Effects of Graft Thickness and Asymmetry on Visual Gain and Aberrations After Descemet Stripping Automated Endothelial Keratoplasty

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Importance: Understanding the contribution of graft thickness and asymmetry to visual gain and posterior corneal (PC) higher-order aberrations (HOAs) may assist optimizing visual outcomes after Descemet stripping automated endothelial keratoplasty (DSAEK).

Objective: To investigate the effects of graft thickness and asymmetry on visual gain and aberrations after DSAEK.

Design: Retrospective analysis of an interventional case series of eyes undergoing DSAEK. Visual gain was defined as the difference between preoperative and 6-month postoperative best-corrected visual acuity in logMAR equivalents. Graft thickness was measured by anterior-segment optical coherence tomography. Corneal topography and HOAs were measured by Scheimpflug imaging. Raw posterior corneal (PC) elevation data were exported and fitted against a best-fitted sphere, providing a measure of donor lenticule asymmetry. Correlation analysis was performed among visual gain, graft thickness, graft asymmetry, and PC HOAs.

Setting: University Eye Clinic Maastricht.

Participants: Seventy-nine eyes with corneal endothelial dysfunction.

Exposure: All patients underwent DSAEK.

Main Outcomes and Measures: Visual gain, graft thickness, graft asymmetry, and PC HOAs.

Results: Mean best-corrected visual acuity improved from 0.63 logMAR equivalents preoperatively to 0.25 logMAR equivalents postoperatively ($P < .001$). Mean (SD) graft thickness of the series was 97 (25) (range, 39-145) µm. After excluding patients with vision-limiting comorbidities, visual gain significantly correlated with graft thickness ($r = -0.35$ [$P = .02$]). This correlation was strongest in patients with pseudophakic bullous keratopathy ($r = -0.62$ [$P = .01$]). Graft thickness significantly correlated with graft asymmetry in the 4- and 6-mm zones ($r = 0.32$ [$P = .007$] and $r = 0.32$ [$P = .006$], respectively), which in turn correlated with all but spherical PC HOAs.

Conclusions and Relevance: After DSAEK, visual gain shows a significant correlation with graft thickness in patients without vision-limiting comorbidities. This relationship is strongest in patients with pseudophakic bullous keratopathy. Graft thickness also correlates with graft asymmetry, which in turn correlates with all but spherical PC HOAs. These findings may assist surgeons in choosing DSAEK graft thickness and shape, particularly in eyes without vision-limiting comorbidities. Further randomized trials are needed to investigate the relationship between graft thickness and visual gain after DSAEK.


DESCEMET STRIPPING AUTOMATED ENDOTHELIAL KERATOPLASTY (DSAEK), a selective corneal transplant technique, has become the procedure of choice for treating corneal endothelial dysfunction, essentially replacing penetrating keratoplasty for this indication. The main advantages of DSAEK over penetrating keratoplasty include faster visual rehabilitation, minimal surgically induced astigmatism, improved postoperative corneal power, and preservation of biomechanical properties.

Although DSAEK favorably compares with penetrating keratoplasty in the proportion of patients achieving 20/40 visual acuity, most eyes do not achieve 20/20 visual acuity despite clear postoperative corneas and otherwise healthy eyes. The presence of stromal irregularities has been suggested to degrade the optical and re-
toplasty techniques. However, manual donor preparation is eliminated currently provides the fastest and best visual recovery of all endothelial keratoplasty grafts.16-21

The relationship between lenticule thickness and visual outcome shows conflicting results.16-21 Preparation and handling of thinner grafts is not influenced by the choice of microkeratome head. However, the extremely thin Descemet membrane endothelial keratoplasty graft is difficult, leading to higher rates of graft dislocation.11,12,14,15

Thinner DSAEK grafts have been suggested to achieve better visual outcomes.16 This proposed relationship is particularly relevant because graft thickness can be influenced by the choice of microkeratome head. However, preparation and handling of thinner grafts is not without challenges, and recent studies on the relationship between lenticule thickness and visual outcome show conflicting results.16-21

Recently, attention has been given to the role of higher-order aberrations (HOAs) in degrading optical quality after DSAEK.22-29 Whole-eye, anterior, and posterior corneal (PC) HOAs were shown to be higher in eyes after DSAEK compared with age-matched control eyes.22,23,27

In addition, DSAEK was found to induce less anterior corneal HOAs than Descemet membrane endothelial keratoplasty.22,26 Moreover, correcting whole-eye HOAs using adaptive optics was shown to result in dramatic improvements in visual acuity and contrast sensitivity after DSAEK.30

In the present study, we examined the relationship between central graft thickness (CGT) measured by anterior-segment optical coherence tomography (AS-OCT [Visante; Carl Zeiss Meditec]) and visual gain after DSAEK. In addition, we evaluated the relationships among graft thickness, asymmetry of the PC surface, and HOAs after DSAEK (Figure 1C).

