

Trends in Corneal Transplantation from 2001 to 2016 in Germany: A Report of the DOG–Section Cornea and its Keratoplasty Registry



ELIAS FLOCKERZI, PHILIP MAIER, DANIEL BÖHRINGER, HELGA REINSHAGEN, FRIEDRICH KRUSE, CLAUD CURSIEFEN, THOMAS REINHARD, GERD GEERLING, NECIP TORUN, AND BERTHOLD SEITZ, ON BEHALF OF ALL GERMAN KERATOPLASTY REGISTRY CONTRIBUTORS

- **PURPOSE:** The purpose of this retrospective panel study was to provide an overview of absolute numbers and of trends in the types of and indications for corneal transplantation in Germany from 2001 to 2016.
- **METHODS:** A questionnaire about absolute numbers, types of transplantation, and indications was sent to 111 ophthalmologic departments in Germany, out of which 94 (85%) provided their data.
- **RESULTS:** Since the year 2001, the number of corneal transplantations has increased by 1.5-fold, from 4730 penetrating keratoplasties (PKPs) in 2001 to 7325 penetrating and lamellar keratoplasties in 2016. The shift from penetrating to lamellar procedures began in 2006. In 2014, lamellar procedures (231 [4%] anterior and 2883 [49%] posterior lamellar keratoplasties) surpassed PKPs (2721, 47%) for the first time. Main indications for keratoplasty in Germany (2016) are Fuchs endothelial corneal dystrophy (46%), pseudophakic corneal decompensation (bullous keratopathy, 13%), repeated keratoplasty after graft failure (11%), keratoconus (8%), and corneal scarring (6%; others: 16%). The number of Descemet membrane endothelial keratoplasties (DMEKs) was 12 times higher (3850, 53%) than Descemet stripping automated endothelial keratoplasties (DSAEKs, 319, 4.4%) in 2016. The proportion of deep anterior lamellar keratoplasties (DALKs) never exceeded 6% (269 in 2011).
- **CONCLUSIONS:** The number of keratoplasties in Germany has increased from 2001 to 2016. Since

2014, posterior lamellar keratoplasties have surpassed PKPs. There was a constant increase of DMEKs, with a 12-fold higher number compared to DSAEKs in 2016. The shorter recovery time after DMEK seems to contribute to the trend toward earlier operative intervention in corneal endothelial diseases. (Am J Ophthalmol 2018;188:91–98. © 2018 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)).

PENETRATING KERATOPLASTY (PKP) IS ONE OF THE oldest, the most commonly performed, and the most successful transplantation in humans.¹ The first successful corneal transplantation was performed by Eduard Zirm in Olmütz (today Olomouc, Czech Republic) in 1905.² The penetrating procedure remained the gold standard in the cure of corneal diseases for much of the 20th century. The process of developing further corneal transplantation techniques already began in the middle of the 20th century, when Tillett described the concept of a posterior lamellar keratoplasty in 1956.³ This pioneering concept was not adopted at that time because it was associated with poor vision¹ in comparison with the penetrating procedure. At the end of the 20th century, in 1998, Melles and associates revitalized not only the concept of a posterior lamellar keratoplasty by presenting the successful attachment of a posterior lamellar graft consisting of stroma, Descemet membrane, and endothelium to recipient stroma without suturing^{4,5} but also the concept of deep anterior lamellar keratoplasty (DALK), which initiated the new era of increasingly implementing lamellar techniques in day-to-day practice. The concept of Descemet membrane endothelial keratoplasty (DMEK) was also published by Melles and associates in 2006.⁵

The aim of this manuscript is to reflect on the changing trends in absolute numbers, surgical techniques, and indications of corneal transplantations having been performed over a period of 16 years in Germany between 2001 and 2016, as evidenced by data from the German Keratoplasty Registry from the Cornea Section of the German Ophthalmological Society (DOG).

AJO.com

Supplemental Material available at AJO.com.

Accepted for publication Jan 16, 2018.

From the Department of Ophthalmology, Saarland University Medical Center, Homburg, Germany (E.F., B.S.); Eye Center, Albert-Ludwigs-University of Freiburg, Freiburg, Germany (P.M., D.B., T.R.); Admedico Eye Center, Olten, Switzerland (H.R.); Department of Ophthalmology and Eye Hospital, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany (F.K.); Department of Ophthalmology, University of Cologne, Cologne, Germany (C.C.); Department of Ophthalmology, Heinrich-Heine University, Düsseldorf, Germany (G.G.); and Department of Ophthalmology, Charité University of Medicine, Berlin, Germany (N.T.).

Inquiries to Elias Flockerzi, Department of Ophthalmology, Saarland University Medical Center, 66421 Homburg, Germany; e-mail: elias.flockerzi@uks.eu

METHODS

THE CORNEA SECTION OF THE GERMAN OPHTHALMOLOGICAL Society (<http://www.dog.org>) was founded in 2001 and annually collects and analyzes data about keratoplasties performed in Germany with the aim of providing an overview of indications and trends in the different types of nationwide performed corneal transplantations. Thereby, the German Keratoplasty Registry is a retrospective panel study including all German patients treated with corneal transplantation from 2001 to 2016. The local ethics committee of Saarland (Ethikkommission bei der Ärztekammer des Saarlandes) was informed. Because the study does not contain individual-related data, no ethical approval is required according to the ethics committee of Saarland. The study was registered at the public database ClinicalTrials.gov, maintained by the U.S. National Institutes of Health (NCT03381794), and follows the principles of the Declaration of Helsinki. A questionnaire about absolute numbers, types of transplantation, and indications (Supplemental Material available at <http://www.ajo.com>) was sent to the 111 ophthalmologic departments in Germany performing corneal transplantation, out of which 94 (85%) responded and provided their data. Among them were 34 (87%) of the 39 contacted chairmen of German university departments (VOL, Vereinigung Ophthalmologischer Lehrstuhlinhaber) and 60 (83%) of the 72 contacted non-university-based corneal transplant surgeons in Germany.

