Extended Long-term Outcomes of Penetrating Keratoplasty for Keratoconus

Sudeep Pramanik, MD, MBA,[1] David C. Musch, PhD, MPH,[2] John E. Sutphin, MD,[1] Ayad A. Farjo, MD[1,3,4]

Objective: To report graft survival results for initial penetrating keratoplasty (PK) performed more than 20 years ago for keratoconus. Secondary outcome measures included recurrent keratoconus, best spectacle-corrected visual acuity (BSCVA), and rates of glaucoma.

Design: Retrospective, consecutive, noncomparative case series.

Participants: All patients with clinical and histopathological keratoconus who underwent initial PK at the University of Iowa Hospitals and Clinics from 1970 to 1983. Patients with pellucid marginal degeneration were excluded.

Methods: At baseline, age, preoperative BSCVA, keratometric astigmatism, and host/donor graft sizes for each eye were recorded. Visual acuity and intraocular pressure were followed until the eyes reached 1 of 4 end points: graft failure, recurrent keratoconus, loss to follow-up, or death. Kaplan–Meier survival analysis was performed to estimate the long-term probability of graft failure and recurrent keratoconus.

Results: Among the 112 eyes of 84 patients who met entry criteria, there was a mean age at transplant of 33.7 years and preoperative BSCVA of 20/193. With a mean follow-up of 13.8 years (range, 0.5–30.4), 7 eyes (6.3%) experienced graft failure. Recurrent keratoconus was confirmed clinically or histologically in 6 eyes (5.4%), with a mean time to recurrence of 17.9 years (range, 11–27). Kaplan–Meier analysis estimated a graft survival rate of 85.4% and a rate of recurrent keratoconus of 11.7% at 25 years after initial transplantation. Six eyes (5.4%) developed open-angle glaucoma, and 2 eyes required trabeculectomy. At the last follow-up visit, 82 eyes (73.2%) had BSCVA of 20/40 or better.

Conclusion: Penetrating keratoplasty offers good long-term visual rehabilitation for keratoconus. Relative to other indications for PK, there is a low rate of graft failure. Late recurrence of disease occurs with increasing frequency over time. Given the younger age at which keratoconus patients undergo corneal transplantation, these long-term findings should be incorporated into preoperative counseling. *Ophthalmology 2006;113: 1633–1638 © 2006 by the American Academy of Ophthalmology.*

Keratoconus is a progressive, noninflammatory, bilateral degeneration of the central and paracentral corneas that can lead to progressive irregular astigmatism. Penetrating keratoplasty (PK) is a well-accepted treatment for advanced keratoconus and is one of the leading indications for corneal transplantation in the United States and internationally.[1–8] Long-range complications of PK for keratoconus include graft rejection and failure, astigmatism, recurrence of keratoconus in the donor graft, and development of cataract or glaucoma.[9]

Studies to date have reported >90% graft survival data between 5 and 12 years from the time of transplant.[10–20] It has been suggested that early surgical intervention can be advised based upon the results in the first several years after PK among these patients.[16] However, reports of late recurrence of keratoconus have been described from 7 to 40 years after keratoplasty,[21–23] with a mean latency of roughly 17 years.[24] Many of these cases are supported by histologic confirmation.[21,24–27] Given the fact that most keratoconus patients receive transplants at a relatively young age,[28] longer follow-up data are necessary in the preoperative counseling of these patients.

Materials and Methods

Approval from the institutional review board of the University of Iowa Hospitals and Clinics was obtained before initiation of this study. The Iowa Lions Eye Bank provided all donor tissue for transplantation, and its records between 1970 and 1983 were

Originally received: November 9, 2005.
Accepted: February 18, 2006. Manuscript no. 2005-1083.

[1] Cornea, External Diseases and Refractive Surgery Services, Department of Ophthalmology and Visual Sciences, University of Iowa Hospitals and Clinics, Iowa City, Iowa.

[2] Departments of Ophthalmology and Visual Sciences and Epidemiology, University of Michigan, Ann Arbor, Michigan.

[3] Department of Ophthalmology and Visual Sciences, University of Wisconsin Hospitals and Clinics, Madison, Wisconsin.

[4] SF Ophthalmology, S.C., Madison, Wisconsin.

Presented in part at: Federated Scientific Session, October 2004, New Orleans, Louisiana.

