Etiology of Global Corneal Blindness and Current Practices of Corneal Transplantation: A Focused Review

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Purpose: The purpose of this focused review was to explore the etiologies of corneal blindness worldwide and compare them with the indications and type of keratoplasties (eg, full-thickness penetrating keratoplasty, anterior lamellar keratoplasty, or endothelial keratoplasty) performed.

Methods: A literature search of the articles published in the top 10 journals (based on the Altmetrics score) relevant to corneal transplantation within the past 20 years was performed to determine how the focus within corneal transplantation has changed over time. These data were compared with the prevalence and etiology of corneal blindness in each respective region worldwide.

Results: The leading etiologies of corneal blindness worldwide are primarily due to anterior corneal pathology with a normal endothelium, and the prevalence is highest in developing countries. In addition, the number and type of corneal transplantations performed globally indicate that current practices are disproportionately skewed in favor of endothelial keratoplasty, which is targeted for the pathology prevalent in developed countries. Despite the large number of individuals who would benefit from anterior lamellar keratoplasty, this technique seems to be infrequently performed.

Conclusions: Most corneal blindness worldwide is secondary to anterior corneal pathology because of infections and trauma. However, this does not align with the current trends and practices in the field of corneal transplantation. We discuss potential solutions to address the current leading causes of global corneal blindness, including increasing the number of anterior lamellar keratoplasties performed, using long-term preserved corneas by trained surgeons, and improving eye bank handling and distribution of procured tissues.

Key Words: corneal transplantation, corneal blindness, endothelial transplantation, deep anterior lamellar keratoplasty, gamma-irradiated sterile cornea

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Worldwide, approximately 216.6 million individuals are visually impaired, and 4.5 million have moderate to severe vision impairment secondary to loss of corneal clarity.[1] Corneal disease is the fifth leading cause of blindness in the world, following cataract, refractive error, glaucoma, and age-related macular degeneration.[1] Because corneal disease primarily affects a younger population, the disability-adjusted life years compared with, for example, cataract-related blindness, are much greater.[2] Despite advances in the field of corneal transplantation, only 1 in 70 individuals with treatable corneal blindness ultimately undergoes surgery because of a multitude of region-specific social, economic, and political factors.[3,4]

Most of those with corneal blindness (98%) live outside developed countries and are, on average, significantly younger than other individuals with blindness due to macular degeneration, cataracts, glaucoma, or similar conditions.[2] Although the greatest burden of corneal blindness is in the developing world, most corneal transplants are performed in developed countries.[3] Therefore, the leading etiologies of corneal blindness globally are not equivalent to the most common indications for corneal transplantation, which reflects the pathology of more developed countries.[5]

In this article, we performed a search of published studies relevant to corneal transplantation to 1) determine the leading indications for corneal transplantation in different regions of the world, 2) examine the number and type of keratoplasties performed, and 3) explore potential intermediate and long-term solutions to improve access to corneal transplantation in the global health setting.

METHODS

We reviewed the studies published in the top 10 international journals relevant to the field of corneal transplantation to understand trends in keratoplasty research. First, all journals related to ophthalmology were ranked by the Altmetrics score, impact factor, and number of citations, which are typically complementary metrics. The Altmetrics score is a measure of the degree of attention an article has received from news sources, blogs, and social media.[6] Using

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this metric, the top 10 journals known to include clinical studies of patients with corneal disease were selected.

A methodologist (K.L.) with expertise in conducting systematic reviews performed a comprehensive PubMed search (conducted on August 4, 2017) with the following keywords: ((keratoplasty, penetrating[MeSH Terms]) OR (keratoplast*.ti) NOT ((“Animals”[Mesh]) NOT (“Humans”[Mesh] AND “Animals”[Mesh])). The search was then further narrowed to articles published between 1995 and 2017, which yielded 2227 records. All publications were then individually reviewed by 1 author (P.M.M.) to be classified as follows: 1) penetrating keratoplasty (PK), 2) anterior lamellar keratoplasty (ALK) and deep anterior lamellar keratoplasty (DALK), 3) endothelial keratoplasty (EK) (which includes Descemet membrane endothelial keratoplasty, Descemet stripping automated endothelial keratopathy, Descemet lamellar endothelial keratoplasty), 4) PK versus ALK, 5) PK versus EK, 6) review articles, and 7) nonrelated articles (eg, basic science, author replies, and artificial corneal transplantation). Other relevant information such as the year of publication and country of origin were extracted as well. The country of origin was defined as the location of the study subjects included in the article, which occasionally differed from the country of the authors of the article.