RESULTS

THE NUMBER OF REPORTED KERATOPLASTIES IN GERMANY increased from 4730 in 2001 to 7325 in 2016 by a factor of 1.5 (Figure 1).

Data about lamellar corneal transplantations distinguishing between anterior (DALK) and posterior lamellar transplantations (DMEK) and Descemet stripping automated endothelial keratoplasty (DSAEK) have been collected from 2006 onward. When comparing the data of PKPs and the data of these 3 types of lamellar corneal transplantations, different trends emerged in the last few years.

First, the proportion of PKPs decreased with the introduction of lamellar procedures, from 3515 (96%) in 2006 to 2944 (40.1%) in 2016 (Figures 2 and 3).

Second, there was an initial increasing trend of DALKs, from 93 (2.6%) in 2006 to a peak of 269 (6%) in 2011 (Figures 2 and 3). From 2011 on, the figures for DALKs have begun to decline again, to 231 in 2013 (4.4%) and 212 (2.9%) in 2016 (Figures 2 and 3).

Third, lamellar posterior transplantations have been increasing by a factor of 83, from 50 (1.4%) in 2006 to 4169 (57%) in 2016 (Figures 2 and 3).

From 2013 on, the increase of overall keratoplasties results from an increasing number of posterior lamellar keratoplasties. This trend is especially seen in the 3 most active corneal transplantation centers in Germany (Figure 4).

The trend toward lamellar posterior corneal transplantation reached an interim peak in 2014, when lamellar posterior transplantations surpassed penetrating transplantations for the first time in Germany (Figures 2 and 3). From 2009 onward, a further differentiation concerning lamellar posterior transplantations has been made between DMEK, transplanting just the endothelium and the Descemet membrane, and DSAEK, transplanting the endothelium, the Descemet membrane, and a part of the stroma of varying thickness. This analysis revealed that in Germany, the number of performed DSAEKs decreased to 319 (4.4%) in 2016, whereas the numbers of performed DMEKs dramatically increased to 3850 (53%) in 2016 (Figure 5).

The number of patients on waiting lists also increased during the last few years, but stayed stable since 2014, which apparently reflects a concomitant effect of the trend toward earlier operative intervention in corneal endothelial diseases with emerging DMEK techniques (Figure 6).

Main reported indications for either penetrating or lamellar corneal transplantation in Germany are, in decreasing numbers of frequencies, Fuchs endothelial corneal dystrophy (FECD), corneal decompensation, repeated keratoplasty after graft failure, keratoconus, and corneal scarring (Figure 7). Sometimes, repeated keratoplasties are human leukocyte antigen (HLA)-typed and the proportion of HLA-typed keratoplasties decreased in the last few years, from 334 (6.4%) in 2013 to 241 (3.3%) in 2016.

DISCUSSION

THIS REPRESENTATIVE RETROSPECTIVE PANEL STUDY provides an overview of absolute numbers of corneal transplantations in Germany, as well as trends in the various types of and indications for corneal transplantation. Functional outcomes have not been considered.

With the increase of either lamellar or penetrating keratoplasties, the number of waiting patients for corneal transplantation and the number of corneal transplant donors⁶ in Germany increased simultaneously. This phenomenon is observed worldwide as a result of improved and widely applied skills in corneal surgery, expanding indications for corneal transplantation, and a trend toward earlier operative intervention in corneal endothelial diseases. The number of performed keratoplasties also steadily increased in the United Kingdom (UK) from 2090 in the year 1999 to 2511 in 2009⁷ and in the United States (US) from 44 277 in the year 2005 to 48 499 in 2016.⁸ Also in these countries, a trend away from PKP toward

The German Keratoplasty Registry of the Cornea Section of the DOG

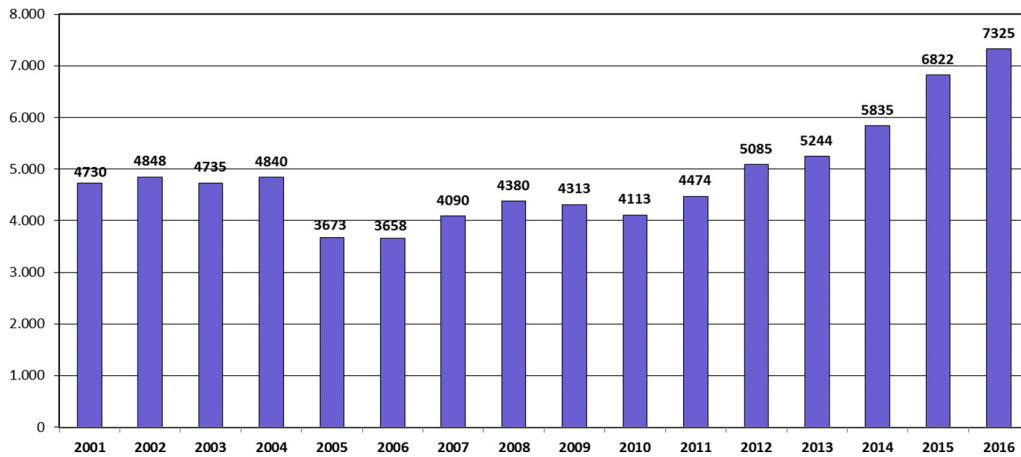


FIGURE 1. Reported corneal transplants in Germany from 2001 to 2016. The x-axis shows year; y-axis, number of reported corneal transplants. DOG = German Ophthalmological Society.