University of Iowa resident research fund sponsored by Research to Prevent Blindness Foundation, New York, New York.

The authors have no commercial or proprietary interests in any products mentioned in the article.

Correspondence and reprint requests to Ayad A. Farjo, MD, Brighton Vision Center, 8589 West Grand River Avenue, Suite E, Brighton, MI 48116. E-mail: afarjo@umich.edu.

ISSN 0161-6420/06/$–see front matter
doi:10.1016/j.ophtha.2006.02.058

reviewed to find all patients receiving PK for keratoconus before 1983. Cases before 1970 were excluded because the indication for transplantation was not recorded. Cases of pellucid marginal degeneration and repeat transplantation were excluded from the subsequent chart review. The clinical diagnosis of keratoconus was confirmed by histopathology in all cases.

Data from patient records were analyzed for age, gender, laterality, preoperative best spectacle-corrected visual acuity (BSCVA), preoperative astigmatism, surgical technique, and donor/host graft sizes. Transplantation was performed by or under the supervision of a cornea faculty or fellow; a total of 18 different faculty or fellows did so for this patient series. Donor age, death-to-preservation time, and preservation-to-transplant time were not available. Additional information, including BSCVA and presence of glaucoma, was collected annually until the patient reached 1 of 4 end points: graft failure, recurrent keratoconus in the donor cornea, loss to follow-up, or death. The primary end point in this study, graft failure, was defined as endothelial failure and/or immune rejection with a persistent cloudy graft for >3 months. The secondary end point was recurrent keratoconus based on histopathology of the donor cornea and/or clinical features, including inferior paracentral corneal thinning and Vogt's striae manifest in the donor cornea. Patients with topography documenting progressive high oblique astigmatism and those with thinning in the inferior host cornea only were not defined as having recurrent keratoconus.

All data were entered into a spreadsheet, and statistical analyses were performed with SAS software (SAS Institute Inc., Cary, NC). Snellen visual acuities (VAs) were converted to the logarithm of the minimum angle of resolution for statistical analysis. When necessary, nonparametric testing (i.e., Mann–Whitney *U* test) was performed. $P<0.05$ was considered significant. Kaplan–Meier survival curves were calculated for time to recurrence and failure, and Cox proportional hazards analysis was performed to adjust for intereye dependence and evaluate risk factors for recurrence and failure.

Table 1. Preoperative Characteristics of Transplanted Eyes

Characteristic	n (% total)
Gender (patients)	84
Male	47 (56.0)
Female	37 (44.0)
Laterality of operated eye	112
Right eye	55 (49.1)
Left eye	57 (50.9)
BSCVA	112
20/40–20/80	44 (39.3)
20/100–20/200	28 (25.0)
<20/200	40 (35.7)
Age at surgery (yrs)	112
<20	9 (8.0)
20–29	29 (25.9)
30–39	48 (42.9)
40–49	14 (12.5)
50–59	10 (8.9)
>59	2 (1.8)
Keratometric astigmatism (D)	112
1–3.9	8 (7.1)
4–6.9	33 (29.5)
>7	29 (25.9)
Too steep to measure	42 (37.5)

BSCVA = best spectacle-corrected visual acuity; D = diopters.

Table 2. Preoperative Characteristics of Patients Lost to Follow-up

Follow-up	<15 yrs	≥15 yrs
Right eye transplanted	28	27
Left eye transplanted	31	26
Mean age (yrs) ± SD	34.6±10.7	32.7±10.4
Mean (median) preoperative BSCVA	20/196 (20/200)	20/190 (20/100)
Mean keratometric astigmatism (D) ± SD (no. of eyes analyzed)	6.84±3.8 (31)	6.5±2.7 (38)
Mean host size (mm) ± SD	8.22±0.5	8.04±0.4
Mean donor size (mm) ± SD	8.35±0.4	8.25±0.5
Mean graft oversize (mm) ± SD	0.14±0.2	0.17±0.2

BSCVA = best spectacle-corrected visual acuity; D = diopters; SD = standard deviation.