Figure 1. Measures of posterior corneal (PC) asymmetry. A, Illustrations of the central 4- and 6-mm zones of 134-µm-thick (top) and 49-µm-thick (bottom) grafts. B, Illustrations of PC surface deviation from a best-fitted sphere (top) and a corresponding color-coded elevation subtraction map (bottom) showing positive and negative differences in green and blue, respectively. C, Anterior segment optical coherence tomography images showing 134-µm-thick (left) and 49-µm-thick (right) grafts 6 months postoperatively. D, Color-coded elevation subtraction maps. E, Topography-derived higher-order aberration maps of PC surfaces shown in the corresponding left and right images of C, respectively (derived using a commercially available imaging system [Pentacam; Oculus, Inc]).

METHODS

PATIENT SELECTION

Inclusion criteria included corneal edema due to Fuchs endothelial dystrophy, pseudophakic bullous keratopathy (PBK), or secondary endothelial dysfunction; a minimum patient age of 18 years; and a best-corrected visual acuity (BCVA) of at least 0.15 logMAR equivalents. Exclusion criteria consisted of a history of corneal transplant and a follow-up of less than 6 months. Informed consent was obtained from all patients, and the study was conducted in accordance with the tenets of the 1996 Declaration of Helsinki.

SURGICAL TECHNIQUE

All patients underwent a DSAEK procedure at the University Eye Clinic Maastricht. Operations were performed by a single corneal surgeon (R.M.M.A.N.) using donor tissues obtained from a single eye bank (Euro Cornea Bank, Beverwijk, the Netherlands). The procedure was performed using a standardized operative technique, with the donor cornea prepared first, followed by transplant to the recipient. To summarize the procedure, donor tissue was mounted on an artificial anterior chamber (Moria), and central corneal thickness was measured 5 times with a pachymeter (Corneo-Gage Plus; Sonogage). Anterior chamber pressure was increased to 65 mm Hg, and a microkeratome (ALT; Moria) equipped with a 300-µm head (8 cases), a 350-µm head (52 cases), or a 400-µm head (19 cases) was used to dissect the donor tissue. The 400-µm head was used when donor pachymetry exceeded 600 µm after removal of the epithelium, and the 350-µm head was used when donor pachymetry measured 550 to 600 µm after removal of the epithelium.

A 4.5-mm limbal incision was made in the recipient eye, and the Descemet membrane and endothelium of the recipient were scored using a reversed Price-Sinskey hook (Moria). A 15° blade was used to make 4 transcorneal venting incisions in the midperipheral recipient cornea. The donor graft was then inserted using a Busin glide (Moria), followed by an insertion of air into the anterior chamber to unfold the donor graft and approximate it against the recipient stroma. The procedure was completed with partial replacement of the air bubble with balanced salt solution (BSS; Alcon Ltd).

CENTRAL DONOR LENTICULE THICKNESS MEASUREMENTS

Central donor lenticule thickness 6 months postoperatively was measured using AS-OCT. Thickness measurements were obtained centrally through the horizontal meridian using the automated flap tool. All measurements were obtained by a single
Keratoplasty.

of eyes.

Quantitative variables and percentages for categorical variables. Snellen
ware (SPSS for Windows, version 20.0; SPSS Inc). Baseline pa-
Data analysis was performed using commercially available soft-
polynomials with expansion up to the eighth order. The complete
software of the topographical imaging system using Zernike poly-
set of Zernike coefficients of the central 4 and 6 mm of the PC
coverage, which included the maximal graft size of 8.5 mm in
this study, with no extrapolated data in the central 6-mm zone.
Raw PC elevation data obtained 6 months after DSAEK were
exported to a spreadsheet (Excel, Microsoft office 2007; Mi-
acceptor (M.M.D.), and the mean of 3 measurements was used
to minimize measurement error.