Absolute proportions of Keratoplasties in Germany 2006-2016

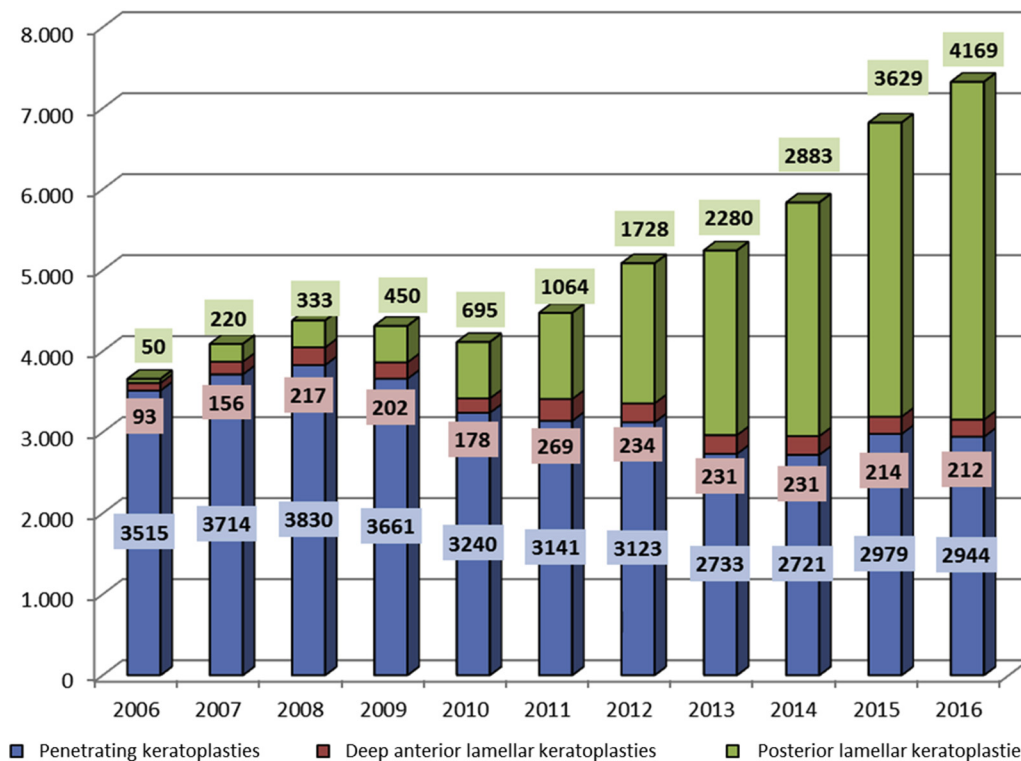


FIGURE 2. Absolute proportions of penetrating keratoplasties, deep anterior lamellar keratoplasties, and posterior lamellar keratoplasties in Germany from 2006 to 2016. The x-axis shows year; y-axis, number of reported corneal transplants.

lamellar procedures is observed. In the UK, there was a decrease of PKPs for endothelial failure, from 98.3% in 1999 to 46.6% in 2009, and, during the same period, an increase of endothelial keratoplasties, from 0.3% in 1999 to 51.2% in 2009.⁷ The corresponding figures for the US

indicate a decrease of PKPs from 42 063 (95%) in 2005 to 18 579 (38.3%) in 2016 and an increase of lamellar procedures from 2039 (4.6%) in 2005 (1398 [3.2%] of which were posterior lamellar keratoplasties and 641 [1.4%] anterior lamellar keratoplasties) to 29 559 (61%) in 2016

