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Cost Minimization Analysis of Precut Cornea Grafts in Descemet Stripping Automated Endothelial Keratoplasty

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Abstract: Descemet stripping automated endothelial keratoplasty (DSAEK) is the most common corneal transplant procedure. A key step in the procedure is preparing the donor cornea for transplantation. This can be accomplished via 1 of 3 alternatives: surgeon cuts the cornea on the day of surgery, the cornea is precut ahead of time in an offsite facility by a trained technician, or a precut cornea is purchased from an eye bank. Currently, there is little evidence on the costs and effectiveness of these 3 strategies to allow healthcare providers decide upon the preferred method to prepare grafts.

The aim of this study was to compare the costs and relative effectiveness of each strategy.

The Singapore National Eye Centre and Singapore Eye Bank performed both precut cornea and surgeon-cut cornea transplant services between 2009 and 2013.

This study included 110 subjects who received precut cornea and 140 who received surgeon-cut cornea. Clinical outcomes and surgical duration were compared across the strategies using the propensity score matching. The cost of each strategy was estimated using the microcosting and consisted of facility costs and procedural costs including surgical duration. One-way sensitivity analysis and threshold analysis were performed.

The cost for DSAEK was highest for the surgeon-cut approach (\$13,965 per procedure), followed by purchasing precut corneas (\$12,659) and then setting up precutting (\$12,421). The higher procedural cost of the surgeon-cut approach was largely due to the longer duration of the procedure (surgeon-cut = 72.54 minutes, precut = 59.45 minutes, $P < 0.001$) and the higher surgeon fees. There was no evidence of differences in clinical outcomes between grafts that were precut or surgeon-cut. Threshold analysis demonstrated that if the number of cases was below 31 a year, the strategy that yielded the lowest cost was purchasing precut cornea from eye bank. If there were more than 290 cases annually, the cheapest option would be to setup precutting facility.

Our findings suggest that it is more efficient for centers that are performing a large number of cornea transplants (more than 290 cases) to set up their own facility to conduct precutting.

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Abbreviations: ALTK = automated lamellar therapeutic keratoplasty, ASC = ambulatory surgical center, DSAEK = Descemet stripping automated endothelial keratoplasty, phaco/ DSAEK = Descemet stripping automated endothelial keratoplasty combined with cataract extraction.

INTRODUCTION

The cornea is the clear tissue in the anterior segment of the eye that allows transmission of light and vision. Cornea transplantation is the most commonly performed organ transplantation in the United States and United Kingdom.^{1,2} Over the last decade the surgery has changed significantly with partial thickness procedures (where anterior lamellar or the posterior lamellar [endothelial keratoplasty] are selectively replaced) have begun to replace the traditional full-thickness cornea replacement (penetrating keratoplasty).^{3,4} In the United States and Singapore, endothelial keratoplasty account for between 48% (unpublished data from Singapore Corneal Transplant Study) and 54.6% of all corneal transplantation performed.³ The impetus for change has been driven by faster visual rehabilitation and better visual acuity with the newer procedure.⁵ However, this has had to be balanced against higher initial early complication rates, the learning of new surgical skills, and new methods of eye banking.⁶⁻⁸

Descemet stripping automated endothelial keratoplasty (DSAEK) is the commonest form of posterior lamellar corneal transplantation. DSAEK has been shown to be comparable or superior to penetrating keratoplasty in outcomes in terms of visual rehabilitation, astigmatism, and graft survival.^{5,9,10} DSAEK requires the preparation of the donor cornea before implantation into recipient's eye. This involves the surgeon/eye bank cutting the donor cornea with a microkeratome to produce a lamellar graft of between 60 and 200 μm .^{8,11,12} In recent years, many eye banks especially in the United States are providing precutting services for the donor cornea. In the United States, about two-thirds of all DSAEK procedures use precut tissue cut by the eye bank.³ The advantages of precutting tissue include quality assurance following the cutting procedure and reduced unexpected cancellation of surgery due to unsuccessful cutting in the operating theatre.^{13,14} Precutting the cornea in an eye bank by trained technicians, who perform this procedure multiple times per day, has allowed optimization of the technique, hence minimizing complications from donor preparation. There is also additional cost saving when precutting pairs of corneas from a single donor, since there are less consumables used. However, in Europe and Asia, precutting services are not widely available due to legislative issues or from lack of adequate eye bank facilities.^{15,16}

A cornea transplant that restores vision for patients with diseased or damaged corneas has tremendous economic benefits. It is estimated that a successful cornea transplant

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could lead to savings of \$77,000 in avoided direct medical expenses associated with blindness and \$214,000 in avoided productivity loss over the course of a patient's life.¹⁷ However, the cost of cornea transplants has been growing over the last decade.^{1,3,4,18} The cost of corneal transplantation in the United States has increased by more than 28% since 2005.^{1,18} Volume too has greatly increased due to an ageing population. Such increase in the volume and the cost have added pressure to an already strained healthcare financing system and raise the need to identify the most efficient approach to transplantation.

