69 IOL Power Calculation in Keratoplasty

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In the last 20 years or so, giant steps have been made in the transition from full thickness (penetrating) to partial thickness (lamellar) corneal grafts, where only the diseased layer is replaced. This has led to safer, less invasive procedures and faster vision recovery. The improvement in the results has also increased the importance of accurate IOL power calculations in these cases.

The most commonly used techniques are **Penetrating Keratoplasty (PK)** (Fig. 69.1e), where all layers of the cornea are replaced and kept in place by several sutures; **Deep Anterior Lamellar Keratoplasty (DALK)** (Fig. 69.1f), where the front layers are removed, only leaving the Descemet membrane and the corneal endothelium (in some cases, a fine layer of the posterior corneal stroma is also left in place); **Descemet Stripping Automated Keratoplasty (DSAEK)** (Fig. 69.1c), where only the endothelium and the Descemet membrane are removed and replaced with a lamella comprising posterior stroma, Descemet membrane and corneal endothelium, held in place with an air bubble. It is called "automated" because the donor lamella is harvested from the eye by means of a mechanical microkeratome; **Endothelial Keratoplasty (EK)** (Fig. 69.1d), where only the endothelium and the Descemet membrane are removed and replaced by Descemet and endothelium carefully stripped from the donor with a manual technique.

For the purpose of IOL power calculations, it is important to understand the changes that the different procedures produce to the anterior and posterior corneal curvature and on the other parameters (Table 69.1).

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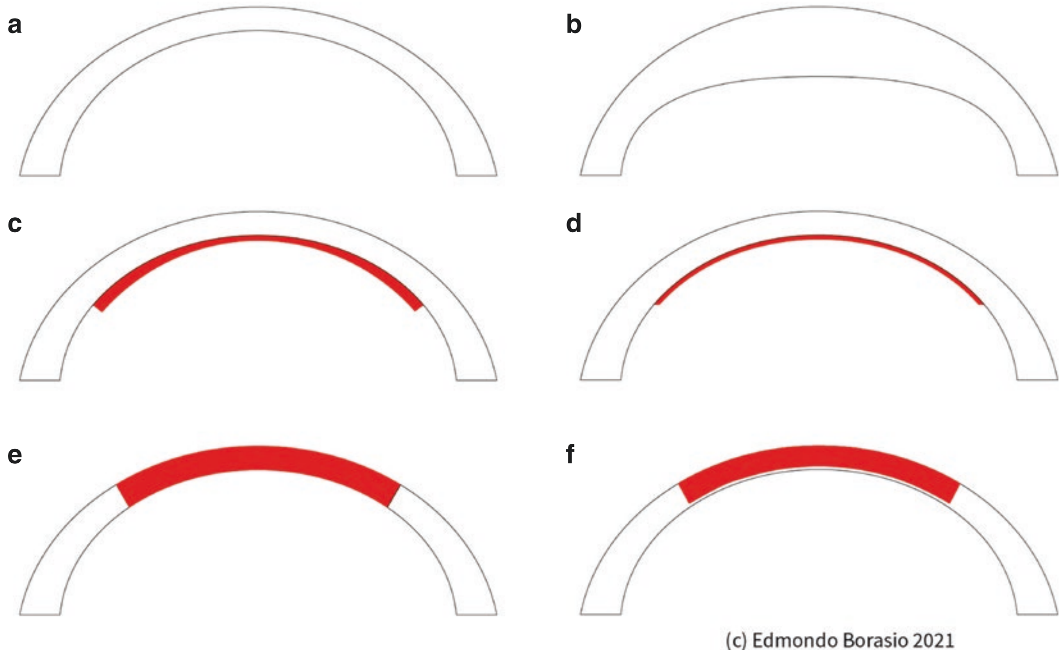

Fig. 69.1 Keratoplasty techniques. **a**) Normal corneal anatomy. **b**) Altered posterior corneal curvature due to endothelial failure such as in Fuch's corneal endothelial dystrophy or bullous keratopathy from any cause. **c**) Status post DSAEK. **d**) Status post DMEK. **e**) Status post PK. **f**) Status post DALK

Table 69.1 Corneal changes induced by keratoplasty techniques

	Changes in anterior corneal curvature	Changes in posterior corneal curvature	Changes in axial length	Changes in ant/post corneal ratio	Changes in central corneal thickness	Changes in ACD
PK	Yes	Possible	Yes	Possible	Yes	Possible
DALK	Yes	Possible	Yes	Possible	Yes	Posssible
DSAEK	No[a]	Yes—marked[b]	No	Yes	Yes—marked	No
EK	No[a]	Yes[b]	No	Yes	Yes—marked	No