Percentages of Keratoplasties in Germany 2006-2016

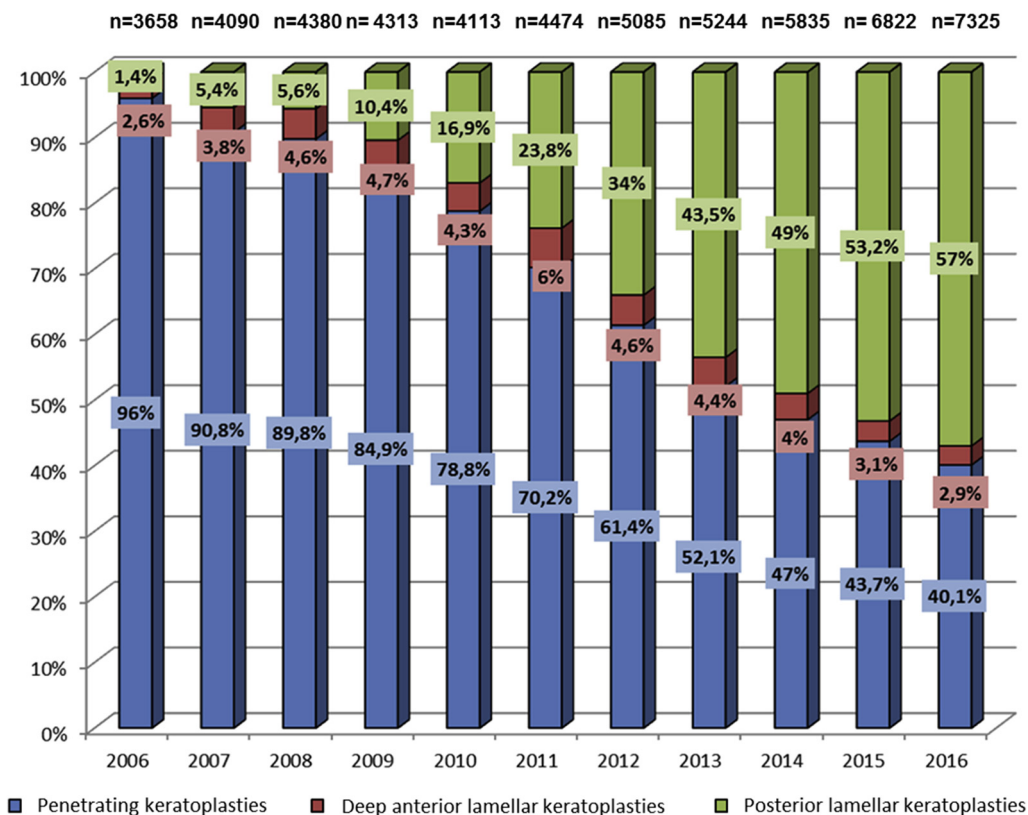


FIGURE 3. Percentages of penetrating keratoplasties, deep anterior lamellar keratoplasties, and posterior lamellar keratoplasties in Germany from 2006 to 2016.

(28 327 [58.4%] of which were posterior lamellar keratoplasties and 1232 [2.5%] anterior lamellar keratoplasties).⁸

According to the annual report of the Eye Bank Association of America, posterior lamellar keratoplasties have surpassed penetrating procedure since 2011, as observed in the same year in Germany.⁸ Other European countries like The Netherlands also report that from 2007 on, endothelial transplantation replaced penetrating transplantation for the treatment of endothelial dysfunction.⁹ The Singapore Corneal Transplant Study reports on 42% of corneal transplantations being lamellar endothelial keratoplasties and 28% being anterior lamellar keratoplasties in 2015.¹⁰ It can be assumed by these figures that this trend away from the PKP also applies for other Asian countries.

In Australia, the number of PKPs was relatively stable from 1996 to 2006 (926 ± 66) and increased to 1482 in 2012.¹¹ From 2005 on, deep anterior lamellar keratoplasties for keratoconus and posterior lamellar procedures increased steadily, while fewer penetrating procedures were performed.¹¹

A preliminary report of the Swedish corneal transplant registry also reports a shift toward posterior lamellar procedures: PKPs decreased from 60% (2007–2009) to 53% (2010–2012), posterior lamellar procedures increased

from 14% (2007–2009) to 28% (2010–2012), and the proportion of anterior lamellar transplantations remained relatively stable at 13%–14%, whereas the proportion of unspecified corneal transplantations decreased from 12% (2007–2009) to 6% (2010–2012).¹²

The indications and distributions to perform corneal transplantations in the different countries, however, do vary. In Germany, main indications are, according to our transplant registry, in decreasing numbers of frequencies, the widespread FECD,^{13,14} corneal decompensation of other origin (pseudophakic bullous keratopathy), repeated keratoplasty after graft failure, keratoconus (formerly the most common indication in Germany between 1992 and 1996¹⁵), and corneal scarring. Throughout Europe, however, keratoconus is still the predominant indication for corneal transplantation, which also applies for Africa, Australia, South America, and the Middle East.¹⁶

In the US and the UK, FECD (US) and corneal decompensation because of pseudophakic bullous keratopathy (UK, and formerly until 2006 the top indication in the US) are the main indications for corneal transplantation ahead of keratoconus and repeated keratoplasty.^{7,17} In contrast to these indications in “western” countries, there

The ten most active Corneal Transplantation Centers in Germany (2016)