Although precutting in a donor eye bank has potential advantages compared with conventional donor preparation, it is not yet known if a precutting service is less expensive than the conventional method of cutting by eye surgeons. Furthermore, within the precutting option, there are 2 alternative choices. One option is to have corneas precut in a facility by trained technicians. Another option is to purchase a cornea which is already precut from another eye bank. Using data from the Singapore National Eye Centre and other sources, this study compared the costs and effectiveness (defined as clinical outcomes and complication rates of the transplants) of 3 alternatives: surgeon cuts the cornea on the day of surgery, the cornea is precut ahead of time in an offsite facility by a trained technician, or a precut cornea purchased from an eye bank. The study also identifies the case volume threshold where setting up a facility for precutting becomes the low cost option. We hypothesize that the clinical outcomes and complication rates are comparable between the surgeon-cut and the precut options. We also expect that precutting is cost saving compared to surgeon-cutting, and setting up a facility for precutting will dominate the other 2 strategies if the case volume threshold exceeds a certain number due to economies of scale.

METHODS

Description of Clinical Procedures

All 3 strategies involved the same surgical technique of DSAEK or DSAEK combined with cataract extraction (phaco/ DSAEK). The only difference was in the way the cornea was prepared. For precut tissue method, donor tissue was prepared in an eye bank or in a facility on site by a trained technician within 24 hours of DSAEK as previously described.¹⁹ Briefly, each donor corneal rim was prepared within a laminar flow hood and mounted onto an artificial anterior chamber (Moria Automated Lamellar Therapeutic Keratoplasty [ALTK] system, Antony, France). Ultrasound pachymetry was done to measure the tissue thickness. Automated microkeratome was used to cut the tissue, and the posterior lamellar thickness was measured using repeated ultrasound pachymetry. The anterior cap and posterior lamellar were then placed back together in the original Optisol GS-filled storage container, and this was stored at 4 °C until surgery.

For the strategy of purchasing a precut cornea, the precut corneas are obtained from an eye bank and air freighted to Singapore where they are stored and transplanted within 48 hours of precutting. If one was to set up a facility to do the precutting, a full thickness donor cornea would be acquired either through local or overseas donations. The corneas would be cut in the facility by trained technicians. With the surgeon-cut method, a donor cornea would be harvested locally, or purchased from overseas, and tissue would be prepared by the surgeon using an ALTK system during surgery. The surgical technique used in this study has previously been described in detail.²⁰

Study Population and Patient Types

The study population consisted of 250 patients, with 110 subjects receiving precut cornea and 140 subjects who received surgeon-cut cornea. Allocations of these patients into the precut or the surgeon-cut options, and DSAEK and phaco/ DSAEK were nonrandom and correlated with the indication of surgery and the presence of significant cataract. Specifically, patients with surgery indication and/or significant cataract were more likely to have phaco/ DSAEK. In the analysis, we performed propensity score matching to correct for any possible bias resulting from this selection into the procedures. This study included all patients who underwent DSAEK or phaco/ DSAEK performed by 2 surgeons (JM or DT) between July 2009 and January 2013 in Singapore National Eye Centre. Patients who had complex combined surgeries, for example, DSAEK combined with tube explant, secondary IOL explant/implant, or vitrectomy were excluded. Written informed consent was obtained from all subjects, and ethics approval was obtained from the Institutional Review Board of the hospital. The study was carried out in accordance with the tenets of World Medical Association's Declaration of Helsinki.

In each option, patients were divided into "complicated" or "uncomplicated" cases. The definition of "complicated" has been previously described.²¹ In brief, complicated cases included anterior segment pathology such as anterior chamber intraocular lens, primary angle closure glaucoma, anterior segment dysgenesis and almost all previous intraocular surgery (e.g., trabeculectomy, tube, and failed graft), and complicated cataract surgery. Corneal edema from previous uncomplicated cataract surgery was included and categorized as "uncomplicated." Complicated cases were expected to have a longer surgical duration and thus have higher costs.

Study Outcomes and Measurements

The main study outcomes were costs and effectiveness. Effectiveness was based on the clinical outcomes of surgeon-cut and precut cornea transplants at the end of 1 year, including baseline visual acuity, graft failure and graft dislocation rates, and proportion of patients who required subsequent surgeries. In this descriptive analysis, we only compared precut setup option with surgeon cut option because all the precut tissues in our center have been cut in our facility. For the cost analysis, however, we compared 3 alternative options, as there were 2 alternative methods of attaining precut corneas, assuming that outcomes of using precut corneas obtained from purchasing or setup facilities were the same.