Results

Data were obtained on 112 eyes of 84 patients, of whom 47 (56.0%) were male (Table 1). There was almost equal representation of right (55) and left (57) eyes, and the mean age at the time of PK was 33.7 years (median, 32.5; standard deviation [SD], 10.6; range, 14–67). Mean preoperative BSCVA was 20/193 (median, 20/150; SD, 0.6; range, 20/40–20/2000). Forty-three eyes (38.4%) of 36 patients (42.9%) had keratometry too steep to measure; of the remaining 69 eyes, the mean preoperative keratometric astigmatism was 6.65 diopters (median, 6.0; SD, 3.2; range, 1–17.75). Mean follow-up was 13.8 years (median, 14; SD, 7.9; range, 0.5–30.4). One hundred ten eyes (98.2%) were available for follow-up at 1 year postoperatively, 105 eyes (93.8%) at 2 years, 92 eyes (82.1%) at 5 years, 75 eyes (67%) at 10 years, 53 eyes (47.3%) at 15 years, 29 eyes (25.9%) at 20 years, and 10 eyes (8.9%) at 25 years. There were no statistically or clinically significant differences between the preoperative characteristics of patients with more than 15 years of follow-up and those who were lost to follow-up before 15 years (Table 2).

The mean host corneal bed size was 8.15 mm (median, 8.0; SD, 0.42; range, 7–10), and the mean donor corneal button size was 8.30 mm (median, 8.25; SD, 0.46; range, 7–10). The most common host bed sizes were 8.0 mm, used in 66 eyes (59.0%), followed by 8.5 mm, used in 23 eyes (20.5%). Donor graft button sizes were distributed more evenly among eyes, with sizes of 8.0 mm (26.8%), 8.25 mm (28.6%), and 8.5 mm (21.4%) accounting for the majority. In 56 eyes (50.0%), donor and host sizes were the same; in 47 eyes (42.0%), a 0.25-mm oversized donor graft was selected; in 8 eyes (7.1%), a 0.5-mm oversized graft was used; and in 1 eye (0.9%), a 1-mm oversized graft was transplanted. Suture techniques varied between cases, with a single running suture used in 49 eyes (43.7%), a single running suture and 4 interrupted sutures used in 32 eyes (28.6%), and 16 interrupted sutures used in 31 eyes (27.7%).

Graft failure occurred in 7 of the 112 transplanted eyes (6.3%), with one episode of bilateral graft failure (Fig 1). The timing of graft failure ranged from 6 months to 23.3 years after transplant (mean, 12.6). The Kaplan–Meier estimates of graft survival probability at 20 and 25 years (Fig 1) were 93.7% (standard error [SE], 2.8%; 95% confidence interval [CI], 88.1%–99.3%) and 85.4% (SE, 6.3%; 95% CI, 72.8%–98.0%), respectively. Nonimmunologic failure occurred in 3 eyes at 142, 181, and 276 months after surgery, whereas immunologic failure occurred in 4 eyes at 6, 50, 65, and 259 months after surgery. The causes of nonimmunologic failure were endothelial failure without active or previous history of rejection in 2 eyes and endothelial failure after complicated

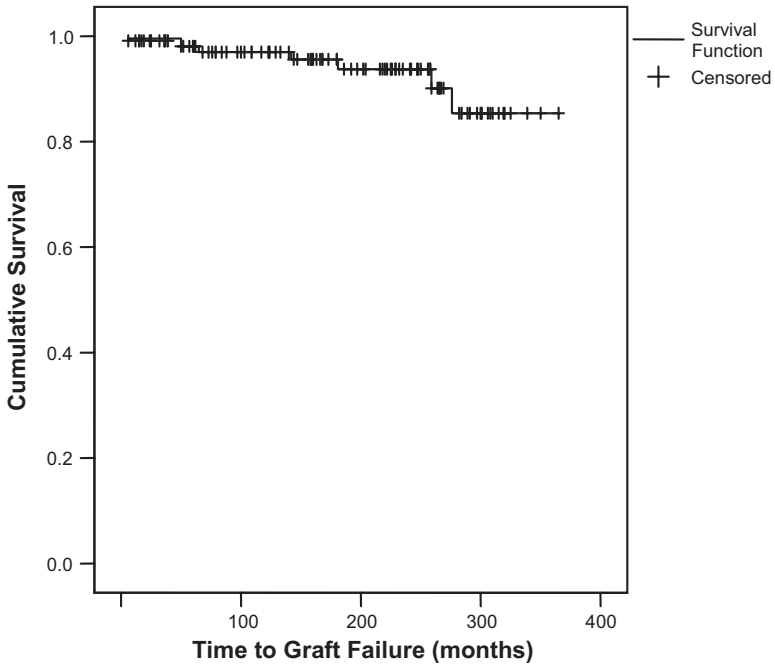

Figure 1. Kaplan–Meier estimate of graft survival.