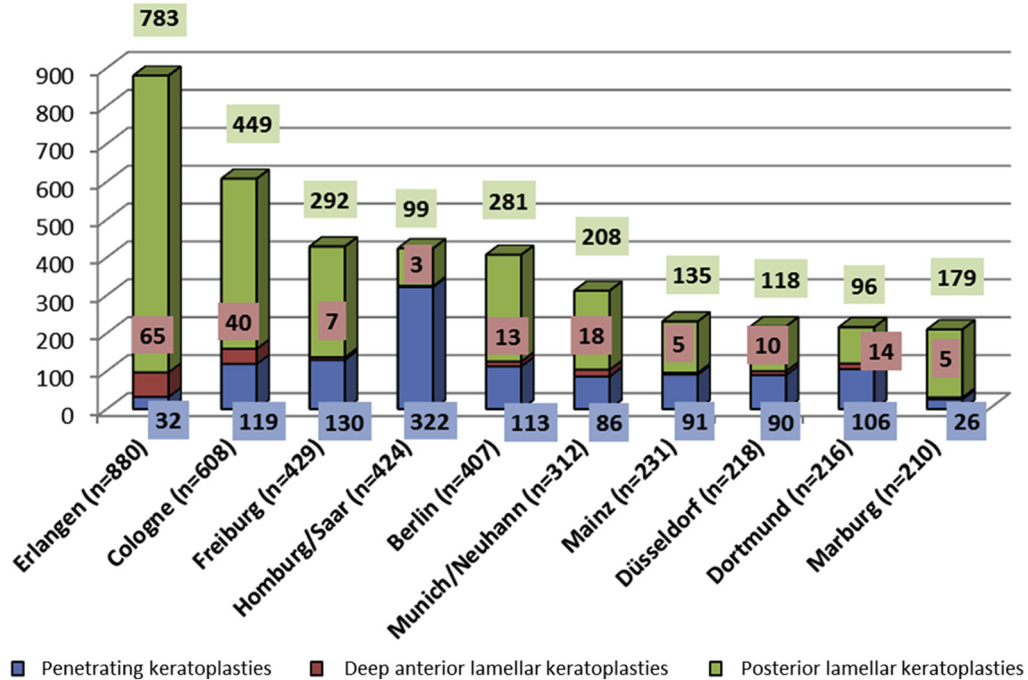


FIGURE 4. The 10 most active corneal transplantation centers in Germany (2016).

DSAEK versus DMEK in Germany 2009-2016

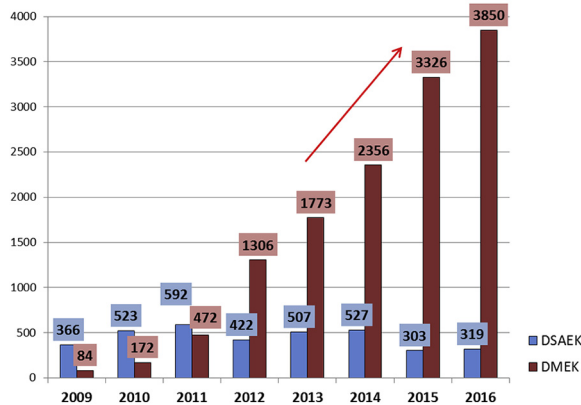


FIGURE 5. Absolute numbers of Descemet stripping automated endothelial keratoplasties (DSAEKs) versus Descemet membrane endothelial keratoplasties (DMEKs) from 2009 to 2016 in Germany. There was a steady increase of DMEKs in Germany with a 12-fold higher number of DMEKs than DSAEKs in 2016.

is another ranking of the indications for corneal transplantation in Singapore and most Asian countries; those are, in decreasing numbers of frequencies, (1) infectious keratitis, (2) corneal decompensation because of pseudophakic bullous keratopathy, (3) repeated keratoplasty after graft failure, (4) postinfectious scarring, (5) keratoconus, and (6) FECD.^{10,16} The authors of the

Singapore Corneal Transplant Study are reasoning a lack of priority for corneal transplantation in keratoconus and FECD to be responsible for this ranking.¹⁰ Other countries like Russia, South Africa, Italy, and Australia, where keratoconus percentages are quite high and range from 30% to 53%,¹⁰ show that, generally, indications depend on the distribution of corneal diseases in the different countries.

Different surgical approaches (ie, penetrating or lamellar procedures) do exist for the cure of keratoconus and endothelial diseases.

Whereas the number of performed DALKs in Germany declined in the last few years (212 [2.9%] in 2016, Figure 2) and PKP is still more common in some centers,^{18–20} DALK is a more preferred therapeutic option in the surgical treatment of keratoconus in other countries. In the US, anterior lamellar keratoplasty accounted for 11.8% of grafts performed for keratoconus in 2016.⁸ In Canada, 30% of the annual keratoplasties in keratoconus patients in 2012 were performed as a DALK.²¹ In Australia and in the Islamic Republic of Iran, the proportion of DALKs performed for keratoconus increased until 2013 but did not surpass the number of penetrating grafts for keratoconus.^{22,23} This trend was also observed in Scotland, where DALK even surpassed the penetrating transplantation in the treatment of keratoconus after 2004,²⁴ and in the whole UK, with a decrease of PKP for keratoconus from 453 (88.4%) in 1999 to 322 (57.1%) in 2009 and an increase of DALK for keratoconus from 45 (8.8%) in 1999 to 226 (40.1%) in 2009.⁷

