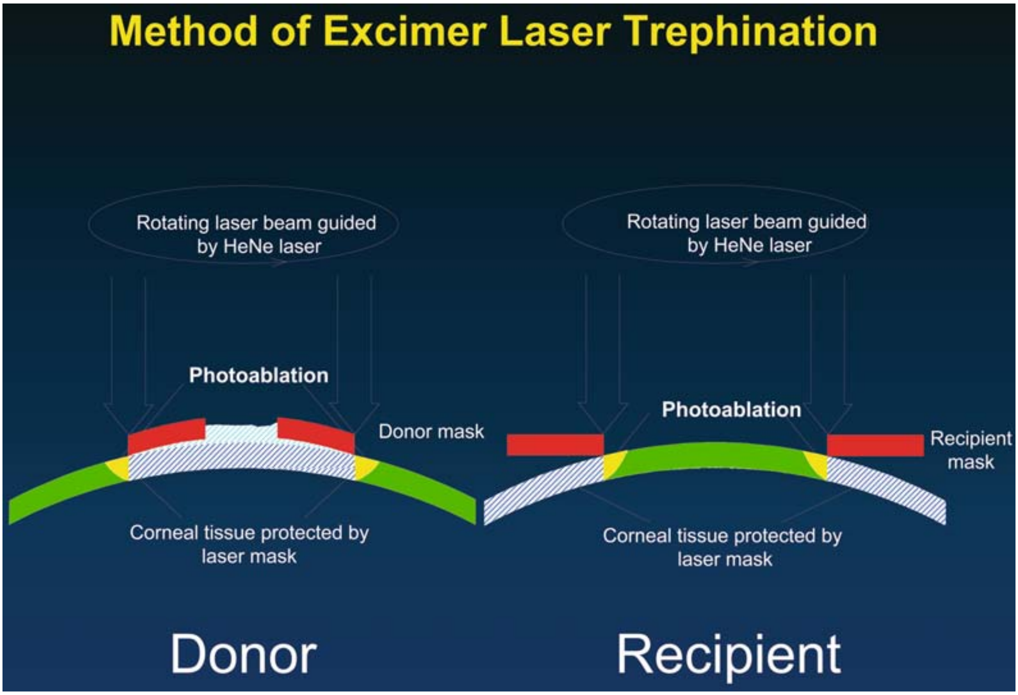


**Fig. 10.15.** Principle of excimer laser trephination in donor and recipient (schematic drawing, sagittal view)

#### 10.3.3.1 The 193-nm Excimer Laser

Since 1989 more than 1650 human eyes have been treated successfully with the Meditec MEL60 excimer laser (Fig. 10.15). Keratoconus has been by far the leading indication (around 37%) for PKP with this non-contact technique (Table 10.7). For donor trephination from the epithelial side an artificial anterior chamber is used [41, 42, 58, 66].

**Technique** (Fig. 10.16). Before starting trephination, the limbus is centered on the perpendicular HeNe aiming beam in donor and patient to ensure a reproducible position of the eye relative to the laser and symmetric cut angles over the entire circumference without tilt. The horizontal positioning of the limbal plane can be controlled using the focusing device of the laser at 3, 6, 9, and 12 o'clock at the limbus before focusing the laser at the trephination edge ("triangulation"). "Horizontal torsion" of the graft may be reduced by employing eight orientation teeth at the donor trephination margin and eight corresponding notches in the recipient bed (a technique which allows the use of eight symmetric cardinal sutures) [2].

**Table 10.7.** Indications for 1656 consecutive non-mechanical excimer laser keratoplasties (06/1989 to 04/2005 in Erlangen)

| | | |
|---|---|---|
| *Keratoconus* | *607* | *(36.7%)* |
| Fuchs' dystrophy | 323 | (19.5%) |
| Bullous keratopathy | 275 | (16.6%) |
| Avascular scars | 181 | (10.9%) |
| Graft failure | 77 | (4.6%) |
| Corneal ulcer | 64 | (3.9%) |
| Stromal dystrophies | 48 | (2.9%) |
| Disabling astigmatism | 40 | (2.4%) |
| Others | 41 | (2.5%) |

For *donor trephination* from the epithelial side using the 193-nm excimer laser MEL60