ANALYSIS OF PC SURFACE ASYMMETRY

Corneal topography was measured using a commercially avail-
able imaging system (Pentacam; Oculus, Inc). The automatic-
release, 30-picture, 3-dimensional scan mode was used, and im-
ages were analyzed using the built-in software (version 1.17r120:
Oculus, Inc). Acceptable maps had at least 10 mm of corneal
coverage, which included the maximal graft size of 8.5 mm in
this study, with no extrapolated data in the central 6-mm zone.

ANALYSIS OF PC ABERRATIONS

Analysis of PC HOAs was performed by means of the built-in
software of the topographical imaging system using Zernike poly-
nomials with expansion up to the eighth order. The complete
set of Zernike coefficients of the central 4 and 6 mm of the PC
surface was exported to the spreadsheet, and the root mean
square value of total PC HOAs (third to eighth orders) and spe-
cific Zernike coefficients was calculated.

STATISTICAL ANALYSIS

Data analysis was performed using commercially available soft-
ware (SPSS for Windows, version 20.0; SPSS Inc). Baseline pa-
tient characteristics were reported in mean (SD) values for quan-
titative variables and percentages for categorical variables. Snellen
BCVA was converted to logMAR equivalents to allow statistical
analysis. Visual gain was defined as the difference between pre-
operative and 6-month postoperative BCVA in logMAR equiva-

tents. Deviation from normal distribution was checked using the
Kolmogorov-Smirnov test. Correlations were tested using the Pear-
sen correlation coefficient for normally distributed data and the
Spearman correlation coefficient when the assumption of nor-
mality was violated. We stated when statistical analysis was per-
formed with the exclusion of patients with vision-limiting co-
morbidities. The purpose of such analysis was to exclude posterior
pole abnormality as an explanation for reduction in vision.

Preoperative and postoperative comparisons were per-
formed using the paired-samples t test for quantitative vari-
bles and the McNemar nonparametric test for categorical vari-
ables. For all statistical tests performed, statistical significance
was set at .05.

RESULTS

The study included 79 eyes of 71 patients who under-
went DSAEK from April 17, 2008, through January 20,
2011, at the University Eye Clinic Maastricht. Demogra-
phies and indications for surgery are presented in
Table 1.

VISUAL AND REFRACTIVE OUTCOMES

Vision results are presented in Table 2. The mean pre-
operative BCVA was 0.63 logMAR equivalents. For the entire
group, BCVA improved to 0.25 logMAR equivalents (P < .001), representing a mean gain of greater than
3 Early Treatment Diabetic Retinopathy Study (ETDRS)
lines (95% CI, 0.22–0.43 logMAR equivalents). Fifty-
five patients (77%) had better visual acuity 6 months post-
operatively than they had preoperatively. Eight patients
(11%) had the same 6-month visual acuity as they had
preoperatively. Eight patients (11%) had worse visual acu-
ity at 6 months than preoperatively. Of all eyes, 53 (67%) achieved a vision of 20/40 or better and 18 (23%) achieved visual acuity of 20/25 or better.

After excluding 35 eyes with documented macular or glaucomatous damage and amblyopia, the mean preop-
erative BCVA was 0.5 logMAR equivalents. The mean

Table 1. Demographics of Patients Undergoing DSAEK

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Dataa</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients/eyes</td>
<td>71/79</td>
</tr>
<tr>
<td>Age, y</td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>70.5 (11.5)</td>
</tr>
<tr>
<td>Range</td>
<td>37-88</td>
</tr>
<tr>
<td>Male sex</td>
<td>24 (30)</td>
</tr>
<tr>
<td>Indication for DSAEKb</td>
<td></td>
</tr>
<tr>
<td>Fuchs dystrophy</td>
<td>53 (67)</td>
</tr>
<tr>
<td>Bullous keratopathy</td>
<td>24 (30)</td>
</tr>
<tr>
<td>Procedure</td>
<td></td>
</tr>
<tr>
<td>DSAEK</td>
<td>68 (86)</td>
</tr>
<tr>
<td>DSAEK + CE-IOL</td>
<td>11 (14)</td>
</tr>
<tr>
<td>Preoperative comorbidities</td>
<td></td>
</tr>
<tr>
<td>Macular/retinal disease</td>
<td>8 (10)</td>
</tr>
<tr>
<td>Glaucoma</td>
<td>9 (11)</td>
</tr>
<tr>
<td>Amblyopia</td>
<td>10 (13)</td>
</tr>
</tbody>
</table>