Patients on Waiting Lists in Germany 2008-2016

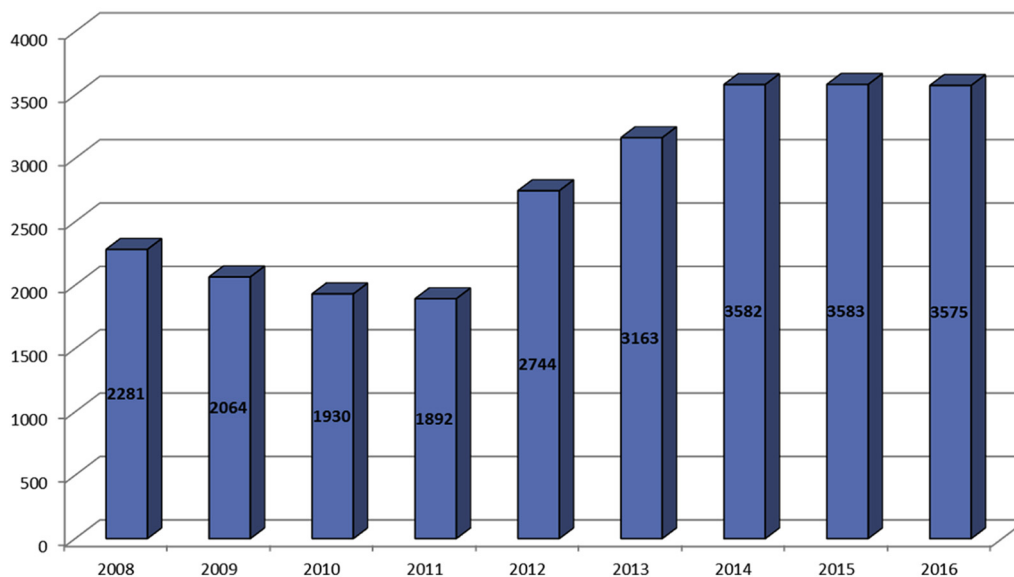


FIGURE 6. Patients on waiting lists for corneal transplantation in Germany from 2008 to 2016.

Indications for Keratoplasties in Germany 2013-2016

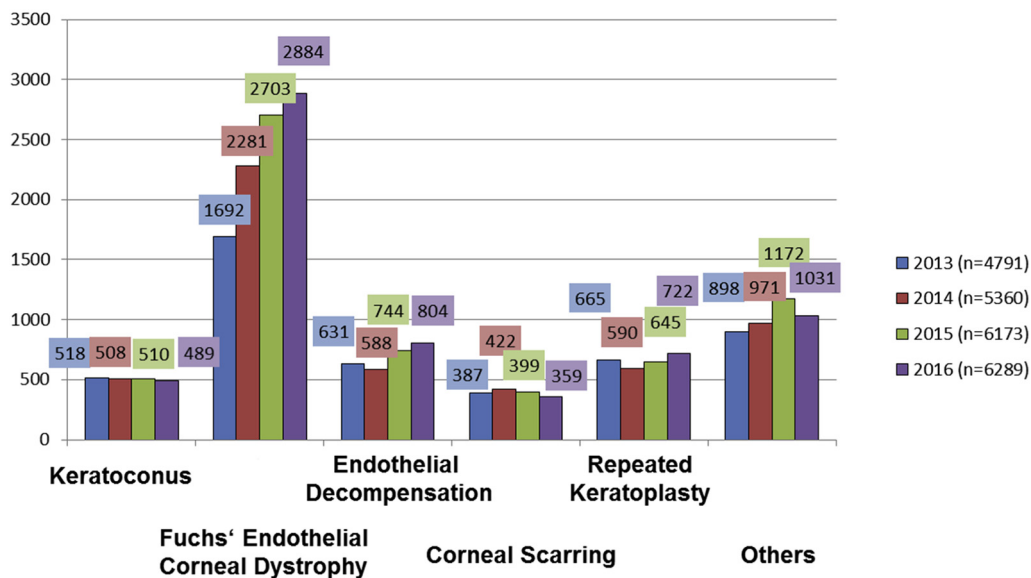


FIGURE 7. Reported main indications for penetrating and lamellar corneal transplantations in Germany from 2013 to 2016. The presented data do not represent the absolute distribution in Germany, as, in some cases, keratoplasties were reported without the underlying diagnosis (1036 keratoplasties in 2016).

With regard to endothelial diseases, DMEK and DSAEK are potential alternatives to PKP. The number of DMEKs is 12 times as high (3850 [53%] in 2016, Figure 5) than the number of DSAEKs in Germany (which even decreased from 527 in 2014 to 319 [4.4%] in 2016; Figure 5). In

Australia, DSAEK has surpassed penetrating transplantation in the treatment of pseudophakic bullous keratopathy and it also almost replaced the penetrating procedure in FECD by the year 2009.²² In contrast to the development in Germany, the number of DMEKs represented only a

small and relatively stable fraction of the total corneal transplantations performed in Australia for both endothelial diseases.²² In the US, DSAEK was the predominant procedure concerning posterior lamellar keratoplasties (a total of 28 327 [58.4%] in 2016) in endothelial diseases: 21 868 (77.2%) of the posterior lamellar transplantations in 2016 were performed as a DSAEK and only 6459 (22.8%) as a DMEK.⁸ DSAEK is also the preferred endothelial keratoplasty method in Asian countries because of the relatively shallow anterior chamber and a dark iris in Asian eyes,²⁵ making DMEK more complex.²⁶ Consequently, only few reports on case series after DMEK in Asian countries do exist up to now, but their general consensus is that DMEK may have a great future potential in the surgical cure of endothelial diseases^{25,26} after a standardization of all steps for donor preparation and host maneuvers.²⁷