RESULTS

Table 1 displays the number of clinical studies relevant to corneal transplantation published by each of the selected journals during the specified period, as yielded by the literature search as detailed above. Table 2 shows the overall number of articles according to the type of corneal transplantation, excluding review, basic science, and other non–clinical-related studies. More than 75% of articles were related to PK and EK surgery. Figure 1 shows distribution of publications by the type of surgery over the past 2 decades. In 2008, the number of publications relevant to EK surpassed the number of articles focused on PKs, and this trend persisted in the subsequent 10 years.

TABLE 1. Clinical Studies Relevant to Corneal Transplantation Published by 10 Ophthalmology Journals Between January 1995 and July 2017*

Journal	No. of Studies
Acta Ophthalmologica	66
American Journal of Ophthalmology	301
British Journal of Ophthalmology	190
Clinical & Experimental Ophthalmology	40
Cornea	989
Eye (London)	89
Graefe's Archive for Clinical and Experimental Ophthalmology	91
Indian Journal of Ophthalmology	56
JAMA Ophthalmology (formerly Archives of Ophthalmology)	124
Ophthalmology	281
Total	2227

*Listed in alphabetical order.

TABLE 2. Total Number of Publications Between January 1995 and July 2017 Pertaining to Corneal Transplantation, Classified by the Type of Surgery*

Type of Corneal Transplantation	No. of Studies (%)
PK	737 (41.1)
ALK/DALK	286 (15.9)
EK	686 (38.2)
PK versus ALK/DALK	50 (2.8)
PK versus EK	35 (2.0)
Total	1794

*Total number of articles pertaining to a specific type of surgery, excluding review articles, basic science, author replies, etc.

Figure 2 shows the trend in corneal transplantation surgery in North America and a few select international eye banks according to the annual Eye Bank Association of America (EBAA) report.[7] In 2011, the number of PKs and EKs performed were approximately equal; however, since 2011, the most frequently performed corneal transplantation is EK.[7] The annual number of ALKs has shown minimal growth over the past 2 decades.

Last, Figure 3 is a world map showing distribution of corneal blindness in different world regions, with a corresponding percentage indicating the proportion of publications (based on our literature search) from this region. Africa and East Asia cumulatively represent close to 50% of corneal blindness worldwide; however, fewer than 5% of publications over the past 2 decades are from these areas. By contrast, North America accounts for approximately 1.5% of worldwide corneal blindness, but one-third of publications originate from North America alone.

DISCUSSION

The objective of this focused review article was to compare distribution of corneal blindness of different areas around the world with the corresponding leading etiologies of corneal disease, primary type of corneal transplantation performed, and trends in research publications from or about each region. In the following paragraphs, we discuss these topics in the context of the literature search.

Indications for Corneal Transplantation Based on the Region

The leading indications for corneal transplantation in a given region are based on a multitude of variables and may not reflect the most common etiologies of corneal disease. Access of patients with corneal pathology to transplantation is based on political, social, geographic, and economic factors, etiology of the corneal disease and prognosis of the graft after surgery, age, and physical fitness of the patient, and the presence of other comorbid ocular and medical factors. Therefore, the top indications for corneal transplantation