[a] No significant changes unless presence of massive bullae in the decompensated cornea
[b] The changes in the posterior corneal curvature are not only due to the actual anatomy of the donor lamella as in the case of DSAEK, but also due to the resolving edema (Fig. 69.1b), in the weeks following a successful DSAEK or EK procedure

Factors Limiting IOL Power Calculation Accuracy in Eyes Undergoing Simultaneous Cataract Surgery and Corneal Transplantation (Triple Procedure)

IOL power calculation in eyes undergoing simultaneous keratoplasty and cataract surgery is intrinsically inaccurate and unpredictable due to the fact that the parameters used in the calculation get altered during the procedure itself [1, 2]. In particular:

- **Anterior corneal curvature (K readings, or Sim Ks)** gets significantly affected after Penetrating Keratoplasty (PK) or Deep Anterior Lamellar Keratoplasty (DALK) as a result of: (a) Disparity between donor corneal button size and host cornea trephination size (undersized grafts leading to central corneal flattening while oversized grafts leading to central corneal steepening) and (b) differences in corneal graft suture tension (the higher the tension, the flatter the central corneal curvature postoperatively).

$$IOL\ power\ formulas\ affected: \boldsymbol{all\ formulas}\begin{pmatrix} both\ those\ based\ on\ regression \\ and\ those\ based\ on\ ray\ tracing \end{pmatrix}.$$

- **Axial length (AL)** can change after PK/DALK as a result of: (a) Different corneal thickness and corneal architecture between diseased excised cornea and healthy donor cornea and (b) variable corneal graft suture tension.

$$IOL\ power\ formulas\ affected: \boldsymbol{all\ formulas}\begin{pmatrix} both\ those\ based\ on\ regression \\ and\ those\ based\ on\ ray\ tracing \end{pmatrix}.$$

- **Anterior/posterior corneal radius ratio** gets altered after endothelial procedures such as Descemet Stripping (Automated) Endothelial Keratoplasty (DSAEK/DSEK) and Descemet Membrane Endothelial Keratoplasty (DMEK).
- In endothelial dysfunction such as in Fuchs' corneal endothelial dystrophy, the cornea becomes edematous. Unless large bullae are present, anterior corneal curvature and axial length remain constant, whereas posterior corneal curvature decreases (becomes flatter) as the cornea becomes more edematous. This progressive edema causes a myopic shift. After endothelial keratoplasty is performed, as the corneal edema resolves, the posterior corneal curvature increases (it goes back towards its normal curvature) and this induces the commonly reported postoperative hyperopic shift [3–9]. This hyperopic shift has been reported both after DSAEK [10–18] and after DMEK [4–9], which demonstrates that the refractive shift is not simply the consequence of the negative lenticule shape of the DSAEK donor lamella as it was previously postulated [14, 16, 19, 20].

$$IOL\ power\ formulas\ affected: \boldsymbol{all\ formulas}.$$

- ***Third-generation formulas*** *(SRK/T, HofferQ, Holladay, Haigis) are all affected because they assume a fixed anterior/posterior corneal radius ratio.* ***Raytracing*** *methods are also affected because the corneal curvature measurements are taken preoperatively when the cornea is still edematous and hence with a flatter posterior curvature compared to the postoperative status in which the edema has resolved, and the posterior curvature has increased.*
- **Central corneal thickness (CCT)** gets altered following endothelial procedures such as DSAEK, DSEK and DMEK due to the fact that corneal edema reduces after endothelial transplantation.

$$IOL\ power\ formulas\ affected: \boldsymbol{ray\ tracing}\ formulas\ only$$
$$(3rd\ generation\ formulas\ do\ not\ require\ CCT\ as\ an\ input\ parameter).$$

The only biometric factor that does not get altered following keratoplasty is the **actual position of the IOL inside the capsular bag**. This position however cannot be accurately predicted before the operation. The "constants" used in its place as predictors of IOL position are the A constant (for SRK/T formula), SF (for Holladay formula), pACD (for HofferQ formula), a0, a1, a2 (for Haigis formula). These constants are derived empirically from back calculations starting from the postoperative refractive outcome and a given set of inputs, including the same ones that get altered during the corneal transplantation itself (mainly K readings). Hence, also these constants are no longer reliable after the procedure and for this reason, **they should ideally be customized for each combination of corneal graft type (penetrating, anterior lamellar, and endothelial graft), surgical technique (extent of donor graft oversizing, suture tension), IOL model implanted, and operating surgeon**. This however is not practical and probably only feasible in centers where a large number of corneal grafts are performed each year.