cataract extraction (CE) in 1 eye. No statistically significant predictors of graft failure were identified. Two of the 7 grafts that failed (28.6%) developed open-angle glaucoma (OAG) during follow-up after PK, versus 4 of the 105 grafts (3.8%) that did not fail over time. Using Cox regression with adjustment for intereye dependence, neither age (hazard ratio, 1.05 [95% CI, 0.97–1.13]; $P = 0.19$), postoperative glaucoma (hazard ratio, 4.86 [95% CI, 0.50–47.48]; $P = 0.17$), nor host size (hazard ratio, 1.56 [95% CI, 0.10–25.04]; $P = 0.75$) was associated significantly with graft failure.

Recurrent keratoconus was documented in 6 eyes (5.4%) of 5 patients (6.0%). In 4 eyes, recurrence was confirmed by histopathology, with breaks in Bowman's layer seen in the donor graft. Two patients had clinical features of keratoconus, including Vogt's striae in the donor cornea and a scissor reflex on retinoscopy. An additional 8 eyes (7.1%) had a pattern of high irregular astigmatism suggestive of keratoconus. As these optical recurrences were not confirmed by histopathology or characteristic clinical features, they were excluded from the Kaplan–Meier analysis (Fig 2). The probabilities of recurrence were estimated to be 7.1% (SE, 3.5%;

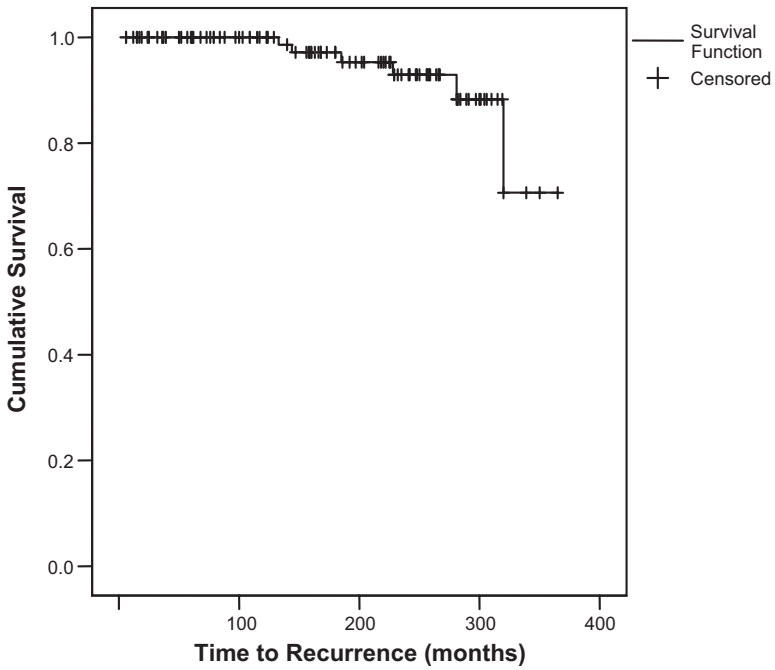

Figure 2. Kaplan–Meier estimate of recurrent keratoconus.

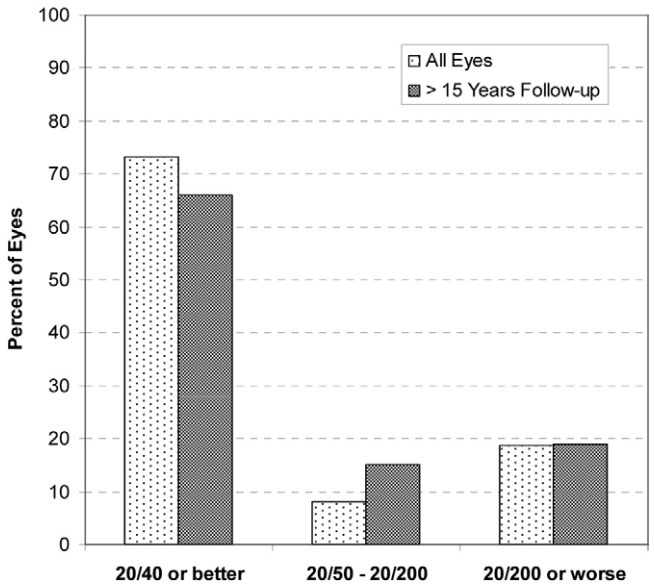

Figure 3. Best spectacle-corrected visual acuity at last follow-up visit.