The cost of each strategy consisted of costs of setting up a facility (if required) and procedure costs. The facility costs consisted of a fixed cost component and a variable component. The fixed costs of setting up a facility for precutting include costs for a Moria Evolution 3 Console, Moria ALTK artificial chamber, turbine, hose, 300 and 350 head, storage trays, eye bank refrigerator, slit-lamp biomicroscope, specular microscope, ultrasound pachymeter, laminar flow hood, small box freezer, instruments, autoclave, trolley, nitrogen tank, nitrogen stand, regulator, and hose (appendix 1, supplemental digital content, <http://links.lww.com/MD/A721>). For the purchase precut cornea option, the fixed cost consisted only of an eye bank refrigerator, slit-lamp, and small box freezer for storage and examination of the precut cornea. Annualized fixed costs of setting up a facility were calculated based on the assumption that equipment would fully depreciate over a 5-year time

horizon. The variable cost component comprised costs of maintenance, manpower (technicians' salary), and space rental.

Procedural costs included costs for corneal grafts, transportation costs, surgical procedure cost, and cost of clinical consultations associated with procedure, which could vary by strategy (appendix 2, supplemental digital content, <http://links.lww.com/MD/A721>). A major component of procedural costs was the surgical duration, which differed between the 3 strategies. Surgeon and ambulatory surgical center (ASC) fees were imputed based on the surgical duration and imputed hourly costs for labor and ASC space. The surgical procedure cost was a weighted average of the costs of DSAEK and phaco/DSAEK procedures. DSAEK accounts for 66% and phaco/DSAEK for 34% of the total procedures performed, based on our center's data.

We estimated both the overall cost of each option and the cost of each transplant under each option. The overall cost of each option was given by the yearly cost of each option multiplied by the 5 year study period. The yearly cost of each option in turn is the sum of the annualized fixed cost of facility set-up, the yearly variable cost component of facility set-up and the yearly procedure costs (which equaled the procedure cost per transplant multiplied by yearly number of transplants).

The cost estimation was based on a number of assumptions. It was assumed that all corneas were obtained from SightLife, an eye bank in Seattle, United States. The purchased precut corneas arrived a day before and would require refrigeration. The manpower required for precutting setup was only 1 trained technician, and there was no cornea tissue wastage. The yearly number of transplants was assumed to be the mean number of transplants conducted at our center between 2011 and 2013. Procedure costs were based on charges for non-subsidized Singapore citizens as of 1st June 2014. As Singapore public hospitals operate on cost recovery basis, these charges reflect the true costs (including fixed costs). For ease of interpretation, all costs and charges were converted from Singapore dollars (S\$) to United State dollars (\$), with S\$1 equivalent to \$0.80, according to the exchange rate as of 1st September 2014.

Data Sources

Outcomes data were obtained from an ongoing cohort from the Singapore Corneal Transplant Study, a longitudinal audited prospective study that collected preoperative, intraoperative, and yearly postoperative data. Costs of setting up the facility (both fixed and variable costs) were obtained from a review of Singapore Eye Bank business office's contracts and payment invoices. The procedure cost items were compiled from billing data from Singapore National Eye Centre.

Statistical Analysis

To account for the differences in the baseline characteristics between precut and surgeon-cut cornea transplant patients, propensity score matching with replacement was performed in the analyses of cost and effectiveness analysis. After a matched sample was formed, effectiveness outcomes were analyzed with paired *t*-test for continuous variables (visual acuity, graft related complications, and subsequent surgeries). In the cost analysis, the matched sample was analyzed with paired *t*-test to compare the time duration between precut and surgeon-cut surgeries, which was a main component of cost difference between the 2 strategies. A statistical significance level of 0.05 was used in this study.

Sensitivity analyses were performed to test the robustness of the results. Key variables which were the main drivers of the costs (i.e., volume of cases, ALTK cost, ASC cost, and cornea cost) were varied to examine their effect on the results. The sensitivity ranges were obtained by varying the lower and upper limit by 50% of the base value. One-way sensitivity analyses were performed in which each of the key variables was varied independently, and the outcome was examined. Threshold analysis was performed by varying the number of cases and looking at the expected costs outcomes of the 3 strategies. A threshold value (for the number of cases) was attained when 1 strategy changed from being less to more expensive than another comparator. We conducted statistical analysis with STATA software (version 13, STATA Corp, College Station, TX) and TreeAge Pro 2013.

RESULTS

The demographics of the study population were summarized in Table 1. Eighty-four of the 250 subjects (34%) underwent phaco/DSAEK and the remaining underwent DSAEK alone. There was a significantly higher ($P < 0.001$) proportion of precut subjects who were labeled as "complicated" cases, and the indications for the transplants in the 2 groups were also significantly different ($P = 0.013$). There were no significant differences in graft-related complications rate as well as the proportion of patients who required to undergo subsequent surgeries between the 2 groups (Table 2).