Abbreviations: CE-IOL, cataract extraction and intracocular lens implantation; DSAEK, Descemet stripping automated endothelial keratoplasty.

a Unless otherwise indicated, data are expressed as number (percentage) of eyes.
b Two eyes underwent surgery for posterior polymorphous corneal dystrophy (n = 1) and iridocorneal endothelial syndrome (n = 1).

Table 2. Comparison of Preoperative vs Postoperative Measurements After DSAEK

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dataa</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCVA, logMAR equivalent</td>
<td>0.63 (0.50)</td>
<td>0.25 (0.20)</td>
<td>&lt;.001b</td>
<td></td>
</tr>
<tr>
<td>Visual acuity, No. (%) of eyes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/40</td>
<td>28 (35)</td>
<td>53 (67)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>20/25</td>
<td>0</td>
<td>18 (23)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Refractive astigmatism, D</td>
<td>−1.3 (1.3)</td>
<td>−1.7 (0.9)</td>
<td>.08b</td>
<td></td>
</tr>
<tr>
<td>Topographic astigmatism, D</td>
<td>2.1 (1.7)</td>
<td>1.78 (1.3)</td>
<td>.14b</td>
<td></td>
</tr>
<tr>
<td>Spherical equivalent, D</td>
<td>−0.4 (1.2)</td>
<td>0.1 (1.4)</td>
<td>.006b</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BCVA, best-corrected visual acuity; D, diopter; DSAEK, Descemet stripping automated endothelial keratoplasty.

a Unless otherwise indicated, data are expressed as mean (SD).
b Calculated using the paired-samples t test.
c Calculated using the McNemar nonparametric test.
d Excludes patients who underwent a triple procedure.
BCVA in this group improved to 0.2 logMAR equivalents \((P < .001)\), representing an average gain of 3 ETDRS lines \((95\% CI, 0.19-0.40 \log)\). Thirty-seven eyes \((84\%)\) had better visual acuity at 6 months postoperatively than they had preoperatively. Four eyes \((9\%)\) had the same 6-month visual acuity as they did preoperatively and 3 \((7\%)\) had worse visual acuity at 6 months than preoperatively. Thirty-eight eyes \((86\%)\) obtained a visual acuity of 20/40 or better and 14 \((32\%)\) obtained a visual acuity of 20/25 or better.

Because of severe corneal edema, accurate preoperative refraction was not possible in 18 patients. Eleven patients who underwent a triple procedure consisting of simultaneous DSAEK, phacoemulsification, and intraocular lens implantation were also excluded from refraction analysis. Therefore, refraction analysis included 50 eyes in this study. The mean \((SD)\) preoperative manifest refraction spherical equivalent was \(-0.4 (1.2)\) diopters \((D)\).

The mean postoperative manifest refraction spherical equivalent was \(0.1 (1.4) \text{ D}\), representing a mean hyperopic shift of \(0.5 (1.1) \text{ D}\) \((P = .006)\).

**CENTRAL DONOR LENTICULE THICKNESS AND BCVA**

Central graft thickness, measured 6 months postoperatively using AS-OCT, ranged from 39 to 145 \((\text{mean SD}, 97 [25]) \mu\text{m}\). When examined across all patients, no significant correlation was found between CGT and visual gain \((r = -0.14 [P = .28])\). After excluding patients with documented retinal disease or amblyopia, a significant correlation was found between CGT and visual gain \((r = -0.35 [P = .02])\) \((\text{Figure 2})\). We found no significant difference in CGT between patients with and without vision-limiting comorbidities that could affect postoperative visual acuity \((P = .43)\). In patients with PBK, a stronger correlation was found between visual gain and CGT despite worse preoperative and postoperative visual acuity \((r = -0.62 [P = .01])\) \((\text{Figure 3})\).