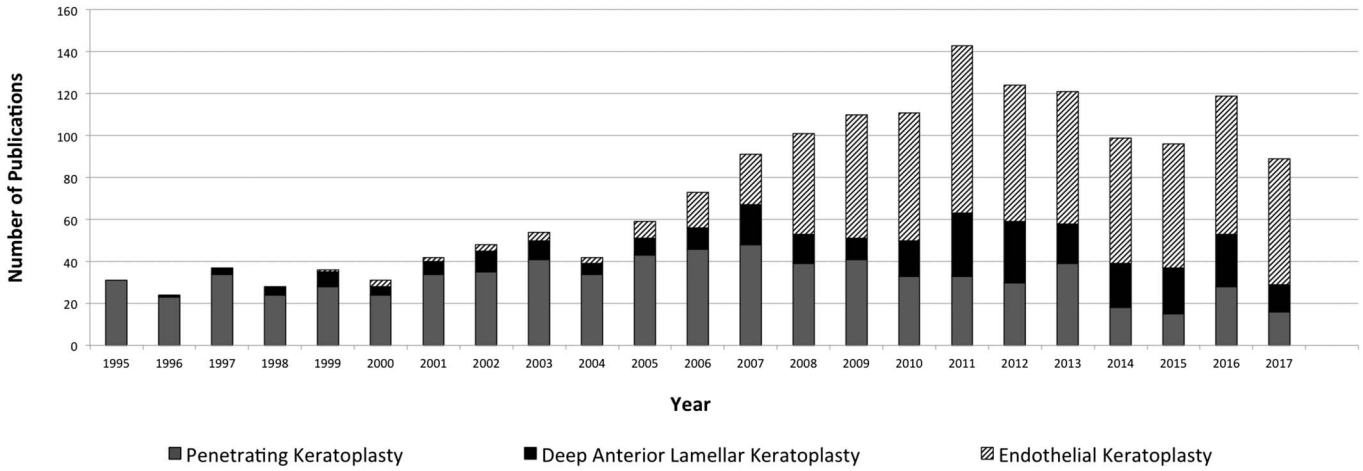

FIGURE 1. Number of clinical studies published in 10 selected journals between 1995 and 2017 related to the outcomes of patients undergoing corneal transplantation. Publications range from January to December for all years between 1995 and 2016, and January to July 2017.

may not be aligned with the leading etiologies of corneal blindness in a given country. For example, although infectious keratitis with associated ocular surface disease is the top cause of corneal blindness in certain regions of Africa,[4] keratoconus is the most common indication for corneal transplantation in Africa,[3] likely influenced by the prognosis after surgery. Furthermore, the most common indications for transplantation in certain areas, such as the United States, may reflect the leading etiologies of "visual impairment" due to corneal disease rather than actual "corneal blindness". Nonetheless, at this time, the leading etiologies of corneal transplantation may be the most reliable and standardized surrogate of corneal blindness in a country, especially in developing countries that may not have other methods of data collection.

According to the 2016 EBAA Statistical Report, the most common indication for any corneal transplantation using domestically distributed intermediate-term preserved corneas in the United States is endothelial cell failure secondary to Fuchs endothelial dystrophy or cataract surgery (eg, pseudophakic bullous keratopathy [PBK]).[8] Of note, it is also likely that a significant proportion of PBK patients have previously undiagnosed Fuchs endothelial dystrophy.[9] The 4 most common indications for all corneal transplantations in 2016 were 1) Fuchs endothelial dystrophy (17,016 individuals), 2) PBK (8287 individuals), 3) repeat corneal transplantation (7389 individuals), and 4) keratoconus (6195 individuals).[8]

The most common indications for corneal transplantation outside the United States are keratoconus and keratitis (encompassing both infectious and noninfectious).[5,10] More specifically, keratoconus is the leading indication for corneal transplantation in Europe, Australia, Middle East, Africa, and South America as opposed to keratitis in Asia.[5] Although patients with mild or moderate keratoconus can be rehabilitated with spectacles and/or contact lenses, a majority of the