For the precut group, the 2 main indications for surgery were previous failed graft and pseudophakic bullous keratopathy, while the surgeon-cut group was pseudophakic bullous keratopathy and Fuch endothelial corneal dystrophy. After the propensity score matching, the precut and surgeon-cut groups were not significantly different in terms of complications ($P = 0.13$) and subsequent surgical procedures ($P = 0.10$) (Table 3). There were also no significant differences in terms of postoperative best-correctable visual acuity (BCVA) ($P = 0.19$) and proportion of subjects with BCVA of 6/12 or better ($P = 0.24$).

After adjusting for differences in baseline characteristics of patients in the 2 groups (i.e., precut vs surgeon-cut), there was significant time savings ($P < 0.001$) of 13.1 minutes (standard error [SE] of 3.5 minutes) for precut over surgeon-cut surgeries. Precut DSAEK alone was significantly faster than surgeon-cut (55.49 vs 71.33 minutes, SE of 6.77 minutes, $P = 0.019$), while combined precut phaco/DSAEK was 11.31 minutes faster than surgeon-cut (69.16 vs 80.46 minutes, SE of 5.67 minutes, $P = 0.054$) (Table 3).

Examining the facility costs required for the 3 different strategies, we found that in the setup precut strategy, the cost was highest at \$160,750 plus \$39,870 per year including rental, manpower, and maintenance. For surgeon-cut strategy, the fixed cost was \$143,750 plus \$3500 per year. In contrast, the fixed cost for purchasing precut corneas was only \$14,750 (Table 4).

The procedure cost per DSAEK was highest for surgeon-cut at \$13,965 per transplant, whereas for precut setup and purchasing precut the procedure cost per transplant was \$12,421 and \$12,659, respectively. This higher cost incurred for surgeon-cut cornea transplant was mainly due to the longer surgical duration, and hence, the higher cost of surgeon and ASC fees. If local corneas (which were cheaper at \$1573 per cornea) were used instead of tissue from SightLife eye bank, the difference in costs would be even more distinct between surgeon-cut and

TABLE 1. Summary of Patients Characteristics

	Total (n = 250)	Precut (n = 110)	Nonprecut (n = 140)	P
Mean age (SD), years	64.22 (14.39)	63.7 (14.92)	64.62 (13.99)	0.62
Male	121	51	70	0.57
Race				0.64
Chinese	147	59	88	
Malay	14	7	7	
Indian	20	9	11	
Indonesian	52	28	24	
Others*	17	7	10	
Phaco/DSAEK	84	32	52	0.18
DSAEK	166	78	88	
Complicated†	136	76	60	<0.001
Uncomplicated	114	34	80	
Indication for surgery				0.01
PBK	93	34	59	
FECD	66	23	43	
Aphakic bullous keratopathy	2	1	1	
Failed graft	53	36	17	
Anterior segment dysgenesis	7	3	4	
DMD	9	5	4	
Post LPI	4	1	3	
Others‡	16	7	9	

Independent *t*-test for age and duration. χ^2 for gender, race, type of surgery, complicated, and indications. DMD = Descemet membrane detachment, DSAEK = Descemet stripping automated endothelial keratoplasty, FECD = Fuch endothelial corneal dystrophy, LPI = laser peripheral iridotomy, PBK = pseudophakic bullous keratopathy, SD = standard deviation.

* Other races include Burmese, Caucasian, and Bangladeshi.

† Complicated cases included anterior segment pathology such as anterior chamber intraocular lens, primary angle closure glaucoma, anterior segment dysgenesis and almost all previous intraocular surgery (e.g., trabeculectomy, tube, and failed graft), and complicated cataract surgery.

‡ Other indication for surgery includes corneal decompensation postglaucoma surgery, posttrauma, postendophthalmitis, chronic uveitis, and keratitis.

setup precut (\$12,538 and \$10,994, respectively). Meanwhile, the overall cost per transplant (i.e., procedure cost plus salary for technicians, rental, maintenance, and fixed cost) is slightly higher for setting up precut facilities than for purchasing precut (\$13,749 vs \$13,893; Table 5).

Sensitivity analyses were performed to test the robustness of the results of this cost-minimization study. In 1-way sensitivity analysis, the results from varying each of the 4 key individual variables (volume of cases, ALTK cost, ASC cost, and cornea cost) to examine their effect on the overall outcome of this cost-minimization analysis were shown in Table 6. The main driver of the cost difference was the number of cases performed in a facility. For example, there was almost a 3-fold

increase in the cost when we increased the number of cases from 50% below the baseline to 50% above the baseline. The second driver of the cost was the ambulatory and surgeon cost: the overall cost almost doubled when the ambulatory and surgeon cost was adjusted from lower to upper limit (Figure 1). The cost savings from the precutting over surgeon-cut strategy will also increase. Hence, the preferred strategy for a center with more inexperienced surgeons should be the precut. Moreover, the novice surgeon could avoid the extra step of the learning curve required for cutting the cornea themselves.