The tendency toward earlier operative intervention via either penetrating or lamellar corneal transplantation and the aging of western societies leads to an increasing paradox: Although the number of performed corneal transplantations steadily increases worldwide, the number of patients waiting for corneal transplantation does not cease to increase. The shift away from PKP toward either anterior or posterior lamellar surgical procedures is a

phenomenon observed worldwide; however, the shift depends on the prevalence of corneal diseases in this country and the microsurgeons' preference. This trend is supported by the increasing demand for corneal transplantation; to treat just the diseased layers of the cornea would, in theory, allow a splitting of the graft in order to treat more than 1 patient with a single corneal graft.²⁸ Lamellar surgical procedures that also meet the demand for minimization of corneal transplantation are on the rise and seem to represent the major part of corneal transplantations, both now and in the future. However, they are not uniformly applied across the world. The practical benefits of DALK (which is associated with a higher failure rate and with poorer visual outcomes in some studies in the UK [2009²⁹], in Germany [2013^{30,31}], and in Australia [2015²²]) or of PKP for the patient will show, in the long run, which procedure will become the surgical therapy of choice in keratoconus. The same applies for the future procedure of choice in endothelial diseases where—up to now—DMEK, primarily applied in Germany, and DSAEK, primarily applied in the US in greater quantities, as well as in Australia and in Asian countries, face off against each other, notwithstanding that the DMEK technique has just started to take root in the latter countries.

FUNDING/SUPPORT: NO FUNDING OR GRANT SUPPORT. FINANCIAL DISCLOSURES: ELIAS FLOCKERZI HAS RECEIVED A TRAVEL grant to the Second Ophthalmology Cystinosis Forum (Orphan Europe, Ulm, Germany) and an invitation to a seminar on presentation training organized by Santen GmbH (Munich, Germany). Claus Cursiefen is a board member of Novaliq GmbH (Heidelberg, Germany) and a consultant of Gene Signal International SA (Lausanne, Switzerland). Claus Cursiefen also received grants from the German Research Council of the German Research Foundation (Deutsche Forschungsgemeinschaft DFG, Bonn, Germany) and payments for lectures from Santen GmbH (Munich, Germany), Ursapharm GmbH (Saarbrücken, Germany), Alcon Pharma GmbH (Freiburg, Germany), and Bayer AG (Leverkusen, Germany). Gerd Geerling has received travel grants from TearLab Inc (San Diego, California, USA) and a research grant from TearScience (Morrisville, North Carolina, USA). Gerd Geerling also received payments for lectures and consultancy from Allergan GmbH (Frankfurt, Germany), Bausch & Lomb Inc. (Rochester, New York, USA), Chiesi GmbH (Hamburg, Germany), Dompé (Milano, Italy), Oculus Pharma Ltd (Kanpur, India), Santen GmbH (Munich, Germany), Shire Pharmaceuticals (Dublin, Ireland), TearLab Inc, TearScience, Théa Pharma GmbH (Berlin, Germany), and VISUfarma B.V. (Amsterdam, The Netherlands). The following authors have no financial disclosures: Philip Maier, Daniel Böhringer, Helga Reinshagen, Friedrich Kruse, Thomas Reinhard, Necip Torun, and Berthold Seitz. The authors attest that they meet the current ICMJE criteria for authorship.

The authors thank all colleagues in Germany who responded and contributed to their survey and Ms Susan Pillion and Ms Lena Kunz (director's assistants, Department of Ophthalmology, Saarland University Medical Center, Homburg, Germany) for collecting data and draft figures.

REFERENCES

- Seitz B, Szentmáry N, El-Husseiny M, Viestenz A, Langenbucher A, Naumann GOH. The penetrating keratoplasty (PKP): a century of success. In: Hjortdal J, ed. *Corneal Transplantation*. Cham, Switzerland: Springer International Publishing AG; 2016:69–92.
- Zirm EK. Eine erfolgreiche totale Keratoplastik. [A successful total keratoplasty]. *Refract Corneal Surg* 1989 1906;5(4): 258–261.
- Tillett CW. Posterior lamellar keratoplasty. *Am J Ophthalmol* 1956;41(3):530–533.
- Melles GR, Eggink FA, Lander F, et al. A surgical technique for posterior lamellar keratoplasty. *Cornea* 1998;17(6):618–626.
- Melles GR, Ong TS, Ververs B, van der Wees J. Descemet membrane endothelial keratoplasty (DMEK). *Cornea* 2006; 25(8):987–990.
- Reinshagen H, Maier P, Böhringer D. *Leistungsbericht 2015 der Sektion Gewebetransplantation und Biotechnologie der Deutschen Ophthalmologischen Gesellschaft*. [Activity report 2015 of the tissue transplantation and biotechnology section of the German Ophthalmological Society]. *Klin Monatsbl Augenheilkd* 2017;234(6):815–816.
- Keenan TD, Jones MN, Rushton S, Carley FM, National Health Service Blood and Transplant Ocular Tissue Advisory Group and Contributing Ophthalmologists (Ocular Tissue Advisory Group Audit Study 8). Trends in the indications for corneal graft surgery in the United Kingdom: 1999 through 2009. *Arch Ophthalmol* 2012; 130(5):621–628.
- Eye Bank Association of America. 2016 Eye Banking Statistical Report. Available at, http://restoresight.org/wp-content/uploads/2017/04/2016_Statistical_Report-Final-040717.pdf. Accessed June 19, 2017.