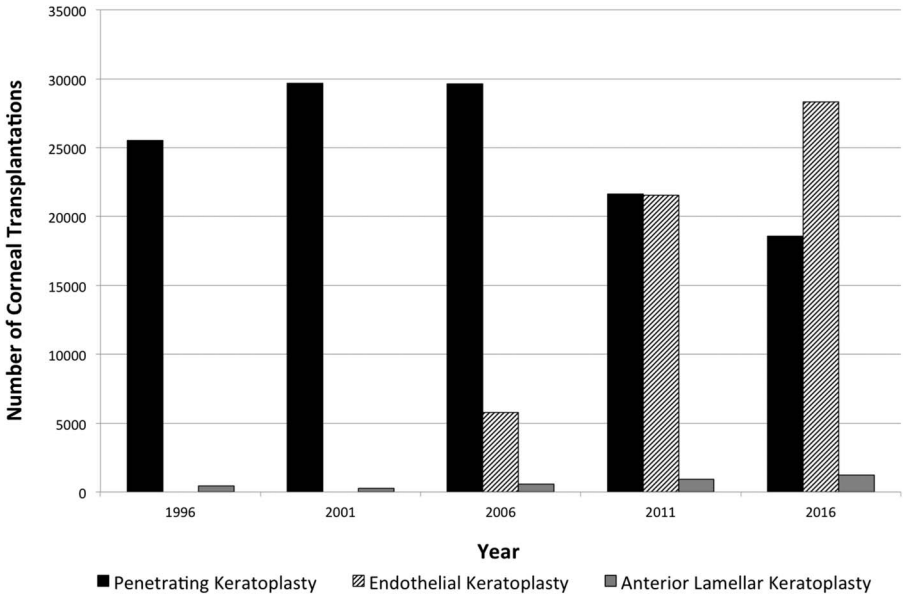

FIGURE 2. Number of corneal transplantations performed in the United States from 1996 to 2016. All numbers obtained from the EBAA Annual Statistical Reports.

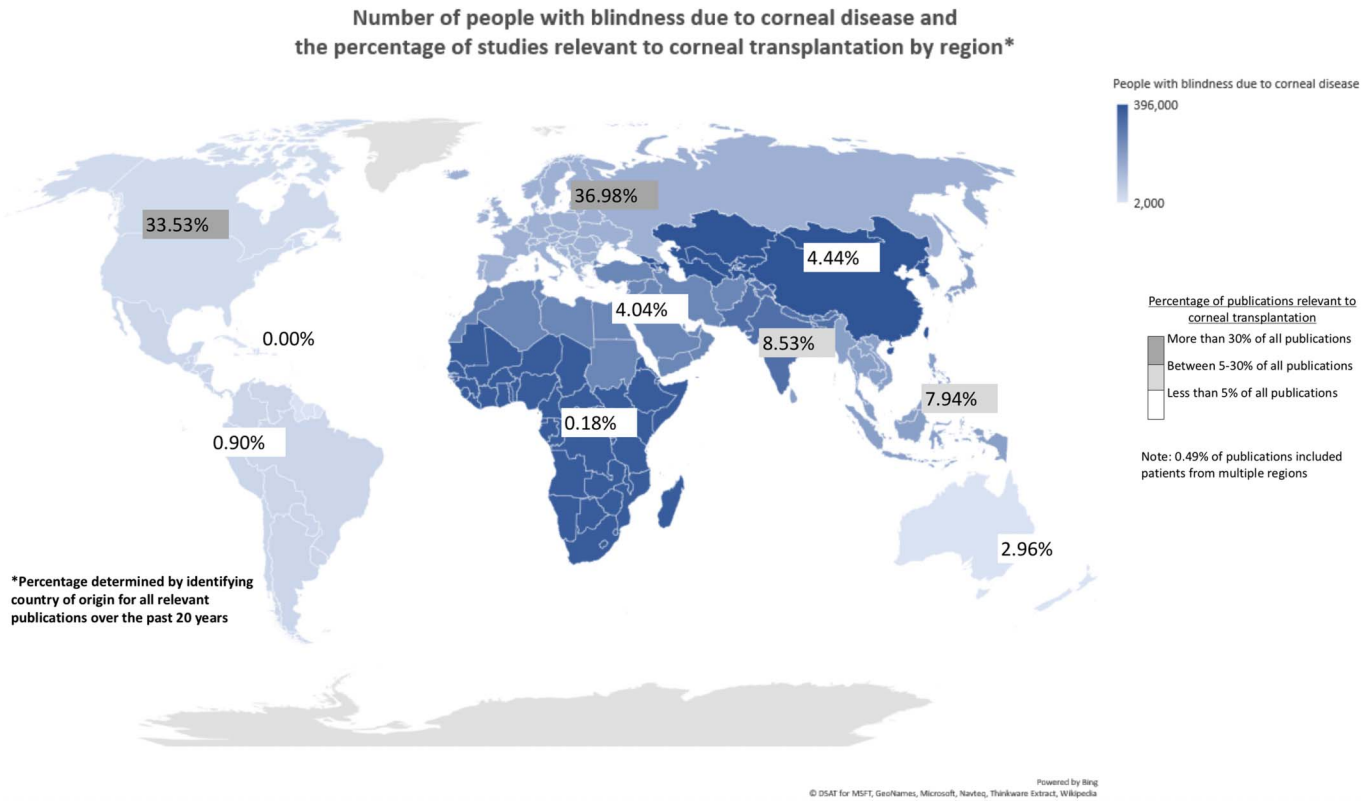

FIGURE 3. Number of individuals with blindness secondary to corneal disease versus percentage of studies relevant to corneal transplantation by region. Number of individuals with corneal blindness based on the study by Flaxman et al.[1] Percentage of studies calculated by identifying the country of origin for all publications published in 10 internationally distributed journals, as specified in the Methods section. Reproduced with permission from Microsoft Bing Maps. This is an independent figure and is neither affiliated with, nor authorized, sponsored, or approved by, Microsoft Corporation.