The threshold analysis demonstrated that if the number of cases was below 31 a year, the strategy that yielded the lowest cost was purchasing precut cornea from an eye bank (Figure 2).

TABLE 2. Postsurgical Graft Related Complications and Subsequent Surgeries

	Total (n = 250)	Precut (n = 110)	Nonprecut (n = 140)	P
Graft related complications, n (%), (SD)	12 (4.8%, 0.21)	9 (8.1%, 0.26)	3 (2.1%, 0.15)	0.14
Failed graft, n (%), (SD)	9 (3.6%, 0.19)	7 (6.4%, 0.25)	2 (1.4%, 0.12)	
Dislocated grafts, n (%), (SD)	3 (1.2%, 0.11)	2 (1.8%, SD 0.13)	1 (0.7%, 0.09)	
Subsequent surgeries, n (%), (SD)	11 (4.4%, 0.21)	9 (8.2%, 0.28)	2 (1.4%, 0.12)	0.11
Repeat graft, n (%), (SD)	8 (3.2%, 0.18)	7 (6.4%, 0.25)	1 (0.7%, 0.09)	
Re-bubbling, n (%), (SD)	3 (1.2%, 0.11)	2 (1.8%, 0.13)	1 (0.7%, 0.09)	

χ^2 test performed for graft related complications and subsequent surgeries. SD = Standard deviation.

TABLE 3. Propensity Score Matched Estimated Duration of Surgery and Clinical Outcomes

	Precut	Nonprecut	Difference	SE	P
Mean surgical duration					
Overall, minutes	59.45	72.54	-13.1	3.5	<0.001
phaco/DSAEK, minutes	69.16	80.46	-11.31	5.87	0.054
DSAEK, minutes	55.49	71.33	-15.84	6.77	0.019
Clinical outcomes					
Mean preoperative BCVA, logmar	1.27	1.23	0.04	0.1	0.66
Mean postoperative BCVA, logmar	0.59	0.49	0.1	0.08	0.19
Proportion of subjects BCVA improve at 1 year, %	87.8	92.8	5	0.05	0.32
Proportion of subjects BCVA 6/12 or better, %	50.5	59.9	9.4	0.08	0.24
Proportion of subjects Graft Related Complications, %*	6.4	2.3	4.1	0.027	0.13
Proportion of subjects Subsequent Surgeries, %†	6.4	2	4.4	0.027	0.10

Propensity score matched (Kernel matching) for age, gender, race, complicated cases, and indications of surgery (Fuchs endothelial corneal dystrophy). SE estimated by Bootstrap method. BCVA=best corrected visual acuity, DSAEK=Descemet stripping automated endothelial keratoplasty, SE=standard Error.

* Graft related complications included graft failure and dislocation of graft.

† Subsequent surgeries included repeat graft and re-bubbling of graft.

If there were 31 cases, the surgeon-cut was the most expensive, but the cost savings would only be \$1284 over setting up a facility. If the center performed between 31 and 290 cases a year, the least costly strategy would be purchasing precut cornea, and the most costly would be the surgeon-cut, with cost differences ranging from \$62,976 (for 31cases) to \$344,336 (for 290 cases). If there were more than cases a year, the cheapest option would be to set up a facility for precutting cornea. The cost savings of the setup precut over surgeon-cut was estimated to be at least \$345,610, although the differences between purchase precut and setup precut was much smaller at \$188 (Table 7).

DISCUSSION

This study showed that using precut donor corneas reduced surgical duration of each transplant by 13.1 minutes (SE 3.5 min). Precut tissue saves time, workload and cost for surgeons and the medical center, especially those who do not have the facility to prepare the tissue in the OT.¹³ The shorter surgical time also benefits the patient with shorter surgical duration and hence shorter anesthetic time. Shorter surgical time saves costs for the center and surgeon, and the time savings could potentially be channeled into other sources of productivity for the center. For example, a surgeon who performs

TABLE 4. Comparison of Facility Costs and Procedural Costs

	Surgeon Cut	Precut – Setup Model	Precut – Purchase
Facility costs			
(A) Fixed cost*	\$143,750	\$160,750	\$14,750
(B) Variable cost			
Maintenance for equipment	\$3500	\$3500	0
Manpower (salary for technician)	0	\$30,000 per person	0
Rental	0	\$6370	0
Total	\$143,750 and \$3500 per year	\$160,750 and \$39,870 per year	\$14,750
Procedural costs			
A) DSAEK†	\$13,965	\$12,421	\$12,659
B) phaco/DSAEK†	\$16,465	\$15,568	\$15,806

DSAEK = Descemet stripping automated endothelial keratoplasty.