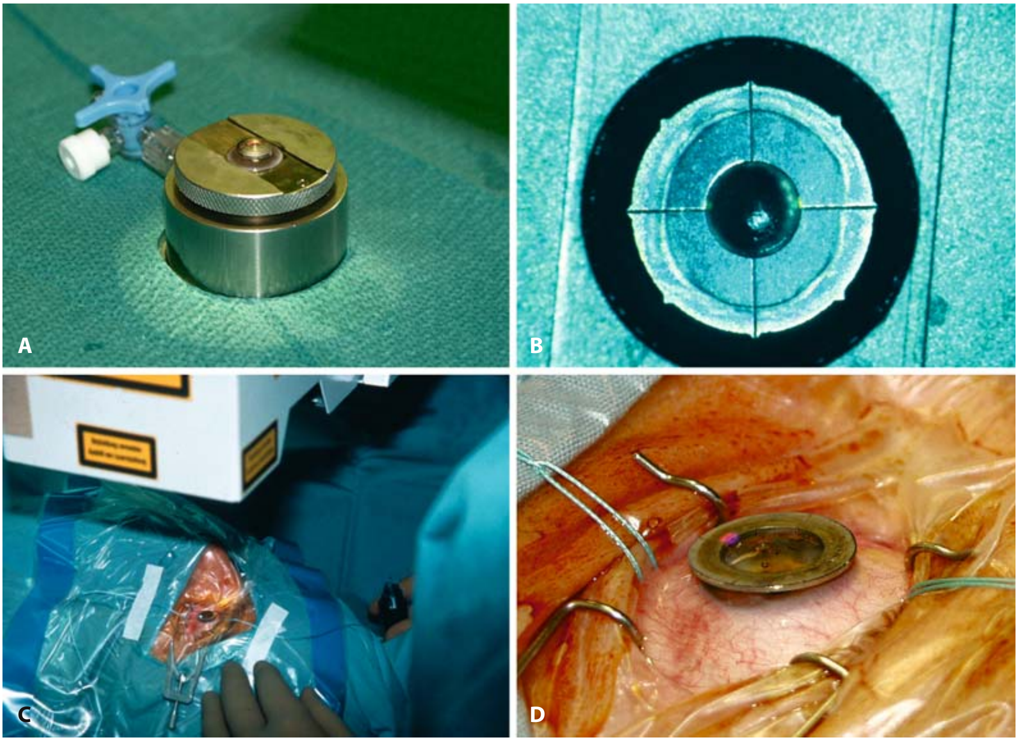


**Fig. 10.16 A–D.** Nonmechanical trephination using the 193-nm excimer laser in combination with metal masks with "orientation teeth/notches." **A** Curved donor mask on top of corneoscleral button fixed in a modified Krumeich artificial anterior chamber; **B** metal donor mask with eight "orientation teeth"; **C** laser arm and joystick for recipient trephination; **D** metal recipient mask with eight "orientation notches" on top of patient's cornea. A 1.5×1.5-mm laser spot is guided along the inner edge of the mask, half of the beam on the mask and half of it on the cornea

(Carl Zeiss Meditec, Jena, Germany), a circular round metal aperture mask (diameter 5.6–8.6 mm, central opening 3.0 mm for centration, thickness 0.5 mm, weight 0.2 g, eight orientation teeth 0.15×0.3 mm) is positioned on a corneoscleral button (16 mm diameter) fixed in an artificial anterior chamber (Polytech, Rossdorf, Germany) under microscopic control (Fig. 10.16 A, B). The pressure within the artificial anterior chamber is adjusted to 22 mmHg. An automated rotation device for the artificial anterior chamber is used.

For *recipient trephination* exclusively performed with the manually guided excimer laser, a corresponding metal mask is used (diameter 12.9 mm, central opening 5.5–8.5 mm), thickness 0.5 mm, weight 0.4 g, eight orientation notches 0.15×0.3 mm (Fig. 10.16 C, D). Before starting the trephination, centration relative to the limbus is achieved by lining up the eight notches with the eight lines of a radial keratotomy marker under microscopic control (Fig. 10.6).

