Pentacam Scheimpflug Evaluation of Corneal Volume After LASIK

Camila M. Gadelha P. Diniz, MD; Rossen M. Hazarbassanov, MD; Ester Yamazaki, MD; Celina Murata, MD; Felipe Mallmann, MD; Mauro Campos, MD

ABSTRACT

PURPOSE: To assess the change in corneal volume and laser ablation volume over time after LASIK using a rotating Scheimpflug camera.

METHODS: Twenty-six patients (49 eyes) underwent LASIK. Pentacam Scheimpflug measurements were performed pre- and postoperatively at 1, 3, 7, 15, and 30 days. Central corneal thickness, total corneal volume (10-mm diameter), and partial corneal volumes (3, 5, and 7 mm) based on the apex of the cornea, were measured. Main outcome measures were differences between pre- and postoperative volume measurements of total and partial corneal regions, volume changes over time postoperatively, and comparison between laser ablation volume and corneal volume.

RESULTS: A strong linear relationship was noted between spherical equivalent refraction and laser ablation volume ($r=−0.931$, $P<.0001$). Furthermore, 30 days after LASIK, a strong linear relationship was noted between planned thickness and achieved thickness ($r=0.9457$, $P<.001$). Corneal volumes for 3-, 5-, and 7-mm diameter regions significantly decreased over time postoperatively (one-way analysis of variance, $P<.05$).

CONCLUSIONS: Alterations in corneal volume correlated with laser ablation volume when the diameter of the region considered was 3, 5, or 7 mm from the corneal apex. [J Refract Surg. 2010;26(8):600-604.]
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Optical coherence tomography and Scheimpflug principle are means to evaluate the anterior eye segment. Optical coherence tomography is a non-contact optical system designed to image the anterior segment of the eye. The Scheimpflug principle applies to the optical properties involved in the photography of objects when the plane of the object is not parallel to the imaging plane of the camera. The plane containing the slit beam and the plane of the image intersect at one point, with the corresponding angles being equal.

Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) measurements of corneal thickness and anterior chamber depth are reproducible in normal eyes and for corneal parameters such as apical, central, and thinnest corneal thickness; horizontal, vertical, peripheral, and mean radii of curvature from the anterior as well as posterior corneal surface; and anterior chamber depth and volume in eyes that have undergone LASIK.

Laser in situ keratomileusis is currently the procedure of choice for correcting moderate to severe myopia and myopic astigmatism. In this technique, a hinged flap is created and folded back, and the exposed stroma is photoablated using an excimer laser. In LASIK for myopia, stromal tissue is removed so that the curvature of the central cornea is flattened to compensate for the excessive refractive power or longer axial length of the myopic eye.

In the present study, corneal volume was evaluated over time after LASIK, correlating the values to laser ablation volume.

PATIENTS AND METHODS

PATIENTS AND SURGICAL METHOD

This prospective, nonrandomized study included 49 eyes of 26 patients who underwent LASIK for myopia and myopic...
Scheimpflug Evaluation of the Anterior Eye Segment

Scheimpflug analyzer (Pentacam) measurements were performed pre- and postoperatively at 1, 3, 7, 15, and 30 days. Pentacam possesses a rotating Scheimpflug camera that takes up to 25 slit images of the anterior segment in less than 2 seconds using a blue light-emitting diode. Only the scans with a quality factor of >95% were chosen for analysis.

Corneal thickness, total volume, and partial volumes were obtained from the Scheimpflug analyzer measurements. Corneal total volume was calculated based on the apex in a 10-mm diameter region and partial volumes were obtained from 3-, 5-, and 7-mm diameter regions, as determined by pachymetry. Laser ablation volume was obtained from surgical data, multiplying the volume per shot by the total amount of shots. (The laser ablation volume is a theoretical value that assumes volume per shot. It is not a clinically measured value.)