Further sources of possible error to consider:

- Donor corneas that have previously undergone laser refractive surgery
- Donor corneas with undetected keratoconous
- Mislabeled IOL power (as in normal eyes undergoing cataract surgery)

With the growing number of laser refractive procedures being done worldwide and the technical difficulties of performing corneal topography on either the cadaver eye or on the harvested corneo-scleral rim (main difficulty being the altered epithelium after death), it is becoming increasingly more likely that a donor cornea could have undergone some refractive procedure in the past, with the risk, generally speaking, of a hyperopic outcome following a myopic procedure and the risk of a myopic outcome following a hyperopic procedure, if not detected. A keratoconic donor cornea could also make the IOL power calculations unreliable.

Methods Available to Limit Refractive Surprises

Triple Procedures (Simultaneous Keratoplasty + Cataract Extraction + IOL Implantation)

- **PK/DALK**
  - Using estimated postoperative, **K values taken from previous cases series done by the same surgeon,** ideally using a **similar suturing** technique **and with a similar graft/donor size disparity.**
  - Using **average estimated postoperative K values** taken from the literature involving cases done with a similar technique. Postoperative average K values vary greatly and are summarized in Table 69.2, ranked in ascending order [1, 21–26].
  - Using **K readings taken from the fellow (unoperated or already transplanted) cornea**.
  - Ideally, one should use the predicted K values taken after suture removal, as sutures can cause a significant flattening especially in the first few months after the operation. In any case, it is always advisable aiming for a mild residual myopia (>−0.75 D),

Table 69.2 Postoperative average K values in keratoplasty techniques

Technique	Pathology	Postop Average K (D)	Author	References
PK (same size)	KC	42.25	Duran	[21]
DMEK	Fuchs'	43.11	Alnawaiseh	[22]
PK	Various but not KC	44.71	Abd Elaziz	[23]
PK	KC	44.80	Raecker	[24]
PK	Various	45.06	Geerards	[25]
PK (oversized graft)	KC	45.16	Duran	[21]
PK	Keratopathy	45.34	Duran	[21]
PK	Keratopathy with vascularization	45.34	Duran	[21]
DALK	KC	45.54	Schiano Lomoriello	[26]
PK (oversized graft)	Various	45.70	Javadi	[1]
PK	Fuchs'	46.10	Raecker	[24]

Table 69.3 Postoperative hyperopic shift: DSAEK vs DMEK

Technique	Postop hyperopic shift (D)	References
DSAEK	From 0.70 to 1.50	[12–18]
DMEK	0.33, 0.43, 0.73, 0.90	[4, 5, 8, 9]

given the fact that a hyperopic result is never a desirable outcome for the patient.

- **DSAEK/DSEK/DMEK**
  - Using third-generation formulas and aiming for a myopic target of around −0.75 to **−1.00 D** [3–9]. Studies show a greater hyperopic shift after DSAEK compared to DMEK (Table 69.3), and therefore, more myopia should be targeted in DSAEK. It has been shown that the most affected formula after endothelial keratoplasty is the Haigis, formula, while the SRK/T is the least affected one [9].
  - **Raytracing**
  - Some studies have shown a reduction of the hyperopic error using raytracing techniques (0.24 D hyperopic error) compared to standard third-generation formulas; however, it should be noted that posterior corneal curvature measurements taken preoperatively differ from the final postoperative measurements, and hence, the scientific validity of this method is limited [5, 27].
- **All Cases**
  - Of all the preoperative parameters, axial length (AL) is the one having the largest impact on IOL power calculation accuracy, and therefore, it should always be measured by means of optical biometry whenever possible in order to minimize the errors [2].

Aphakic Eyes (Eyes Which Have Undergone Keratoplasty and Cataract Surgery and Have Been Left Aphakic)

One option is performing keratoplasty with simultaneous cataract extraction leaving the eye aphakic in order to plan for a secondary IOL implantation at a later stage. Typically, the secondary IOL is placed in the ciliary sulcus as the capsular bag layers soon coalesce after surgery, not allowing in-bag implantation. The power of the secondary IOL can be calculated in different ways:

- Aphakic Refraction Using the Refractive Vergence Formula [28]

$$IOL_e = \frac{1336}{\frac{1336}{\frac{1000}{\frac{1000}{PreRx} - V} + K_o} - ELP_o} - \frac{1336}{\frac{1336}{\frac{1000}{\frac{1000}{DPostRx} - V} + K_o} - ELP_o}$$

With this formula by J Holladay, for a given pre-operative refractive error (**PreRx**) [e.g., +2.25 D] measured at a specific vertex distance (**V**) [e.g., 12 mm] in an eye with a given corneal true net power (**Ko**) [e.g., 41.98 D], it is possible to calculate the IOL power required (**IOLe**) to achieve the desired post-operative refraction (**DPostRx**) [e.g., 0.00 D]. The formula requires a value to be entered for the effective lens position (**ELPo**). This is the distance from the secondary corneal principal plane to the IOL principal plane in thin-lens equivalent terms and it varies according to the position of the IOL (typically 4.80 mm is used for the sulcus, 5.55 mm for the capsular bag, and 3.50 mm for the anterior chamber). Corneal true net power (**Ko**) can be taken from devices that are able to measure both the anterior and the posterior corneal curvature, such as Pentacam (Oculus), Sirius or MS-39 (CSO), Galilei G6 (Ziemer), Anterion (Heidelberg), or alternatively, it can be approximated from K1 and K2 with the following equation:

$$0.5^{*}\left(K1+K2\right)*0.98765431$$

In the example above, a 3.24 D sulcus IOL would be required to achieve emmetropia. A more advanced version of this formula is present in the Holladay IOL Consultant software.