**Advantages** (Table 10.8). The main advantage of this novel laser cutting technique performed from the epithelial side in donor and recipient is the avoidance of mechanical distortion during trephination, resulting in smooth cut edges (Fig. 10.17 A) which are congruent in donor and patient, potentially reducing "vertical tilt" [33]. Such cut edges in combination with "orientation teeth" (Fig. 10.17 B) at the graft margin [2] and corresponding notches at the recipient margin for symmetric positioning of the eight cardinal sutures minimize "horizontal torsion," thus potentially improving the optical performance

**Table 10.8.** Advantages of nonmechanical trephination with the 193-nm excimer laser along metal masks with "orientation teeth/notches" [41, 42, 58, 66]

1. No trauma to intraocular tissues
2. Avoid deformation and compression of tissue during trephination
3. Reduction of horizontal torsion ("Erlangen orientation teeth/notches")
4. Reduction of vertical tilt (congruent cut edges)
5. Reduction of host and donor decentration
6. Feasibility of "harmonization" of donor and host topography
7. Reduction of anterior chamber inflammation early after PKP
8. Reduction of astigmatism after suture removal
9. Higher regularity of corneal topography
10. Significantly better visual acuity with spectacle correction
11. Feasibility of trephination with unstable cornea (e.g., "open eye", descemetocele, after radial keratotomy, iatrogenic keratectasia after LASIK)
12. Arbitrary shape (e.g., elliptical) [28]

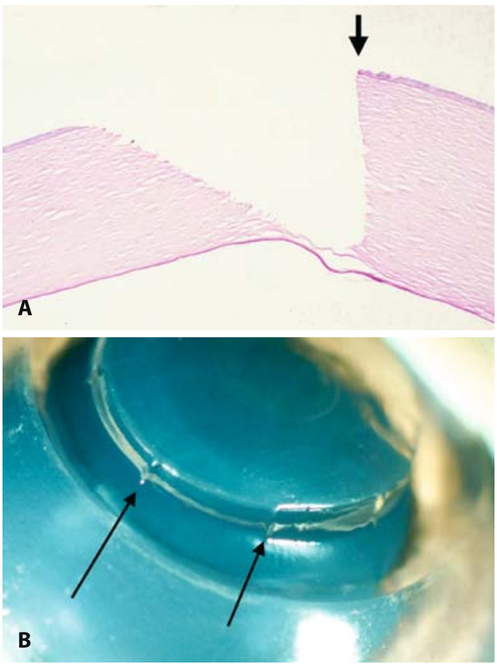


**Fig. 10.17 A, B.** Donor trephination immediately before perforation. **A** Histologic view with smooth almost perpendicular cut edge; **B** macroscopic view with smooth cut surfaces and "orientation teeth"

after transplantation [42]. Furthermore, recipient and donor decentration may be reduced [30, 61]. The use of metal masks allows for arbitrary shapes of the trephination [28].

These favorable impacts on major intraoperative determinants of post-keratoplasty astigmatism (cf. Table 10.2) result in lower keratometric astigmatism, higher topographic regularity and better visual acuity after suture removal. After sequential removal of a double running suture, keratometric astigmatism increased in 80% of eyes with conventional trephination, but further decreased in 52% of eyes with laser trephination [58]. In addition to less blood-aqueous barrier breakdown during the early postoperative time course after PK [26], laser trephination induces neither cataract formation nor higher endothelial cell loss of the graft. Likewise, the rates of immunologic graft rejection and secondary ocular hypertension are comparable using either technique. In addition, trephination of an unstable cornea, such as in (pre-)perforated corneal ulcers or after RK or LASIK, is facilitated [64].

**Practical Considerations for the Microsurgeon** [66]. The longer trephination time of around 6 min for the donor and around 4 min for the recipient are by far compensated for by practical advantages for the microsurgeon during the subsequent course of surgery: (1) injuries of in-

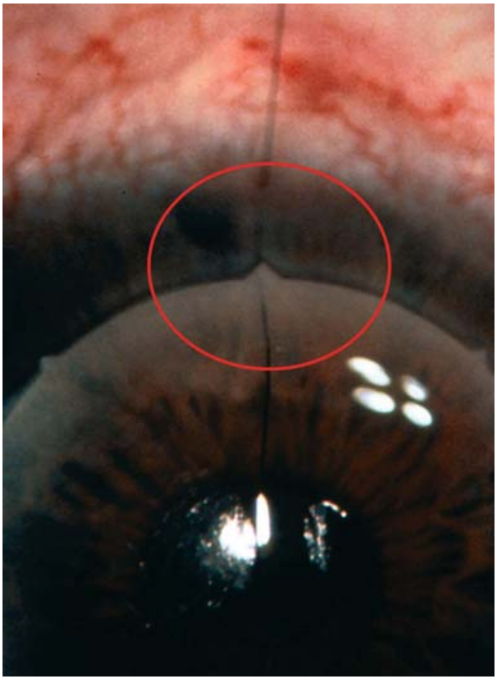

**Fig. 10.18.** Correct position of *second* cardinal suture (*arrow*) is facilitated by orientation tooth (donor) and corresponding notch (host)