95% CI, 0.2%–14.0%) and 11.7% (SE, 5.6%; 95% CI, 0.5%–22.9%) at 20 and 25 years postoperatively. Mean time to recurrence was 17.9 years (median, 17.2; SD, 6.3; range, 11–27). Among those eyes that experienced recurrence, the mean host bed size was 8.25 mm (median, 8.0; SD, 0.38; range, 8–9), with a mean donor button size of 8.45 mm (median, 8.25; SD, 0.55; range, 8–10). Using Cox regression with adjustment for intereye dependence, neither age (hazard ratio, 1.01 [95% CI, 0.97–1.06]; $P = 0.63$) nor host size (hazard ratio, 1.31 [95% CI, 0.45–3.80]; $P = 0.62$) was associated significantly with keratoconus recurrence. As none of the cases of recurrent keratoconus had postoperative glaucoma, a hazard ratio could not be estimated for this factor.

A BSCVA of 20/40 or better was achieved in 82 eyes (73.2%) at the last follow-up visit (Fig 3). Nine eyes (8.0%) saw between 20/50 and 20/200, and 21 eyes (18.8%) were worse than 20/200 at the last follow-up visit. Among eyes with more than 15 years' follow-up, 35 of 53 eyes (66.0%) obtained a final BSCVA at the last follow-up examination of 20/40 or better. Eight of 53 eyes (15.1%) obtained BSCVA between 20/50 and 20/200, and 10 eyes (18.9%) had acuity worse than 20/200. Visual acuity remained relatively stable throughout the first 20 years' follow-up (Fig 4).

Six eyes (5.3%) developed OAG at a mean time of 10.8 years after surgery (median, 12.5; SD, 8.7; range, 0.5–20). Two eyes were from the same patient, who underwent combined PK, intracapsular CE (ICCE), and anterior vitrectomy in each eye and required treatment for glaucoma within 6 months postoperatively. The other 4 eyes underwent PK alone, and mean time to development of glaucoma was 16 years (median, 16.5; SD, 4.2; range, 11–20). None of these patients had a family history of OAG. Four eyes were managed successfully with topical aqueous suppressants, and 2 required trabeculectomy. One of these eyes experienced a suprachoroidal hemorrhage during trabeculectomy and subsequently lost all vision.

Discussion

The goals of this study were to assess the long-term graft survival of PK for keratoconus, determine the rate of recurrent keratoconus, and appraise the functional visual results as well as the development of glaucoma. In this series of