– **Raytracing**

Raytracing allows corneal and IOL power calculations from objective anterior and posterior corneal curvature measurements and axial length and, differently from third- and fourth-generation formulas, does not require any adjustment or regression for special cases such as post-laser refractive surgery eyes which assume a constant anterior/posterior corneal curvature ratio [29, 30]. Good results, comparable to those using the SRK/T and HofferQ formula, have been shown with this technique in normal eyes and the method has also been used successfully in post-laser refractive surgery eyes, especially after myopic laser vision correction [31–34]. Raytracing can also be used to accurately back-calculate IOL power in pseudophakic eyes provided that the IOL position can be accurately measured [35]. A single paper describes the use of raytracing in keratoconus [36]. To our knowledge, publications are lacking on raytracing IOL power calculations after corneal transplantation. This is a pity, because theoretically, the cases that would benefit the most from raytracing would indeed be post-keratoplasty eyes, especially those with irregular corneal graft curvature or those with tilted/eccentric grafts or distorted/eccentric pupils. More studies are needed on this subject.

– **Intraoperative aberrometry**

The validity of this method has been proven in studies involving both normal eyes [37–41] and eyes that had undergone laser refractive surgery [42–46]; however, no data is available for post-keratoplasty eyes.

In theory also, this method should be able to provide accurate results, provided that the transplanted cornea is clear and it is possible to scan it well. Its main limitation however, cost aside, is the need of a large stock of IOLs with different powers directly on the premises in order to be able to choose the exact power required. Having a complete stock of IOLs is already an issue for standard spherical IOLs, and it is even more so in the case of corneal grafts because they often require a toric IOL to correct high residual astigmatism. In most clinical settings, it is probably better to perform biometry well ahead of surgery.

The following ones are the main drawbacks of implanting the IOL via an additional procedure at a later date after the initial keratoplasty:

– The patient has to cope with poor vision for several months (in the case of a PK, sutures are removed after 12 months and it would take another couple of months for the cornea to stabilize before an accurate biometry can be done).
– It is often not possible to wear a contact lens immediately after surgery to cope with being aphakic.
– Aphakic glasses may be unbearable due to anisometropia.
– The secondary IOL implantation procedure may trigger a corneal graft rejection.
– The secondary IOL implantation procedure may further damage the weak corneal graft endothelium.
– Extended usage of steroid drops prescribed to reduce the risk of graft rejection may cause a raised IOP (steroid response).

For these reasons, although leaving the eye aphakic on purpose would seem to be the best method in terms of IOL power calculation, this is not clinically safe and therefore it is not advised.

Pseudophakic Eyes (Eyes Which Have Undergone Keratoplasty and Have Been Left Pseudophakic with a Significant Residual Refractive Error)

The same principles (and drawbacks) of the aphakic method above apply with the sole difference being the fact that the correcting IOL can either be implanted as a piggyback IOL in the ciliary sulcus or in the capsular bag, or as as a single new primary IOL as in the cases of IOL exchanges.

To prevent interlenticular opacification, lab studies suggest that it would be advisable not to implant two hydrophobic acrylic IOLs in contact with each other, but rather combining an acrylic IOL with a silicon IOL, or using two silicon IOLs [47].

Recently, implantable collamer lenses (Visian ICL, Staar) have been used as alternative sulcus piggyback lenses to standard 3-piece IOLs with good results in children [48]. Their advantage is the minimal incision size required and the ease of explantation whenever needed.

Transplanted Corneas Which Still Have Cataract (Eyes Which Have Undergone Keratoplasty But Still Have to Undergo Cataract Surgery)

When planning cataract surgery in an eye that has previously undergone keratoplasty, it is essential that corneal curvature measurements are taken when the refraction has fully stabilized. This occurs after at least 2–3 months following complete suture removal.

In eyes that have undergone DSAEK and where the donor corneal lenticule is particularly thick and negative-meniscus shaped, it is advisable **to aim for a mild residual myopia** and comparing standard IOL power calculations results with those of **raytracing**.