traocular structures are impossible with the laser – even in beginner's hands – since the ablation stops as soon as aqueous humor fills the trephination groove after focal perforation. (2) The need for completion of the cut by scissors is reduced to a minimum. (3) The localization of the first eight cardinal sutures is unequivocally given by the "orientation teeth/notches" (Fig. 10.18). (4) Crescent-shaped tissue deficits at the graft-host junction (e.g., at other than round recipient openings in keratoconus) are avoided, thus achieving a latent watertight wound closure often as soon as after four cardinal sutures. (5) During further suturing the anterior chamber tends to remain stable. (6) The final double running suture needs very little tension to keep a watertight wound after removal of the eight cardinal sutures. (7) Therefore, only very rarely are additional single sutures with adverse effects on graft topography required at the end of surgery. (8) In addition, the so-called "barrel-top formation" at the proximal suture endings inducing a relative cornea plana and delaying optical rehabilitation can be avoided. (9) After removal of lid speculum and fixation sutures, the use of a Placido's disk often enables an almost round projection image to be achieved during intraoperative suture adjustment.

**Summary for the Clinician**

- **Nonmechanical trephination using the 193-nm excimer laser along metal masks has improved functional outcome after PKP with all-sutures-out**
- **The application of excimer lasers allows controlled trephination of unstable corneas such as perforated ulcers or iatrogenic keratectasia after LASIK**

#### 10.3.3.2 The 2.94-μm Erbium:YAG Laser

The erbium:YAG laser was investigated to improve handling, reduce acquisition and maintenance costs, and provide solid state laser safety but keep the morphological advantages of the excimer laser trephination [1]. However, shrinkage effects due to thermal damage of the cut edges especially in the free-running but even with Q-switched laser pulses are major drawbacks of this infrared laser [69]. The induced thermal damage of the Q-switched mode erbium:YAG laser has been detected to be around 2–15 μm, in comparison to only 200 nm using the excimer laser [54, 68].

**Summary for the Clinician**

- **The erbium:YAG laser will probably not substitute the excimer laser for nonmechanical trephination in the near future without a loss of advantages**

#### 10.3.3.3
#### The Femtosecond Laser

In contrast to the excimer laser, which allows only surface ablation, the femtosecond (= $10^{-15}$ s) laser allows the cornea to be cut within the stroma, enabling truly three-dimensional cuts without opening the eye and without thermal damage. No masks but an ultra-fast eye tracking system is required. There is no significant tissue loss to be compensated. For PKP especially in keratconus a non-contact approach of laser application is favored to avoid deformation.

Self-sealing keratoplasty wounds would be a major step towards rapid visual rehabilitation in PKP. Various kinds of nut-and-bolt configurations to fit in the donor including "orientation teeth" of the graft in the recipient bed are feasible using a femtosecond laser. We have introduced an *inverse mushroom shaped trephination* with the larger diameter of the graft at the level of Descemet's membrane (Fig. 10.19). Variation of the diameter of the "stipe" and the "cap" may help to produce the best individual compromise between the amount of transplanted endothelium and distance to limbal vessels and resistance to intraocular pressure [67].

In addition, *posterior lamellar keratoplasty* (PLKP) can be performed more easily with a femtosecond laser [63].

**Fig. 10.19.** Macrophotograph of *inverse mushroom shaped trephination* using a femtosecond laser [67]

**Summary for the Clinician**

- **Femtosecond laser application is the "*excitement of tomorrow*" in microsurgery of the cornea**
- **New nut-and-bolt type variants for potentially self-sealing donor/host appositions are on the horizon, offering a promising approach towards minimally invasive "*no-stitch keratoplasty*"**

### 10.4
### Concluding Remarks

Today, expectations concerning the outcome after penetrating keratoplasty are not only restricted towards achieving a clear graft. The only criterion that counts for the patient is good vision preferably without the need for contact lenses but with an easily tolerable need for correction using spectacles. Therefore, transplant microsurgeons should not only consider all the means available to prevent high or irregular post-PKP astigmatism. Due to the lack of predictability of the refractive result in an individual patient after PKP, they should also familiarize themselves with the surgical techniques for correcting refractive errors after PKP in order to achieve the individually best outcome for a given patient.

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