**ASYMMETRY OF THE PC SURFACE**

Posterior corneal asymmetry, expressed in the logarithm root mean square error between raw PC elevation and a best-fitted sphere, significantly correlated with CGT in the 4-mm \((r = 0.32 [P = .007])\) and 6-mm \((r = 0.32 [P = .006])\) central zones 6 months postoperatively. The scatterplot is shown in \textbf{Figure 4}. No significant correlation was found between visual gain and PC asymmetry in the 4-mm \((r = -0.06 [P = .66])\) and 6-mm \((r = -0.04 [P = .79])\) central zones 6 months after DSAEK.
PC ABERRATIONS

Correlations among PC HOAs in the 4- and 6-mm central zones and visual gain, CGT, and PC asymmetry 6 months after DSAEK are given in Table 3. Examples of PC HOA imaging from the Pentacam system are shown in Figure 1E. We found a significant correlation between PC asymmetry in the 4- and 6-mm central zones and total HOA root mean square value and all higher-order Zernike terms except spherical and sphericallike aberrations (Figure 5). We found no significant correlation between PC HOAs and visual gain or CGT in the 4- and 6-mm central zones.

Table 3. Correlations Between PC Aberrations in the Central 4- and 6-mm Zones and Visual Gain, Central Graft Thickness, and PC Asymmetry After DSAEK

<table>
<thead>
<tr>
<th>PC Aberration</th>
<th>Visual Gain, LogMAR Equivalents</th>
<th>Graft Thickness, µm</th>
<th>PC Asymmetry, LogRMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Patients</td>
<td>No Vision-Limiting Abnormality</td>
<td>All Patients</td>
</tr>
<tr>
<td>RMS CB</td>
<td>4-mm Zone</td>
<td>6-mm Zone</td>
<td>4-mm Zone</td>
</tr>
<tr>
<td>RMS HOOA CB</td>
<td>+0.08</td>
<td>+0.05</td>
<td>+0.04</td>
</tr>
<tr>
<td>RMS HOOA CB</td>
<td>+0.07</td>
<td>+0.02</td>
<td>+0.03</td>
</tr>
<tr>
<td>RMS SA CB</td>
<td>+0.07</td>
<td>+0.01</td>
<td>+0.03</td>
</tr>
<tr>
<td>RMS SA-like CB</td>
<td>+0.07</td>
<td>+0.01</td>
<td>+0.03</td>
</tr>
<tr>
<td>RMS coma CB</td>
<td>+0.07</td>
<td>+0.01</td>
<td>+0.03</td>
</tr>
<tr>
<td>RMS coma-like CB</td>
<td>+0.07</td>
<td>+0.01</td>
<td>+0.03</td>
</tr>
<tr>
<td>RMS secondary astigmatism CB</td>
<td>+0.04</td>
<td>+0.02</td>
<td>+0.01</td>
</tr>
<tr>
<td>RMS trefoil CB</td>
<td>+0.04</td>
<td>+0.01</td>
<td>+0.04</td>
</tr>
<tr>
<td>RMS tetrafoil CB</td>
<td>+0.18</td>
<td>+0.20</td>
<td>+0.31</td>
</tr>
</tbody>
</table>

Abbreviations: CB, cornea back; DSAEK, Descemet stripping automated endothelial keratoplasty; HOA, higher-order-aberration; LOA, lower-order aberration; PC, posterior corneal; RMS, root mean square; RMSE, RMS error; SA, spherical aberration; SA-like, sphericallike aberration.

Calculating as Pearson correlation coefficient. Statistically significant values appear in boldface type.

Coma aberration is calculated as $Z_4$; cornealike aberrations, $Z_4$ and $Z_6$; SA, $Z_4$; SA-like, $Z_4$ and $Z_6$; secondary astigmatism, $Z_6$; trefoil, $Z_8$; and tetrafoil, $Z_{10}$, where $Z$ indicates Zernike polynomials.

Understanding the contributions of the various factors limiting visual function after DSAEK is particularly important, considering the increasing popularity of endothelial keratoplasty. In the present study, thinner grafts were associated with greater visual gain in patients without vision-limiting comorbidities, emphasizing the importance of careful patient selection when considering a more challenging DSAEK procedure using thin donor tissue. In our study, graft thickness significantly correlated with visual gain in patients with preoperative PBK. This result is particularly encouraging considering the worse prognosis of PBK, although it should be interpreted with caution owing to the small number of patients with PBK in this study. Furthermore, selection bias might have occurred because, in our institution, patients with PBK are referred for DSAEK only in the absence of evident stromal scarring.