In eyes that have undergone PK or DALK and in which there are no major corneal irregularities, third-generation formulas can generally be used as in normal eyes with fairly accurate results. In very irregular corneas, raytracing may provide better clues.

In corneal grafts where the final corneal anatomy is similar to that of a normal cornea (such as after either DMEK or after an extremely thin DSEK or after a shallow femtolaser ALK), standard third-generation formulas can be used without any major adjustments.

To reduce the risk of triggering a graft rejection, the operation should be done when the eye is completely quiet. Postoperative treatment with cortisone eye drops should be tapered slowly over several weeks or months, especially after PK/DALK.

Management of Refractive Surprises

1. Glasses or contact lenses
2. Femto LASIK or PRK with Mitomycin C
3. IOL Exchange or piggyback IOL implantation using vergence formula

Small errors on the myopic side are usually fairly well tolerated and may be corrected with glasses or contact lenses. Hybrid or gas-permeable contact lenses or scleral lenses are sometimes required in grafts with unusual curvatures or in irregular graft-host interfaces.

Enhancements by means of Femto LASIK or PRK (always with the application of Mitomycin C 0.02% for >30 s in order to prevent the onset of corneal haze) have shown to give excellent results with a low risk of triggering a graft rejection. This should always be followed by several weeks of cortisone drops treatment on a tapering regime to prevent graft rejection.

For severe refractive errors, the best approach is either replacing the IOL or placing a piggyback IOL in the ciliary sulcus after calculating the power using the refractive vergence formula or raytracing.

Summary

1. Accurate IOL power prediction at the same time of cataract surgery is not possible.
2. Leaving the eye aphakic on purpose after corneal transplantation and aiming for accurate IOL power calculation for a secondary IOL implantation later on theoretically would provide the most accurate results; however, it is very debilitating for the patient and poses a serious risk of triggering a corneal graft rejection or damaging the corneal endothelium, and therefore, it is not advisable.
3. Implanting an IOL at the same time of keratoplasty is by far the best option and K values should ideally be taken from individual case series done with a similar surgical technique (similar corneal graft type; surgical and suturing technique; donor-host cornea size disparity) and always aiming for a mild residual myopia. In endothelial transplants, a myopic target of at least -0.75 D should always be targeted due to the expected postoperative hyperopic shift.
4. Residual refractive errors can be well managed by means of glasses/contact lenses or by means of laser refractive surgery (such as PRK + Mitomycin C or Femto LASIK) and in extreme cases by means of IOL exchange or piggyback IOL implantation using the refractive vergence formula or raytracing.

References

1. Javadi MA, Feizi S, Moein HR. Simultaneous penetrating keratoplasty and cataract surgery. J Ophthalmic Vis Res. 2013;8(1):39–46. PMID: 23825711; PMCID: PMC3691977.