* Includes Moria Evolution 3 Console, Moria ALTK artificial chamber, turbine, Hose, 300 and 350 head, storage trays (1 set), eye bank refrigerator, specular microscope, ultrasound pachymeter, laminar flow hood, Small box freezer, Instruments, autoclave, trolley, nitrogen tank & stand, regulator and hose. (Refer to Appendix 1, supplemental content, <http://links.lww.com/MD/A721>, for details on facility costs of surgeon-cut, setup precut and purchase precut strategies).

† Includes office initial consultations fees, surgeon and ambulatory surgical center fees, 7 follow-up visit consultations over a year, precut fees by US eye bank (Seattle), freight shipping from USA to Singapore, courier fees, Singapore Eye Bank precut fees (primary consumables, manpower, utilities) and cornea cost (including handling fees). (Refer to Appendix 2, supplemental content, <http://links.lww.com/MD/A721>, for details on comparison of procedural costs for DSAEK & phaco/DSAEK).

TABLE 5. Overall Costs Evaluation

	Surgeon Cut	Precut – Setup Model	Precut – Purchase
Fixed cost	\$143,750	\$160,750	\$14,750
Length	5	5	5
Fixed cost per year	\$28,750	\$32,150	\$2950
Variable per year*	\$3500	\$39,870	\$0
Procedural cost	\$14,815	\$13,491	\$13,729
Number of cases	164	164	164
Procedural cost per year	\$2,429,678.30	\$2,212,488	\$2,251,520
Total cost per year	\$2,461,928	\$2,284,508	\$2,254,470
Total cost 5 years	\$12,309,641	\$11,422,541	\$11,272,351
Estimated cost per transplant†	\$15,012	\$13,930	\$13,747

* Includes maintenance fee, salary of technician, and rental cost.

† Assuming 164 cases per year.

4 precut transplant saves 52 minutes, and this extra time may be used to perform a 5th transplant or other surgeries.

Our study showed no differences in transplant outcome using either surgeon-cut or precut corneas. This is similar to other reports which showed precut cornea were safe and outcomes comparable to surgeon-cut tissue.^{22–25} Eye bank prepared precut tissue was reliable with good endothelial cell count postcutting and minimal tissue wastage,⁸ and an eye bank survey of surgeons using precut donor tissue reported high satisfaction rate.²⁶ It has also been shown that there were no differences in outcome for cornea tissue that was prepared in advanced with storage for 1 or 2 days compared with same-day preparation.²⁷ For countries which do not have the facilities to precut cornea, there is an option to procure precut corneas from elsewhere, as internationally shipped precut corneas are safe.^{28,29} However, there is an increased storage time associated with international transport, and there may potentially be additional logistic issues such as airplane delay that prevents the cornea to be implanted while the tissue is still viable.

With regards to cost, the cost differences were variable depending on the volume of cases. DSAEK procedural costs ranged from \$12,421 to \$16,465 in this study. In the United States, the cost of endothelial keratoplasty was estimated to be \$20,953 for under age 65 years and \$16,500 for age 65 and above.¹⁷ These differences may be accounted for by the different facility costs and manpower costs. Among the 3 different

strategies, it appeared least costly for centers to set up their own facility to prepare precut corneas if they are performing more than 290 cases yearly. The higher volume of tissue processing in a center ensures that the investment in equipment that is necessary for optimal processing is financially feasible.⁸ A low volume center would likely find the purchasing of the equipment for setup prohibitive.³⁰ For a low volume center (less than 31 cases yearly), it would be less expensive to purchase precut corneas from other eye banks or facilities than for the surgeon to perform the cutting of cornea. Between 31 and 290 cases, the preferred strategy should be precut (either setup or purchase) rather than surgeon-cut. As the caseload increases, the cost savings of purchasing precut over setup facility to precut gets smaller. If the center was high volume (more than 290 cases), it would pay to develop a facility to precut. As clinical outcomes were the same in all strategies, the implication was that it is more advantageous to move away from surgeon-cut cornea and choose pre-cutting (either purchasing or setting up a facility).

Although the overall transplant costs indicated that purchasing precut corneas is a less expensive option than the precut setup option in the base case analysis (Table 5), this result is based on our center's mean number of grafts from 2011 to 2013, that is, 164 cases per year. If a center performs a sufficiently high number of grafts (i.e., more than 290 cases per year), setting up a precut facility will become less expensive than

TABLE 6. Sensitivity Ranges*

Variable	Base Value	Sensitivity Range
Set of full ALTK	\$80,000	\$40,000–\$120,000
Number of cases	164	82–246
Cost of each cornea	\$3000	\$1500–\$4500
Surgeon and ambulatory surgical fees		
Precut DSAEK	\$7904	\$3952–\$11,856
Precut phaco/DSA EK	\$11,051	\$5526–\$16,577
Surgeon-cut DSAEK	\$10,160	\$5080–\$15,240
Surgeon-cut phaco/DSA EK	\$12,660	\$6330–\$18,990

ALTK = automated lamellar therapeutic keratoplasty, DSAEK = Descemet stripping automated endothelial keratoplasty.