In the group without vision-limiting comorbidities, 3 patients had worse visual acuity 6 months postoperatively than they did preoperatively. Two years after the operation, visual acuity exceeded preoperative values in all 3 patients. This gradual improvement over time is in agreement with Li and colleagues, who found that, in patients without vision-limiting comorbidities, visual acuity continues to improve even years after DSAEK.

One limitation of this study is that postoperative donor thickness might not be correlated with intraoperative donor lenticule pachymetry. However, intraoperative subtraction pachymetry correlated significantly with postoperative CGT in this series (data not shown). Another limitation of this study is that the measurement precision of the AS-OCT (in the order of 10-20 µm) becomes more important as thinner structures are measured. To minimize the measurement error, we used the mean of 3 thickness measurements taken by a single operator.
GRAFT THICKNESS AND PC ASYMMETRY

The meniscus shape of the donor lenticule dramatically changes the geometry of the PC surface after DSAEK. Because graft thickness varies in all directions from the center,32-34 thickness measurements in this study were limited to a single central value expected to be relatively constant across different meridians. Alternatively, the asymmetry of the PC surface was calculated by fitting raw PC elevation data against a best-fitted sphere, providing a measure of donor lenticule asymmetry in the entire 4- and 6-mm central zones, analogous to a 3-dimensional graft profile composed of numerous measurements across different meridians. Repeatability and reproducibility of the topographical imaging system in measuring PC elevation have been established in prior studies.35-38

We found that thicker grafts were associated with greater asymmetry of the PC surface. Thick grafts have been suggested to magnify the curvature mismatch between donor and recipient, resulting in the formation of stromal folds when donor stroma fits against that of the recipient.27 Such folds may explain the relationship between graft thickness and PC asymmetry found in this study. The greater asymmetry of thicker grafts may also result from thicker peripheral edges denuded of endothelium, making them less susceptible to differential deturgescence.

We did not find a relationship between PC asymmetry and visual gain. Nevertheless, individual eyes may vary from the mean, and an asymmetric PC surface may be a source of decreased vision in some cases after DSAEK. Indeed, in a large case series by Letko and colleagues,39 the most common indication for regrafting was unsatisfactory visual acuity resulting from graft folds that crossed the visual axis or uneven donor thickness. In their study, repeated endothelial keratoplasty resulted in improved visual acuity in all but 1 case.39

RELATIONSHIPS AMONG ABERRATIONS, GRAFT THICKNESS, ASYMMETRY, AND VISUAL GAIN

Using adaptive optics, Pantanelli and colleagues30 showed that correcting HOAs after DSAEK leads to dramatic improvements in visual acuity and contrast sensitivity, elegantly confirming the role of HOAs as a vision-limiting factor after endothelial keratoplasty. However, aberrations in their study were measured using a Hartman-Shack wavefront sensor, which was unable to separate the contributions of the anterior and posterior cornea. Evaluation of the separate contributions of the anterior corneal and PC surfaces is important if we wish to prevent or treat HOAs effectively after DSAEK. The HOAs of the anterior cornea are most likely the result of the underlying corneal abnormalities and longstanding corneal edema. These could be addressed by a paradigm shift toward earlier surgery before the development of irreversible corneal changes or by wavefront-guided refractive surgery. The HOAs of the posterior cornea, on the other hand, are most likely due to donor graft or procedure-related factors and could therefore best be addressed by