world may not have access to these visual aids.[11] Contact lenses fail to improve vision in patients with advanced keratoconus. In addition, there are environmental factors that decrease the feasibility and advisability of contact lens wear in certain geographies.[11–13] A survey of patients in Ghana, for instance, showed that only 3.3% of patients with spectacles have access to contact lenses.[14]

Keratitis is the second leading indication for corneal transplantation as a whole outside the United States.[5,10] Trachoma remains the leading infectious cause of blindness and accounts for a majority of keratitis cases worldwide that result in significant conjunctival and corneal opacification and scarring.[15,16] Corneal opacification is also the leading cause of blindness among children in Africa.[17] The incidence of childhood cornea-related visual loss due to infection and trauma in some areas of Africa and Asia is up to 20 times higher than that in developed countries.[4] A recent review of patients undergoing corneal transplantation in Ethiopia revealed that leukoma and trachoma together represented more than half of the patients who underwent PK.[11] Last, other etiologies such as traditional eye drop therapy also have contributed to cases of irreversible corneal damage. In Tanzania, 25% of corneal ulcers were associated with traditional eye medicine use.[18]

In comparison with the United States, indications for surgery such as Fuchs endothelial dystrophy are rarely reported in Asia and Africa.[5] Two large studies examining the indications for thousands of corneal transplants performed in both Northern and Southern India found that only approximately 1% of the corneal transplants were performed for Fuchs dystrophy.[19,20] Similarly, only 0.6-2.2% of corneal transplantations in Saudi Arabia are performed for this condition.[21,22] The etiology of corneal blindness is highly dependent on the geographical location, with most patients in the developing world having anterior corneal pathologies as opposed to the overwhelming prevalence of endothelial disease reported in the US literature.

Type of Corneal Transplantation Based on the Region

The United States has the highest rate of transplants per capita.[3] According to 2016 EBAA statistics, EK comprised 57% of corneal transplantations in the United States, followed by PK (38% of transplants).[8] The technique of EK was first introduced in 1999, and since that time, there has been an active and growing interest in EK.[23,24] This trend corresponds to the exponential increase in publications relating to EK compared with PK or ALK/DALK since 2008, as shown in Figure 1. This rapid rise differs from relatively weak expansion of ALK/DALK surgery, which was first introduced in 1959 and has not grown in popularity since that time

(Figure 2).[25] However, this pattern is consistent with the 2 leading indications for corneal transplantation in the United States in 2016: 1) Fuchs dystrophy (15,845 transplants) and 2) PBK (5558 transplants).[8] Although PK was previously the surgery of choice for any corneal disease, most of those patients with endothelial disease are now undergoing EK in the United States (83.1% of individuals with endothelial cell failure had EK in 2016).[8] Keratoconus was the third leading indication for corneal transplantation in the United States, with a majority undergoing PK (88.2%).[8]

The proportion of endothelial and anterior lamellar keratoplasties relative to PK is much lower outside the United States. Overall, approximately 90% of all corneal transplantation surgeries performed in 95 reporting countries are PK, regardless of surgical indication.[3] In fact, approximately one-third of countries reported no lamellar keratoplasties of any kind.[3] The current distribution of corneal transplantations performed is likely biased by the high number of surgeries performed in the United States and other developed regions that have preferential access and availability of corneal tissue.[3]

DALK: Indications, Outcomes, and Advantages

Currently, only a small fraction (8.5%) of those with anterior corneal disease (including keratoconus and other stromal opacities) in the United States receive ALK/DALK, with more than 90% of this population still receiving full-thickness PK despite having a functioning endothelium.[8] There is no clear consensus regarding visual acuity outcomes in DALK versus PK, with some studies showing that DALK results in better uncorrected visual acuity,[26,27] others indicating PK has superior outcomes,[28] and few reporting no difference between the 2.[29–32]

DALK has several advantages over PK that are under-recognized and underappreciated. When performed by a well-trained surgeon, DALK is shown to be successful and safe in patients with keratoconus or anterior corneal opacities, with lower rates of endothelial cell loss, higher rates of graft survival, and fewer intraocular complications compared with PK.[28,33–36] Patients undergoing DALK report better quality of life as well.[36] Despite these advantages, there are no countries that use DALK as the mainstay of treatment for patients eligible for this surgical technique, including the United States.