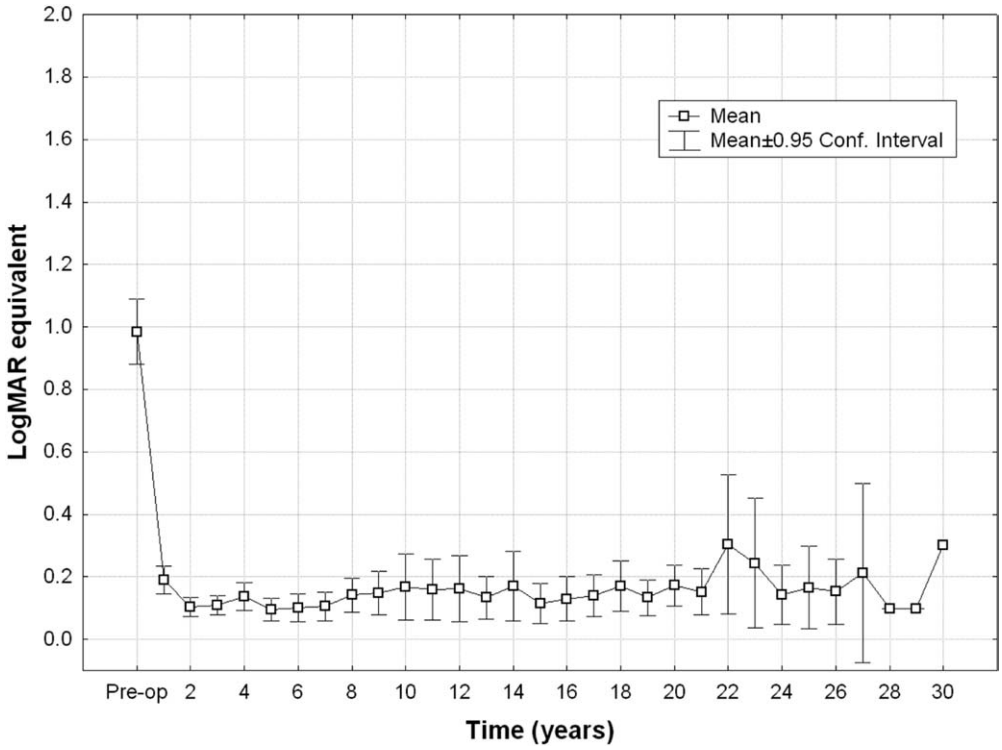

Figure 4. Mean best spectacle-corrected visual acuity. Conf. = confidence; logMAR = logarithm of the minimum angle of resolution; pre-op = preoperative.

corneal transplants performed at our institution, the point estimate of graft failure was 6.3% at 20 years. This is similar to the 7% graft failure rate noted by Paglen et al in their cohort of 326 eyes with 11.3 years' follow-up.[11] Early graft failure was rare in this series, with only 1 graft (0.9%) failing before 24 months. Olson et al[16] reported no cases of graft failure in their 24-month follow-up period, and Paglen et al[11] had only 5 cases (1.5%) of early graft failure. Price et al[29] found a 98% 5-year graft survival rate among patients who received PK for keratoconus and Fuchs' dystrophy, comparable to the results in our series. Our ability to determine risk factors for graft failure was limited, given the few occurrences of this untoward outcome in our graft series. However, the possibility that glaucoma might place a patient at a higher risk for failure is supported by past studies[10,14,15,18–20] and, although not statistically significant, is suggested by the hazard ratio of 4.86 for postoperative glaucoma from the Cox regression model.

This series provides the first survival analysis-based estimate of the rate of recurrent keratoconus after PK. The mean time to recurrence of 17.9 years is longer than the follow-up obtained in most other studies. One possible explanation for recurrence could be incomplete excision of the ectatic area of cornea at the time of original surgery, as has been suggested in patients who underwent smaller excisions of the host cornea in the 4- to 6-mm range.[30,31] Arguing against this mechanism in our patients were 2 observations: the mean host bed size was 8.15 mm, and we found no recurrences among those eyes with a host bed size that was <8.0 mm. Another possibility for recurrent keratoconus is that of undetected or preclinical keratoconus in the donor cornea. Although this is a plausible mechanism, one case report of recurrent keratoconus documents the absence of ectasia in the fellow eye of a donor 12 years after surgery,[32] and another, 7 years after surgery.[21] We were unable to locate the recipients of the opposite donor cornea in our patients with recurrence, and therefore, we cannot determine if the donor tissue we used was predisposed to ectasia. A final hypothesis suggests that recurrence of keratoconus is the manifestation in donor tissue of the same mechanisms that caused ectasia in the host cornea. This could be due to degradative enzymes liberated by abnormal host epithelium,[33] infiltration of the graft by abnormal host keratocytes that produce abnormal collagen,[34] or another mechanism. As the time to recurrence was fairly lengthy and close to the time for keratoconus to manifest in the original host cornea, this process could explain recurrence of keratoconus in these eyes.

Visual rehabilitation after keratoplasty was good, with average BSCVAs of 20/50 at 6 months, 20/40 at 1 year, and 20/20 by 2 years after transplantation. Visual acuity remained fairly stable throughout the first 20 years' follow-up. These VA findings were consistent with previous reports,[11,16,35] suggesting that our results are valid despite the attrition of patients over time. With longer follow-up, it is anticipated that VA may further decline as cataract or other age-related ocular conditions develop. Likewise, more eyes may develop optical recurrences with high irregular astigmatism over time.