9. Dickman MM, Peeters JM, van den Biggelaar FJ, et al. Changing practice patterns and long-term outcomes of endothelial versus penetrating keratoplasty: a prospective Dutch registry study. *Am J Ophthalmol* 2016;170:133–142.
10. Tan D, Ang M, Arundhati A, Khor WB. Development of selective lamellar keratoplasty within an Asian corneal transplant program: The Singapore Corneal Transplant Study (An American Ophthalmological Society Thesis). *Trans Am Ophthalmol Soc* 2015;113:T10 [1–23].
11. Coster DJ, Lowe MT, Keane MC, Williams KA, Australian Corneal Graft Registry Contributors. A comparison of lamellar and penetrating keratoplasty outcomes: a registry study. *Ophthalmology* 2014;121(5):979–987.
12. Claesson-Armitage M. Cornea Transplant Registry - the Swedish model. Available at, <http://www.gaeba.org/wp-content/uploads/2015/12/Session-4-Claesson.pdf>. Accessed June 19, 2017.
13. Seitz B, Lisch W, Weiss J. Die revidierte neueste IC3D-Klassifikation der Hornhautdystrophien. [The revised newest IC3D classification of corneal dystrophies]. *Klin Monatsbl Augenheilkd* 2015;232(03):283–294.
14. Lang SJ, Bischoff M, Böhringer D, Seitz B, Reinhard T. Analysis of the changes in keratoplasty indications and preferred techniques. *PLoS One* 2014;9(11):e112696.
15. Cursiefen C, Kuchle M, Naumann GO. Changing indications for penetrating keratoplasty: histopathology of 1,250 corneal buttons. *Cornea* 1998;17(5):468–470.
16. 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(6):1387–1399.
17. Park CY, Lee JK, Gore PK, Lim CY, Chuck RS. Keratoplasty in the United States: a 10-year review from 2005 through 2014. *Ophthalmology* 2015;122(12):2432–2442.
18. Seitz B, Langenbucher A, Kus MM, Kuchle M, Naumann GO. Nonmechanical corneal trephination with the excimer laser improves outcome after penetrating keratoplasty. *Ophthalmology* 1999;106(6):1156–1164. discussion 1165.
19. Seitz B, Szentmáry N, Langenbucher A, et al. Perforierende Keratoplastik bei fortgeschrittenem Keratokonus – vom Hand-/Motortrepan hinauf zum Excimerlaser und zurück zum Femtosekundenlaser. [PKP for keratoconus - from hand/motor trephine to excimer laser and back to femtosecond laser]. *Klin Monatsbl Augenheilkd* 2016;233(6):727–736.
20. Wang J, Hasenfus A, Schirra F, Bohle RM, Seitz B, Szentmáry N. Changing indications for penetrating keratoplasty in Homburg/Saar from 2001 to 2010—histopathology of 1,200 corneal buttons. *Graefes Arch Clin Exp Ophthalmol* 2013;251(3):797–802.
21. Zhang AQ, Rubenstein D, Price AJ, et al. Evolving surgical techniques of and indications for corneal transplantation in Ontario: 2000-2012. *Can J Ophthalmol* 2013;48(3):153–159.
22. Williams K, Keane M, Galettis R, Jones V, Mills R, Coster D. The Australian Corneal Graft Registry - 2015 Report. Available at, http://dSPACE.flinders.edu.au/xmlui/bitstream/handle/2328/35402/ACGR%20report%202015_2.pdf?sequence=3. Accessed June 19, 2017.
23. Rezaei Kanavi M, Javadi MA, Motevasseli T, et al. Trends in indications and techniques of corneal transplantation in Iran from 2006 to 2013; an 8-year review. *J Ophthalmic Vis Res* 2016;11(2):146–152.
24. Ting DS, Sau CY, Srinivasan S, Ramaesh K, Mantry S, Roberts F. Changing trends in keratoplasty in the West of Scotland: a 10-year review. *Br J Ophthalmol* 2012;96(3):405–408.
25. Hayashi T, Oyakawa I, Kato N. Techniques for learning Descemet membrane endothelial keratoplasty for eyes of Asian patients with shallow anterior chamber. *Cornea* 2017;36(3):390–393.
26. Bhandari V, Reddy J, Chougale P. Descemet's membrane endothelial keratoplasty in south Asian population. *J Ophthalmic Vis Res* 2016;11(4):368–371.
27. Seitz B, Daas L, Bischoff-Jung M, et al. Anatomy-based DMEK Wetlab in Homburg/Saar: novel aspects of donor preparation and host maneuvers to teach descemet membrane endothelial keratoplasty. *Clin Anat* 2018;31(1):16–27.
28. Heindl LM, Riss S, Laaser K, Bachmann BO, Kruse FE, Cursiefen C. Split cornea transplantation for 2 recipients – review of the first 100 consecutive patients. *Am J Ophthalmol* 2011;152(4):523–532.e2.
29. Jones MN, Armitage WJ, Ayliffe W, Larkin DF, Kaye SB, NHSBT Ocular Tissue Advisory Group and Contributing Ophthalmologists (OTAG Audit Study 5). Penetrating and deep anterior lamellar keratoplasty for keratoconus: a comparison of graft outcomes in the United Kingdom. *Invest Ophthalmol Vis Sci* 2009;50(12):5625–5629.
30. Maier P, Reinhard T, Cursiefen C. Hauchdünne Hornhauttransplantate - schnelle und gute Sehschärfenerholung. [Descemet stripping endothelial keratoplasty - rapid recovery of visual acuity]. *Dtsch Arztebl Int* 2013;110(21):365–371.
31. Brockmann T, Brockmann C, Maier AK, et al. Descemet membrane endothelial keratoplasty for graft failure after Descemet stripping endothelial keratoplasty: clinical results and histopathologic findings. *JAMA Ophthalmol* 2015;133(7):813–819.