Another argument for the increased use of ALK/DALK is the efficient and cost-effective utilization of the harvested tissues. According to the most recent EBAA statistical report, close to one-fourth of corneal tissue was discarded in 2016 because of defects in Descemet membrane or the endothelium,[8] which potentially could have been used in patients with anterior pathology. In addition, the anterior cap of the donor graft prepared for the EK procedure is also discarded by many eye banks, although it might be perfectly suitable to use this tissue for ALK/DALK.

Future Initiatives to Expand Corneal Transplantation

One significant obstacle to increasing the number of ALK/DALKs performed is a lack of properly trained ophthalmic surgeons. Although most corneal surgeons in developing countries can perform PK, only a small number have had the opportunity to learn and/or practice lamellar keratoplasty, particularly ALK/DALK. Perhaps eye banks could allocate a portion of resources to design skill transfer courses for anterior lamellar procedures in various regions around the world, which would facilitate propagation of appropriate surgical techniques and improve communication and information sharing among surgeons in various world regions.

In addition, exploring further preservation techniques such as gamma irradiation may help increase the use of these tissues with transparent stroma.[14,37–41] Gamma irradiation sterilizes the tissue without affecting the biomechanics, resulting in a long shelf life at room temperature (up to 2 years), less risk of allograft rejection, and, essentially, no eye banking requirements for utilization.[42–44] These advantages are especially relevant in less-developed countries because close to one-third of patients in developing countries have evidence of infectious keratitis after full-thickness corneal transplantation.[11,38] Other methods for preserving corneas may include hypothermia (7–12 days), organ culture (4 weeks), preservation in glycerin, and cryopreservation (potentially unlimited time).[45] Some researchers have suggested using biosynthetic corneal substitutes in patients who require corneal transplantation.[46]

Obviously, a close collaboration among government leaders, ophthalmologists, and public health officials is critical to address corneal blindness. Even if a hospital is able to offer corneal transplantation by an experienced surgeon, there are many logistical and financial barriers preventing the patient from undergoing surgery or having a successful outcome.[12,13] For example, a study of patients undergoing corneal transplantation in Nepal showed that the strongest predictor of graft clarity was the distance that the patient lived from a tertiary hospital.[45] Another study demonstrated that a more extensive transportation process (eg, by air) of donor corneas was correlated with significantly worse outcomes compared with locally retrieved corneas.[30]

Last, there is currently no comprehensive organization, database, or registry that collects and reviews information about corneal transplantation worldwide. Many countries attempt to compile their transplantation rates for certain organs or tissues (eg, kidney, liver, or bone marrow); however, this information relies on the contribution of experts in the field and may be incomplete and/or underestimated.[47] Statistics from the EBAA reflect the pathology and indications for transplantation of 83 North American and 14 international eye banks, which is only a small fraction of the world's population of those with corneal blindness.[7] Perhaps an international registry of cornea donations and transplantations led by professional societies could be established to unite experts around the world to collaborate and efficiently distribute tissue according to areas of greatest need.

SUMMARY

Over the past few decades, significant strides have been made to address global corneal blindness. These include implementation of preventive and ameliorative treatments for trachoma, vitamin A supplementation, and improved nutrition

and public sanitation, which have made a significant impact.[2] Although corneal blindness worldwide is largely due to anterior corneal pathology, distribution of surgery and techniques used are not reflective. The areas with the greatest need for corneal transplantation also have the fewest resources available for proper execution, such as eye banks, appropriate surgical facilities, and trained surgeons.[2,48] The burden of corneal blindness continues to plague the developing world, and it is time to undertake new and innovative global initiatives to expand current techniques and knowledge to impact those regions most in need.