2. Norrby S. Sources of error in intraocular lens power calculation. J Cataract Refract Surg. 2008;34(3):368–76. https://doi.org/10.1016/j.jcrs.2007.10.031. PMID: 18299059.
3. Price MO, Price FW Jr. Descemet membrane endothelial keratoplasty. Int Ophthalmol Clin. 2010;50(3):137–47. https://doi.org/10.1097/IIO.0b013e3181e21a6f. PMID: 20611024.
4. Schoenberg ED, Price FW Jr, Miller J, McKee Y, Price MO. Refractive outcomes of Descemet membrane endothelial keratoplasty triple procedures (combined with cataract surgery). J Cataract Refract Surg. 2015;41(6):1182–9. https://doi.org/10.1016/j.jcrs.2014.09.042. Epub 2015 Jun 19. PMID: 26096520.
5. Diener R, Treder M, Lauermann JL, Eter N, Alnawaiseh M. Assessing the validity of corneal power estimation using conventional keratometry for intraocular lens power calculation in eyes with Fuch's dystrophy undergoing Descemet membrane endothelial keratoplasty. Graefes Arch Clin Exp Ophthalmol. 2021;259(4):1061–70. https://doi.org/10.1007/s00417-020-04998-w. Epub 2020 Nov 13. PMID: 33185732; PMCID: PMC8016760.
6. Alnawaiseh M, Rosentreter A, Eter N, Zumhagen L. Changes in corneal refractive power for patients with Fuchs endothelial dystrophy after DMEK. Cornea. 2016;35(8):1073–7. https://doi.org/10.1097/ICO.0000000000000842. PMID: 27055217.
7. Ham L, Dapena I, Moutsouris K, Balachandran C, Frank LE, van Dijk K, Melles GR. Refractive change and stability after Descemet membrane endothelial keratoplasty. Effect of corneal dehydration-induced hyperopic shift on intraocular lens power calculation. J Cataract Refract Surg. 2011;37(8):1455–64. https://doi.org/10.1016/j.jcrs.2011.02.033. PMID: 21782088.
8. Korine van Dijk K, Ham L, Tse WH, Liarakos VS, Quilendrino R, Yeh RY, Melles GR. Near complete visual recovery and refractive stability in modern corneal transplantation: Descemet membrane endothelial keratoplasty (DMEK). Cont Lens Anterior Eye. 2013;36(1):13–21. https://doi.org/10.1016/j.clae.2012.10.066. Epub 2012 Oct 26. PMID: 23108011.
9. Alnawaiseh M, Zumhagen L, Rosentreter A, Eter N. Intraocular lens power calculation using standard formulas and ray tracing after DMEK in patients with Fuchs endothelial dystrophy. BMC Ophthalmol. 2017;17(1):152. https://doi.org/10.1186/s12886-017-0547-7. PMID: 28835226; PMCID: PMC5569506.
10. Kim SE, Lim SA, Byun YS, Joo CK. Comparison of long-term clinical outcomes between Descemet's stripping automated endothelial keratoplasty and penetrating keratoplasty in patients with bullous keratopathy. Korean J Ophthalmol. 2016;30(6):443–50. https://doi.org/10.3341/kjo.2016.30.6.443. Epub 2016 Dec 6. PMID: 27980363; PMCID: PMC5156618.
11. Koenig SB, Covert DJ, Dupps WJ Jr, Meisler DM. Visual acuity, refractive error, and endothelial cell density six months after Descemet stripping and automated endothelial keratoplasty (DSAEK). Cornea. 2007;26(6):670–4. https://doi.org/10.1097/ICO.0b013e3180544902. PMID: 17592314.
12. Gorovoy MS. Descemet-stripping automated endothelial keratoplasty. Cornea. 2006;25(8):886–9. https://doi.org/10.1097/01.ico.0000214224.90743.01. PMID: 17102661.
13. Koenig SB, Covert DJ. Early results of small-incision Descemet's stripping and automated endothelial keratoplasty. Ophthalmology. 2007;114(2):221–6. https://doi.org/10.1016/j.ophtha.2006.07.056. Epub 2006 Dec 5. PMID: 17156845.