* Refer to Appendix 3, supplemental content, <http://links.lww.com/MD/A721>, on details of sensitivity ranges and cost evaluation for 5 years.

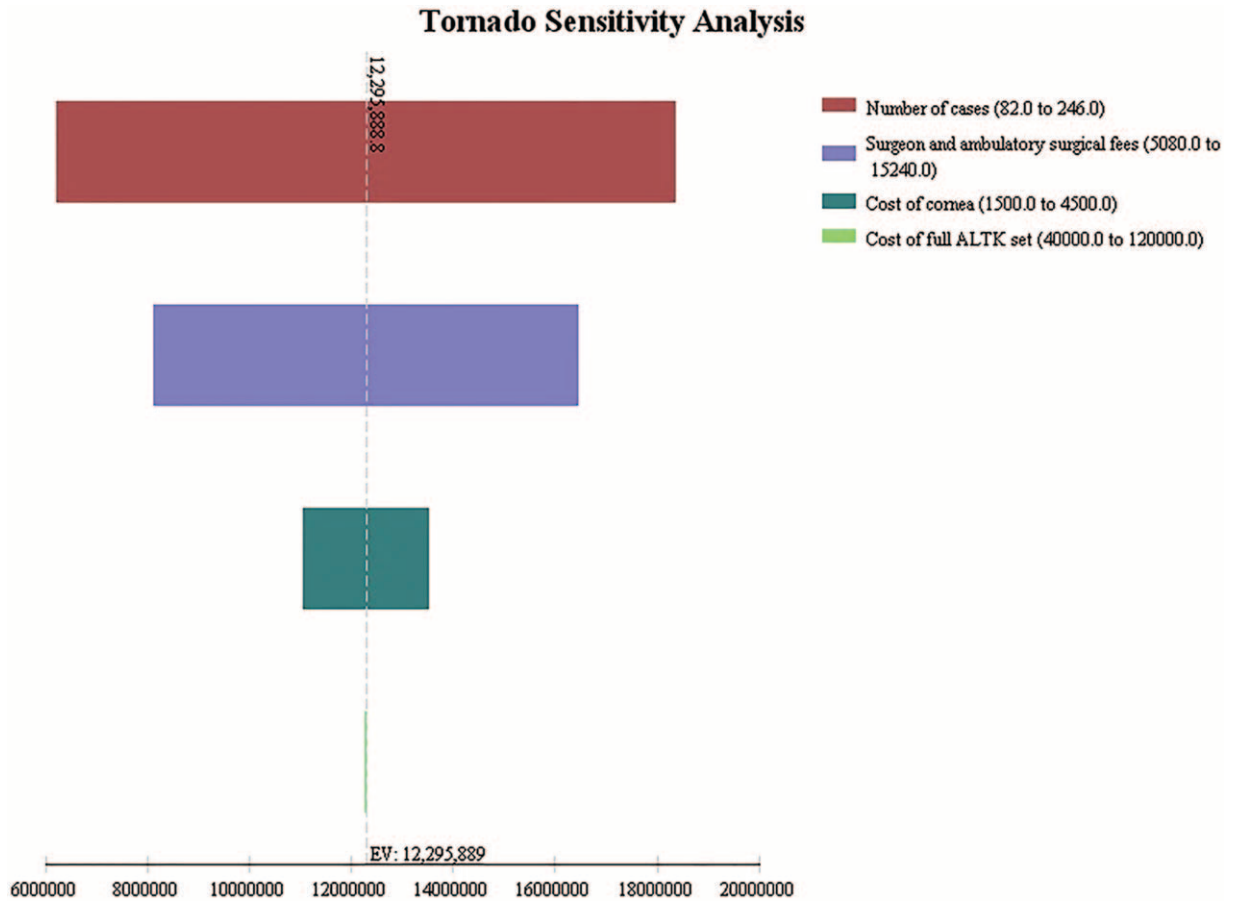


FIGURE 1. Sensitivity analysis of key variables. ALTK = automated lamellar therapeutic keratoplasty, EV = estimated value.

purchasing precut corneas. This scenario is likely to apply to countries that face a larger demand for DSAEKs than Singapore. Yet, even in Singapore, the number of DSAEKs will likely exceed the threshold value of 290 case per year soon as the number of cases have increased in the past few years (from 108 cases in 2009 to 188 cases in 2014, Singapore Cornea Transplant Study, unpublished data).