REFERENCES

1. Flaxman SR, Bourne RRA, Resnikoff S, et al. Global causes of blindness and distance vision impairment 1990-2020: a systematic review and meta-analysis. *Lancet Glob Health.* 2017;5:e1221–e1234.
2. Oliva MS, Schottman T, Gulati M. Turning the tide of corneal blindness. *Indian J Ophthalmol.* 2012;60:423–427.
3. Gain P, Jullienne R, He Z, et al. Global survey of corneal transplantation and eye banking. *JAMA Ophthalmol.* 2016;134:167–173.
4. Whitcher JP, Srinivasan M, Upadhyay MP. Corneal blindness: a global perspective. *Bull World Health Organ.* 2001;79:214–221.
5. Matthaei M, Sandhaeger H, Hermel M, et al. Changing indications in penetrating keratoplasty: a systematic review of 34 years of global reporting. *Transplantation.* 2017;101:1387–1399.
6. Trueger NS, Thoma B, Hsu CH, et al. The altmetric score: a new measure for article-level dissemination and impact. *Ann Emerg Med.* 2015;66: 549–553.
7. *About the Eye Bank Association of America*. 2017. Available at: http://restoresight.org/eye-bank-association-america/. Accessed August 22, 2017.
8. Eye Bank Association of America. *2016 Eye Banking Statistical Report*. Washington DC: Eye Bank Association of America; 2017.
9. Afshari NA, Pittard AB, Siddiqui A, et al. Clinical study of Fuchs corneal endothelial dystrophy leading to penetrating keratoplasty: a 30-year experience. *Arch Ophthalmol.* 2006;124:777–780.
10. Garg P, Krishna PV, Stratis AK, et al. The value of corneal transplantation in reducing blindness. *Eye (Lond).* 2005;19:1106–1114.
11. Ayalew M, Tilahun Y, Holsclaw D, et al. Penetrating keratoplasty at a tertiary referral center in Ethiopia: indications and outcomes. *Cornea.* 2017;36:665–668.
12. Tilahun Y, Shimelash D. The outcome of corneal transplantation versus indications in a tertiary eye care center in Ethiopia. *Ethiop Med J.* 2010; 48:35–39.
13. Yorston D, Wood M, Foster A. Penetrating keratoplasty in Africa: graft survival and visual outcome. *Br J Ophthalmol.* 1996;80:890–894.
14. Abokyi S, Manuh G, Otchere H, et al. Knowledge, usage and barriers associated with contact lens wear in Ghana. *Cont Lens Anterior Eye.* 2017;40:329–334..
15. Lansingh VC. Trachoma. *BMJ Clin Evid.* 2016;2016:706.
16. Gambhir M, Grassly NC, Burton MJ, et al. Estimating the future impact of a multi-pronged intervention strategy on ocular disease sequelae caused by trachoma: a modeling study. *Ophthalmic Epidemiol.* 2015;22: 394–402.
17. Kong L, Fry M, Al-Samarraie M, et al. An update on progress and the changing epidemiology of causes of childhood blindness worldwide. *J AAPOS.* 2012;16:501–507.
18. Yorston D, Foster A. Traditional eye medicines and corneal ulceration in Tanzania. *J Trop Med Hyg.* 1994;97:211–214.
19. Dandona L, Ragu K, Janarthanan M, et al. Indications for penetrating keratoplasty in India. *Indian J Ophthalmol.* 1997;45:163–168.
20. Sony P, Sharma N, Sen S, et al. Indications of penetrating keratoplasty in Northern India. *Cornea.* 2005;24:989–991.
21. al Faran MF, Tabbara KF. Corneal dystrophies among patients undergoing keratoplasty in Saudi Arabia. *Cornea.* 1991;10:13–16.
22. Al-Towerki AE, Gonnah el S, Al-Rajhi A, et al. Changing indications for corneal transplantation at the king khaled eye specialist hospital (1983-2002). *Cornea.* 2004;23:584–588.
23. Melles GR, Lander F, Beekhuis WH, et al. Posterior lamellar keratoplasty for a case of pseudophakic bullous keratopathy. *Am J Ophthalmol.* 1999;127:340–341.
24. Terry MA, Ousley PJ. Endothelial replacement without surface corneal incisions or sutures: topography of the deep lamellar endothelial keratoplasty procedure. *Cornea.* 2001;20:14–18.
25. Hallermann W. Some remarks on keratoplasty. *Klin Monbl Augenheilkd Augenarztl Fortbild.* 1959;135:252–259.