14. Scorcia V, Matteoni S, Scorcia GB, Scorcia G, Busin M. Pentacam assessment of posterior lamellar grafts to explain hyperopization after Descemet's stripping automated endothelial keratoplasty. Ophthalmology. 2009;116(9):1651–5. https://doi.org/10.1016/j.ophtha.2009.04.035. Epub 2009 Jul 29. PMID: 19643500.
15. Lee WB, Jacobs DS, Musch DC, Kaufman SC, Reinhart WJ, Shtein RM. Descemet's stripping endothelial keratoplasty: safety and outcomes: a report by the American Academy of Ophthalmology. Ophthalmology. 2009;116(9):1818–30. https://doi.org/10.1016/j.ophtha.2009.06.021. Epub 2009 Jul 30. PMID: 19643492.
16. Holz HA, Meyer JJ, Espandar L, Tabin GC, Mifflin MD, Moshirfar M. Corneal profile analysis after Descemet stripping endothelial keratoplasty and its relationship to postoperative hyperopic shift. J Cataract Refract Surg. 2008;34(2):211–4. https://doi.org/10.1016/j.jcrs.2007.09.030. PMID: 18242442.
17. Xu K, Qi H, Peng R, Xiao G, Hong J, Hao Y, Ma B. Keratometric measurements and IOL calculations in pseudophakic post-DSAEK patients. BMC Ophthalmol. 2018;18(1):268. https://doi.org/10.1186/s12886-018-0931-y. PMID: 30332995; PMCID: PMC6192275.
18. Dupps WJ Jr, Qian Y, Meisler DM. Multivariate model of refractive shift in Descemet-stripping automated endothelial keratoplasty. J Cataract Refract Surg. 2008;34(4):578–84. https://doi.org/10.1016/j.jcrs.2007.11.045. PMID: 18361978; PMCID: PMC2796246.
19. Rao SK, Leung CK, Cheung CY, Li EY, Cheng AC, Lam PT, Lam DS. Descemet stripping endothelial keratoplasty: effect of the surgical procedure on corneal optics. Am J Ophthalmol. 2008;145(6):991–6. https://doi.org/10.1016/j.ajo.2008.01.017. Epub 2008 Mar 14. PMID: 18342831.
20. Bahar I, Kaiserman I, McAllum P, Slomovic A, Rootman D. Comparison of posterior lamellar keratoplasty techniques to penetrating keratoplasty. Ophthalmology. 2008;115(9):1525–33. https://doi.org/10.1016/j.ophtha.2008.02.010. Epub 2008 Apr 28. PMID: 18440638.
21. Duran JA, Malvar A, Diez E. Corneal dioptric power after penetrating keratoplasty. Br J Ophthalmol. 1989;73(8):657–60. https://doi.org/10.1136/bjo.73.8.657. PMID: 2669941; PMCID: PMC1041840.
22. Alnawaiseh M, Zumhagen L, Rosentreter A, Eter N. Changes in anterior, posterior, and total corneal astigmatism after Descemet membrane endothelial keratoplasty. J Ophthalmol. 2017;2017:4068963. https://doi.org/10.1155/2017/4068963. Epub 2017 May 2. PMID: 28553547; PMCID: PMC5434235.
23. Abd Elaziz MS, Elsobky HM, Zaky AG, Hassan EAM, KhalafAllah MT. Corneal biomechanics and intraocular pressure assessment after penetrating keratoplasty for non keratoconic patients, long term results. BMC Ophthalmol. 2019;19(1):172. https://doi.org/10.1186/s12886-019-1186-y. PMID: 31391006; PMCID: PMC6686420.
24. Raecker ME, Erie JC, Patel SV, McLaren JW, Hodge DO, Bourne WM. Long-term keratometric changes after penetrating keratoplasty for keratoconus and Fuchs endothelial dystrophy. Am J Ophthalmol. 2009;147(2):227–33. https://doi.org/10.1016/j.ajo.2008.08.001. Epub 2008 Oct 2. PMID: 18834579; PMCID: PMC3783204.
25. Geerards AJ, Hassmann E, Beekhuis WH, Remeyer L, van Rij G, Rijneveld WJ. Triple procedure; analysis of outcome, refraction, and intraocular lens power calculation. Br J Ophthalmol. 1997;81(9):774–7. https://doi.org/10.1136/bjo.81.9.774. PMID: 9422932; PMCID: PMC1722304.
26. Schiano Lomoriello D, Savini G, Naeser K, Colabelli-Gisoldi RM, Bono V, Pocobelli A. Customized toric intraocular lens implantation in eyes with cataract and corneal astigmatism after deep anterior lamellar keratoplasty: a prospective study. J Ophthalmol. 2018;(2018):1649576. https://doi.org/10.1155/2018/1649576. PMID: 30057802; PMCID: PMC6051070.
27. Olsen T. On the calculation of power from curvature of the cornea. Br J Ophthalmol. 1986;70(2):152–4. https://doi.org/10.1136/bjo.70.2.152. PMID: 3947615; PMCID: PMC1040942.
28. Holladay JT. Refractive power calculations for intraocular lenses in the phakic eye. Am J Ophthalmol. 1993;116(1):63–6. https://doi.org/10.1016/s0002-9394(14)71745-3. PMID: 8328545.
29. Olsen T, Jeppesen P. Ray-tracing analysis of the corneal power from Scheimpflug data. J Refract Surg. 2018;34(1):45–50. https://doi.org/10.3928/1081597X-20171102-01. PMID: 29315441.
30. Langenbucher A, Szentmáry N, Weisensee J, Wendelstein J, Cayless A, Menapace R, Hoffmann P. Prediction model for best focus, power, and spherical aberration of the cornea: raytracing on a large dataset of OCT data. PLoS One. 2021;16(2):e0247048. https://doi.org/10.1371/journal.pone.0247048. PMID: 33617531; PMCID: PMC7899355.
31. Miyata K, Otani S, Honbou N, Minami K. Use of Scheimpflug corneal anterior-posterior imaging in ray-tracing intraocular lens power calculation. Acta Ophthalmol. 2013;91(7):e546–9. https://doi.org/10.1111/aos.12139. Epub 2013 Jul 26. PMID: 23890181.
32. Minami K, Kataoka Y, Matsunaga J, Ohtani S, Honbou M, Miyata K. Ray-tracing intraocular lens power calculation using anterior segment optical coherence tomography measurements. J Cataract Refract Surg. 2012;38(10):1758–63. https://doi.org/10.1016/j.jcrs.2012.05.035. Epub 2012 Aug 1. PMID: 22857986.
33. Ghoreyshi M, Khalilian A, Peyman M, Mohammadinia M, Peyman A. Comparison of OKULIX ray- tracing software with SRK-T and Hoffer-Q formula in intraocular lens power calcula-