None of the patients had glaucoma before PK, and 6 eyes developed this condition postoperatively. In 4 eyes, the glaucoma was felt to be steroid induced. In 2 eyes of one patient, ICCE resulted in vitreous prolapse into the anterior chamber and secondary glaucoma. This patient required trabeculectomy in one eye, resulting in complete loss of vision through a suprachoroidal hemorrhage. The increased intraocular pressure in the other eyes was controlled adequately with aqueous suppressants.

The findings of this study should be interpreted in the context of several limitations. Two factors led to limited statistical power to detect risk factors of potential relevance: our sample size decreased with increasing follow-up, and we had a low number of graft failures and recurrent keratoconus occurrences. Although all surgical procedures were performed at a single institution, multiple surgeons were involved, and it is possible that variations in technique may account for some of the findings. Likewise, although 47.3% of eyes had over 15 years' follow-up, there was notable attrition of patients and eyes over time, and it is possible that the outcomes could have been much worse among those patients lost to follow-up. Additionally, reporting the BSCVA results at the last follow-up visit rather than predetermined time points could have introduced bias. However, given the similar characteristics and results of eyes lost to follow-up and those that remained with >15 years' follow-up, it appears reasonable to assume that this bias may be minimal. In particular, our point estimate of the graft failure probability at 25 years, 14.6%, had an upper 95% confidence limit of 26.9%, based on statistical considerations. However, given the serious nature of graft failure that compels patients to return for evaluation and the fact that most censoring events in our follow-up were losses to follow-up, not deaths, we believe the true expected rate is close to our point estimate. Finally, it is possible that even longer follow-up would reveal increasing rates of graft failure or recurrence, especially as these eyes undergo CE.

In summary, this study provides an important long-term benchmark of PK for keratoconus. As other surgical procedures such as epikeratoplasty[36] and deep anterior lamellar keratoplasty[37] are utilized, it is important to compare the results of these techniques with the standard set by PK.

References

1. Krachmer JH, Feder RS, Belin MW. Keratoconus and related noninflammatory corneal thinning disorders. Surv Ophthalmol 1984;28:293–322.
2. Sugar A, Sugar J. Techniques in penetrating keratoplasty: a quarter century of development. Cornea 2000;19:603–10.
3. Cosar CB, Sridhar MS, Cohen EJ, et al. Indications for penetrating keratoplasty and associated procedures, 1996–2000. Cornea 2002;21:148–51.
4. Dobbins KR, Price FW Jr, Whitson WE. Trends in the indications for penetrating keratoplasty in the midwestern United States. Cornea 2000;19:813–6.
5. Yahalom C, Mechoulam H, Solomon A, et al. Forty years of changing indications in penetrating keratoplasty in Israel. Cornea 2005;24:256–8.
6. Al-Towerki AE, Gonnah el-S, Al-Rajhi A, Wagoner MD. Changing indications for corneal transplantation at the King Khaled Eye Specialist Hospital (1983–2002). Cornea 2004; 23:584–8.