26. Yuksel B, Kandemir B, Uzunel UD, et al. Comparison of visual and topographic outcomes of deep-anterior lamellar keratoplasty and penetrating keratoplasty in keratoconus. *Int J Ophthalmol.* 2017;10:385–390.
27. Patel AK, Nayak H, Kumar V. Comparative evaluation of big-bubble deep anterior lamellar keratoplasty and penetrating keratoplasty in a case of macular corneal dystrophy. *Cornea.* 2009;28:583–585.
28. Chen G, Tzekov R, Li W, et al. Deep anterior lamellar keratoplasty versus penetrating keratoplasty: a meta-analysis of randomized controlled trials. *Cornea.* 2016;35:169–174.
29. Reddy JC, Murthy SI, Vaddavalli PK, et al. Clinical outcomes and risk factors for graft failure after deep anterior lamellar keratoplasty and penetrating keratoplasty for macular corneal dystrophy. *Cornea.* 2015; 34:171–176.
30. Keane MC, Lowe MT, Coster DJ, et al. The influence of Australian eye banking practices on corneal graft survival. *Med J Aust.* 2013;199:275–279.
31. Sogutlu Sari E, Kubaloglu A, Unal M, et al. Deep anterior lamellar keratoplasty versus penetrating keratoplasty for macular corneal dystrophy: a randomized trial. *Am J Ophthalmol.* 2013;156:267–274.e1.
32. Kim MH, Chung TY, Chung ES. A retrospective contralateral study comparing deep anterior lamellar keratoplasty with penetrating keratoplasty. *Cornea.* 2013;32:385–389.
33. Reinhard T, Larkin DFP. *Cornea and External Eye Disease*. Berlin, NY: Springer; 2006.
34. Shimazaki J, Shimmura S, Ishioka M, et al. Randomized clinical trial of deep lamellar keratoplasty vs penetrating keratoplasty. *Am J Ophthalmol.* 2002;134:159–165.
35. Han DC, Mehta JS, Por YM, et al. Comparison of outcomes of lamellar keratoplasty and penetrating keratoplasty in keratoconus. *Am J Ophthalmol.* 2009;148:744–751.e1.
36. van den Biggelaar FJ, Cheng YY, Nuijts RM, et al. Economic evaluation of deep anterior lamellar keratoplasty versus penetrating keratoplasty in The Netherlands. *Am J Ophthalmol.* 2011;151:449–459.e2.
37. Akpek EK, Aldave AJ, Aquavella JV. The use of precut, gamma-irradiated corneal lenticules in Boston type 1 keratoprosthesis implantation. *Am J Ophthalmol.* 2012;154:495–498.e1.
38. Calhoun WR, Akpek EK, Weiblinger R, et al. Evaluation of broadband spectral transmission characteristics of fresh and gamma-irradiated corneal tissues. *Cornea.* 2015;34:228–234.
39. Daoud YJ, Smith R, Smith T, et al. The intraoperative impression and postoperative outcomes of gamma-irradiated corneas in corneal and glaucoma patch surgery. *Cornea.* 2011;30:1387–1391.
40. Ekici F, Moster MR, Cvintal V, et al. Tube shunt coverage with gamma-irradiated cornea allograft (VisionGraft). *Clin Ophthalmol.* 2015;9:751–755.
41. Sharma N, Agarwal P, Titiyal JS, et al. Optimal use of donor corneal tissue: one cornea for two recipients. *Cornea.* 2011;30:1140–1144.
42. Bourne RRA, Flaxman SR, Braithwaite T, et al. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *Lancet Glob Health.* 2017;5:e888–e897.
43. Stevenson W, Cheng SF, Emami-Naeini P, et al. Gamma-irradiation reduces the allogenicity of donor corneas. *Invest Ophthalmol Vis Sci.* 2012;53:7151–7158.
44. Chae JJ, Choi JS, Lee JD, et al. Physical and biological characterization of the gamma-irradiated human cornea. *Cornea.* 2015;34:1287–1294.
45. Tabin GC, Gurung R, Paudyal G, et al. Penetrating keratoplasty in Nepal. *Cornea.* 2004;23:589–596.
46. Eghrari AO, Gottsch JD. Fuchs' corneal dystrophy. *Expert Rev Ophthalmol.* 2010;5:147–159.
47. *IRODaT Main Guidelines*. Available at: http://www.irodat.org/?p=about. Accessed September 10, 2017.
48. Smith GT, Taylor HR. Epidemiology of corneal blindness in developing countries. *Refract Corneal Surg.* 1991;7:436–439.