tion. J Curr Ophthalmol. 2017;30(1):63–7. https://doi.org/10.1016/j.joco.2017.06.008. PMID: 29564411; PMCID: PMC5859630.
34. Savini G, Bedei A, Barboni P, Ducoli P, Hoffer KJ. Intraocular lens power calculation by ray-tracing after myopic excimer laser surgery. Am J Ophthalmol. 2014;157(1):150–153.e1. https://doi.org/10.1016/j.ajo.2013.08.006. Epub 2013 Oct 5. PMID: 24099275.
35. Olsen T, Funding M. Ray-tracing analysis of intraocular lens power in situ. J Cataract Refract Surg. 2012;38(4):641–7. https://doi.org/10.1016/j.jcrs.2011.10.035. Epub 2012 Feb 18. PMID: 22342009.
36. Schedin S, Hallberg P, Behndig A. Three-dimensional ray-tracing model for the study of advanced refractive errors in keratoconus. Appl Opt. 2016;55(3):507–14. https://doi.org/10.1364/AO.55.000507. PMID: 26835925.
37. Davison JA, Potvin R. Preoperative measurement vs intraoperative aberrometry for the selection of intraocular lens sphere power in normal eyes. Clin Ophthalmol. 2017;11:923–9. https://doi.org/10.2147/OPTH.S135659. PMID: 28553072; PMCID: PMC5440073.
38. Zhang Z, Thomas LW, Leu SY, Carter S, Garg S. Refractive outcomes of intraoperative wavefront aberrometry versus optical biometry alone for intraocular lens power calculation. Indian J Ophthalmol. 2017;65(9):813–7. https://doi.org/10.4103/ijo.IJO_163_17. PMID: 28905823; PMCID: PMC5621262.
39. Cionni RJ, Dimalanta R, Breen M, Hamilton C. A large retrospective database analysis comparing outcomes of intraoperative aberrometry with conventional preoperative planning. J Cataract Refract Surg. 2018;44(10):1230–5. https://doi.org/10.1016/j.jcrs.2018.07.016. Epub 2018 Aug 10. PMID: 30104081.
40. Sudhakar S, Hill DC, King TS, Scott IU, Mishra G, Ernst BB, Pantanelli SM. Intraoperative aberrometry versus preoperative biometry for intraocular lens power selection in short eyes. J Cataract Refract Surg. 2019;45(6):719–24. https://doi.org/10.1016/j.jcrs.2018.12.016. Epub 2019 Mar 8. PMID: 30853316.
41. Cionni RJ, Breen M, Hamilton C, Williams R. Retrospective analysis of an intraoperative aberrometry database: a study investigating absolute prediction in eyes implanted with low cylinder power toric intraocular lenses. Clin Ophthalmol. 2019;13:1485–92. https://doi.org/10.2147/OPTH.S191887. PMID: 31496639; PMCID: PMC6689545.
42. Raufi N, James C, Kuo A, Vann R. Intraoperative aberrometry vs modern preoperative formulas in predicting intraocular lens power. J Cataract Refract Surg. 2020;46(6):857–61. https://doi.org/10.1097/j.jcrs.0000000000000173. PMID: 32176162.
43. Canto AP, Chhadva P, Cabot F, Galor A, Yoo SH, Vaddavalli PK, Culbertson WW. Comparison of IOL power calculation methods and intraoperative wavefront aberrometer in eyes after refractive surgery. J Refract Surg. 2013;29(7):484–9. https://doi.org/10.3928/1081597X-20130617-07. PMID: 23820231.
44. Ianchulev T, Hoffer KJ, Yoo SH, Chang DF, Breen M, Padrick T, Tran DB. Intraoperative refractive biometry for predicting intraocular lens power calculation after prior myopic refractive surgery. Ophthalmology. 2014;121(1):56–60. https://doi.org/10.1016/j.ophtha.2013.08.041. Epub 2013 Oct 30. PMID: 24183339.
45. Fram NR, Masket S, Wang L. Comparison of intraoperative aberrometry, OCT-based IOL formula, Haigis-L, and Masket formulae for IOL power calculation after laser vision correction. Ophthalmology. 2015;122(6):1096–101. https://doi.org/10.1016/j.ophtha.2015.01.027. Epub 2015 Mar 10. PMID: 25766733.
46. Fisher B, Potvin R. Clinical outcomes with distance-dominant multifocal and monofocal intraocular lenses in post-LASIK cataract surgery planned using an intraoperative aberrometer. Clin Exp Ophthalmol. 2018;46(6):630–6. https://doi.org/10.1111/ceo.13153. Epub 2018 Feb 23. PMID: 29360197; PMCID: PMC6100005.
47. Werner L, Mamalis N, Stevens S, Hunter B, Chew JJ, Vargas LG. Interlenticular opacification: dual- optic versus piggyback intraocular lenses. J Cataract Refract Surg. 2006;32(4):655–61. https://doi.org/10.1016/j.jcrs.2006.01.022. PMID: 16698490.
48. Eissa SA. Management of pseudophakic myopic anisometropic amblyopia with piggyback Visian® implantable collamer lens. Acta Ophthalmol. 2017;95(2):188–93. https://doi.org/10.1111/aos.13203. Epub 2016 Sep 29. PMID: 27681455.

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