7. Williams KA, Muehlberg SM, Lewis RF, Coster DJ. How successful is corneal transplantation? A report from the Australian Corneal Graft Register. Eye 1995;9:219–27.
8. Edwards M, Clover GM, Brookes N, et al. Indications for corneal transplantation in New Zealand: 1991–1999. Cornea 2002;21:152–5.
9. Patel SV, Hodge DO, Bourne WM. Corneal endothelium and postoperative outcomes 15 years after penetrating keratoplasty. Am J Ophthalmol 2005;139:311–9.
10. Muraine M, Sanchez C, Watt L, et al. Long-term results of penetrating keratoplasty: a 10-year-plus retrospective study. Graefes Arch Clin Exp Ophthalmol 2003;241:571–6.
11. Paglen PG, Fine M, Abbott RL, Webster RG Jr. The prognosis for keratoplasty in keratoconus. Ophthalmology 1982;89: 651–4.
12. Ehlers N, Olsen T. Long term results of corneal grafting in keratoconus. Acta Ophthalmol (Copenh) 1983;61:918–26.
13. Sharif KW, Casey TA. Penetrating keratoplasty for keratoconus: complications and long-term success. Br J Ophthalmol 1991;75: 142–6.
14. Yamagami S, Suzuki Y, Tsuru T. Risk factors for graft failure in penetrating keratoplasty. Acta Ophthalmol Scand 1996;74: 584–8.
15. Ing JJ, Ing HH, Nelson LR, et al. Ten-year postoperative results of penetrating keratoplasty. Ophthalmology 1998;105: 1855–65.
16. Olson RJ, Pingree M, Ridges R, et al. Penetrating keratoplasty for keratoconus: a long-term review of results and complications. J Cataract Refract Surg 2000;26:987–91.
17. Dandona L, Ragu K, Janarthanan M, et al. Indications for penetrating keratoplasty in India. Indian J Ophthalmol 1997; 45:163–8.
18. Thompson RW Jr, Price MO, Bowers PJ, Price FW Jr. Long-term graft survival after penetrating keratoplasty. Ophthalmology 2003;110:1396–402.
19. Inoue K, Amano S, Oshika T, Tsuru T. Risk factors for corneal graft failure and rejection in penetrating keratoplasty. Acta Ophthalmol Scand 2001;79:251–5.
20. Sit M, Weisbrod DJ, Naor J, Slomovic AR. Corneal graft outcome study. Cornea 2001;20:129–33.
21. Kremer I, Eagle RC, Rapuano CJ, Laibson PR. Histologic evidence of recurrent keratoconus seven years after keratoplasty. Am J Ophthalmol 1995;119:511–2.
22. Thalasselis A, Etchepareborda J. Recurrent keratoconus 40 years after keratoplasty. Ophthalmic Physiol Opt 2002;22:330–2.
23. de Toledo JA, de la Paz MF, Barraquer RI, Barraquer J. Long-term progression of astigmatism after penetrating keratoplasty for keratoconus: evidence of late recurrence. Cornea 2003;22:317–23.
24. Abelson MB, Collin HB, Gillette TE, Dohlman CH. Recurrent keratoconus after keratoplasty. Am J Ophthalmol 1980;90: 672–6.
25. Bechrakis N, Blom ML, Stark WJ, Green WR. Recurrent keratoconus. Cornea 1994;13:73–7.
26. Nirankari VS, Karesh J, Bastion F, et al. Recurrence of keratoconus in donor cornea 22 years after successful keratoplasty. Br J Ophthalmol 1983;67:23–8.
27. Bourges JL, Savoldelli M, Dighiero P, et al. Recurrence of keratoconus characteristics. A clinical and histologic follow-up analysis of donor grafts. Ophthalmology 2003;110:1920–5.
28. Mendes F, Schaumberg DA, Navon S, et al. Assessment of visual function after corneal transplantation: the quality of life and psychometric assessment after corneal transplantation (Q-PACT) study. Am J Ophthalmol 2003;135:785–93.
29. Price FW Jr, Whitson WE, Marks RG. Graft survival in four common groups of patients undergoing penetrating keratoplasty. Ophthalmology 1991;98:322–8.
30. Jähne M. Keratokonusrezidiv nach Keratoplastik. Z Arztl Fortbild (Jena) 1974;68:434–6.
31. Fanta H. Akuter keratoconus. Ber Zusammenkunft Dtsch Ophthalmol Ges 1972;71:46–51.
32. Rubinfeld RS, Traboulsi EI, Arentsen JJ, Eagle RC Jr. Keratoconus after penetrating keratoplasty. Ophthalmic Surg 1990; 21:420–2.
33. Teng CC. Electron microscope study of the pathology of keratoconus: I. Am J Ophthalmol 1963;55:18–47.
34. Cannon DJ, Foster CS. Collagen crosslinking in keratoconus. Invest Ophthalmol Vis Sci 1978;17:63–5.
35. Tuft SJ, Gregory W. Long-term refraction and keratometry after penetrating keratoplasty for keratoconus. Cornea 1995; 14:614–7.
36. Wagoner MD, Smith SD, Rademaker WJ, Mahmood MA. Penetrating keratoplasty vs. epikeratoplasty for the surgical treatment of keratoconus. J Refract Surg 2001;17:138–46.
37. Anwar M, Teichmann KD. Deep lamellar keratoplasty: surgical techniques for anterior lamellar keratoplasty with and without baring of Descemet's membrane. Cornea 2002;21:374–83.