There are a shortage of cornea donors in many countries,²⁸ and setting up a facility to perform precutting may allow distribution of precut corneas to nearby regional centers which do not have sufficient tissue or the facility to cut the corneas themselves. This will also increase the volume of tissue processing, hence maximizing the investment cost and minimizing the cost per case of DSAEK using precut cornea. If the precut cost could be further reduced, the overall cost savings of issuing precut cornea over surgeon-cut will be even more pronounced.

Our study has a number of limitations. First, this cost minimization model is based on Singapore current medical financing model and may not be exactly extrapolated to other countries with different health care financing systems. One author commented that the current prevailing reimbursement in United States for surgeon cutting cornea tissue is substantially lower than the precutting fees charged by eye banks, and the financial circumstances may favor surgeon-cut tissue processing.²⁵ Although it would have been preferable to use data from multiple institutions and eye banks, Singapore only has 1 eye bank and Singapore National Eye Centre performs over

83% of the country’s DSAEK cases. As a result, adding additional eye banks or centers is not realistic. Moreover, because Singapore draws patients from around the world, including UK and US, the prices are set based on market forces and therefore are generalizable to other highly skilled transplantation centers. In addition, we have performed sensitivity

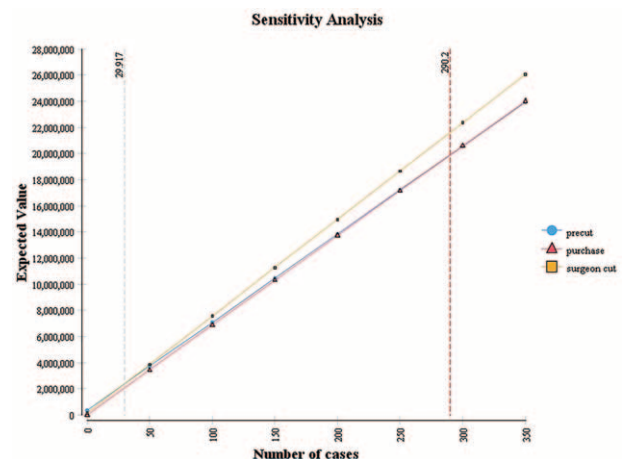


FIGURE 2. Threshold analysis of number of cases of setup precut, surgeon-cut, and purchase of precut.

TABLE 7. Number of Cases Performed and Resulting Annual Cost in Various Strategies

Number of Cases Per Year	1 to 30	31 to 290	291 and Above
Most costly	Setup precut facility	Surgeon cut	Surgeon cut
Range of costs	\$85,511 to \$476,743	\$491,518 to \$4,328,632	\$4,343,447 and above
Second most costly	Surgeon cut	Setup precut facility	Purchase precut
Range of costs	\$47,065 to \$476,703	\$490,234 to \$3,894,347	\$3,998,025 and above
Least costly	Purchase precut	Purchase precut	Setup precut facility
Range of costs	\$16,679 to \$414,813	\$428,528 to \$3,984,297	\$3,997,837 and above

analysis that vary costs cost components (i.e., cornea cost, surgical cost, and costs of the ALTK system) within reasonable ranges and found that our results are robust to these changes.

There are some risks with precut corneas. During the training of technicians, the wastage of cornea may be higher.⁸ Questions and issues with accountability may arise should the cornea graft or transplantation run into problems. The disadvantage of precut cornea graft is that the surgeon passes control of this important step of surgery to the eye bank technician, and is unable to personally observe the tissue processing and any complications that may occur.⁷ Our cost minimization analysis did not quantify the monetary value of these risks. Also, this study was based on DSAEK performed by 2 experienced surgeons. If the procedure was performed by a novice transplant surgeon, the cost of the surgeon cut option would be higher (due to longer time of cutting and possible complications associated with learning to cut the cornea themselves), making it even more expensive compared with the 2 precut options.

Another limitation is that we did not account for cornea wastage during precutting, reported as 1.2% at our center,⁸ which was comparable to rates of 1.5% to 1.9% shown in other studies.^{8,22,26} A newly setup facility would expect much higher tissue wastage during the training of technicians due to the learning curve. One of the strengths of our study is a fairly large population number of 250 subjects. Although the baseline characteristics of the 2 groups were different, we performed propensity score matching with replacement to estimate the duration of surgeries.

Finally, although our paper focused on quantifying the lowest cost approach for preparing donor cornea for transplantation, this is not to minimize other factors that are also critical in the decision of which method to pursue. For example, regardless of method, it is vital to ensure good quality donor material as per Eye Bank Association of America standards prior to any tissue processing.³¹ Moreover, all those involved in the acquisition and transplantation process must be appropriately trained to ensure the best possible outcomes.

In conclusion, there are many advantages of using precut cornea, especially in terms of time and cost savings, and there were no differences in safety and outcomes of precut or surgeon-cut DSAEK grafts. Therefore, high volume centers should consider setting up a facility to precut corneas for transplantation.

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