Table 4. Higher-Order Aberrations Related to BCVA After DSAEK

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of DSAEK Eyes</th>
<th>Maximal Follow-up, mo</th>
<th>Method</th>
<th>HOA Order</th>
<th>Zone, mm</th>
<th>Structure Analyzed</th>
<th>Pearson Correlation Coefficient</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamaguchi et al,28 2009</td>
<td>13</td>
<td>3</td>
<td>Scheimpflug imaging</td>
<td>3 to 8</td>
<td>4</td>
<td>AC</td>
<td>0.94</td>
<td>&lt;.001</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yamaguchi et al,26 2011</td>
<td>10</td>
<td>6</td>
<td>AS-OCT, ray tracing</td>
<td>3 to 14</td>
<td>4</td>
<td>TC</td>
<td>0.37</td>
<td>.047</td>
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<td></td>
</tr>
<tr>
<td>Patel et al,44 2009</td>
<td>49</td>
<td>24</td>
<td>ATLAS system,4 ray tracing</td>
<td>3 to 6</td>
<td>4</td>
<td>AC</td>
<td>0.59</td>
<td>&lt;.001</td>
</tr>
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<td></td>
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</tr>
<tr>
<td>Chamberlain et al,22 2012</td>
<td>22</td>
<td>19</td>
<td>Scheimpflug imaging</td>
<td>3 to 8</td>
<td>4</td>
<td>AC</td>
<td>0.5</td>
<td>&lt;.001</td>
</tr>
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<tr>
<td>Muftuoglu et al,24 2010</td>
<td>31</td>
<td>3</td>
<td>Scheimpflug imaging</td>
<td>3 to 6</td>
<td>4</td>
<td>AC</td>
<td>0.29</td>
<td>.15</td>
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</tr>
<tr>
<td>Seery et al,27 2011</td>
<td>46</td>
<td>24</td>
<td>Hartman-Shack wavefront sensor</td>
<td>3 to 6</td>
<td>4</td>
<td>Whole eye</td>
<td>0.25</td>
<td>.1</td>
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<tr>
<td>Present study</td>
<td>79</td>
<td>6</td>
<td>Scheimpflug imaging</td>
<td>3 to 8</td>
<td>4</td>
<td>Whole eye</td>
<td>0.38</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Abbreviations: AC, anterior cornea; AS-OCT, anterior segment optical coherence tomography; BCVA, best corrected visual acuity; DSAEK, Descemet stripping automated endothelial keratoplasty; HOA, higher-order aberration; PC, posterior cornea; TC, total cornea.

a Available from Carl Zeiss International.
b Indicates 12 months after DSAEK.
c Indicates 24 months after DSAEK.
changes to the surgical technique and equipment or by regrafting.

The topographical imaging system we used enables wavefront analysis of the anterior corneal and PC surfaces. Although Shankar and colleagues\(^\text{60}\) found that corneal wavefront measurements by the device do not have good repeatability, their analysis was limited to the anterior cornea, and they extrapolated elevation data and converted it to wavefront errors using another system. In contrast, Muftuoglu and colleagues\(^\text{24}\) found good repeatability coefficients for PC and anterior corneal wavefront errors using the built-in software of the same topographical imaging system that we used in this study.

We found a significant correlation between the uneven thickness profile of the donor lenticule and PC HOAs after DSAEK. To the best of our knowledge, this relationship has not been reported before. However, this finding is in agreement with Rudolph and colleagues\(^\text{20}\), who found that Descemet membrane endothelial keratoplasty, the thinnest endothelial graft available, results in significantly less PC HOAs compared with DSAEK. Although this finding suggests that thinner and more uniform grafts may result in better visual outcomes and less PC HOAs, current microkeratome technology is limited by its variable cuts and affected by donor thickness, microkeratome head width, and manual transition time.\(^\text{41-43}\)

**Table 4** summarizes the findings of studies reporting on the relationship between HOAs and visual acuity after DSAEK. Although most studies found a significant correlation between BCVA and anterior corneal HOAs, BCVA was not correlated with PC HOAs in any of the studies, similar to our findings.

The lack of correlation could be explained by the large change in refractive index at the anterior surface compared with the posterior surface and by the presence of subepithelial fibrosis, stromal interface haze, and corneal light scatter, further complicating the evaluation of a relationship between PC HOAs and visual gain.\(^\text{27,28}\) Nevertheless, the effect of PC aberrations on visual function should not be ignored because they have been shown to offset regular and irregular astigmatism of the anterior corneal surface.\(^\text{29-37}\) Further studies including contrast sensitivity measurements, more sensitive to the effect of HOAs on vision, are needed to better define the relationship between PC HOAs and visual function after DSAEK.

In conclusion, thinner grafts were associated with greater visual gain in patients without concurrent vision-limiting disease. This relationship was stronger in patients undergoing DSAEK for PBK despite worse preoperative and postoperative visual acuity compared with patients who underwent DSAEK for Fuchs endothelial dystrophy. Thicker grafts were associated with greater asymmetry of the PC surface, which in turn was associated with more PC HOAs. However, neither was correlated with visual gain.

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**REFERENCES**