Initially, a descriptive analysis was performed. Pearson's linear coefficient (r) was then estimated to quantify the relationship between spherical equivalent refraction with ≤−0.50 diopters (D) of astigmatism and the volume of ablation, planned thickness and achieved thickness, and the volume of ablation and changes (preoperative minus postoperative) in total and partial volumes. Repeated measures analysis of variance (ANOVA) was used to compare the mean change in volume of the 3-, 5-, 7-, and 10-mm diameter regions over time postoperatively. For analysis, using one-way ANOVA with Student–Newman–Keuls test for continuous variables, Pearson’s correlation test was used to determine correlations with SPSS version 15 (SPSS Inc, Chicago, Illinois). Probabilities <5% were considered statistically significant. For repeated tests, the Bonferroni correction was used to correct for cumulative type I errors.

RESULTS

Twenty-six patients (49 eyes) were included in the study. Mean patient age was 31.9±5.88 years (range: 25 to 46 years), mean spherical equivalent refraction before LASIK was −3.44±1.20 D (range: −1.50 to −6.75 D) with mean astigmatism −0.23±0.21 D (range: 0 to −0.50 D). Mean laser ablation volume was 1.29±0.44 mm³ (range: 0.6 to 2.22 mm³) (Table 1). Laser ablation depth was provided by the laser. Data from central ultrasound pachymetry are provided in Table 1; however, corneal thickness as measured by Pentacam was used for the calculations.

Figure 1 depicts a strong linear relationship between spherical equivalent refraction and laser ablation volume (r=−0.931, P<.0001).

Mean preoperative central corneal thickness was 505.27±33.72 µm (range: 438 to 591 µm) and at 30 days postoperatively was 496.5±28.06 µm (range: 439 to 545 µm). Figure 2 shows a strong linear relationship between planned thickness and achieved thickness at 30 days after LASIK (r=0.9457, P<.001).

### TABLE 1
Pre- and Intraoperative Characteristics of 26 Patients (49 Eyes) Who Underwent LASIK

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± Standard Deviation</th>
<th>Standard Error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>31.92±5.878</td>
<td>1.153</td>
<td>25.00 to 46.00</td>
</tr>
<tr>
<td>Sphere (D)</td>
<td>−3.32±1.192</td>
<td>0.17</td>
<td>−6.50 to −1.50</td>
</tr>
<tr>
<td>Cylinder (D)</td>
<td>−0.24±0.207</td>
<td>0.029</td>
<td>−0.50 to 0.00</td>
</tr>
<tr>
<td>Spherical equivalent refraction (D)</td>
<td>−3.44±1.204</td>
<td>0.172</td>
<td>−6.75 to −1.50</td>
</tr>
<tr>
<td>Anterior chamber volume (mm³)</td>
<td>206.79±27.63</td>
<td>3.948</td>
<td>163.0 to 286.0</td>
</tr>
<tr>
<td>Laser ablation volume (mm³)</td>
<td>1.2994±0.4388</td>
<td>0.0627</td>
<td>0.6017 to 2.2187</td>
</tr>
<tr>
<td>Laser ablation depth (µm)</td>
<td>53.6667±19.63</td>
<td>3.5844</td>
<td>24.80 to 95.00</td>
</tr>
<tr>
<td>Ultrasound pachymetry (µm)</td>
<td>556.098±37.224</td>
<td>5.3176</td>
<td>489.0 to 626.0</td>
</tr>
<tr>
<td>Central corneal thickness (µm)</td>
<td>505.267±33.724</td>
<td>5.0272</td>
<td>438.0 to 591.0</td>
</tr>
</tbody>
</table>
Dispersion graphs (Fig 3) were applied to quantify the linear relationship between laser ablation volume and alterations in corneal volume of the 3-, 5-, 7-, and 10-mm diameter regions. A linear relationship was noted between ablation volume and change in the corneal volume of the 10-mm diameter region postoperatively ($r=0.314$, $P=0.036$). A strong linear relationship was present between ablation volume and change in volume in the 3-mm ($r=0.769$, $P<.0001$), 5-mm ($r=0.723$, $P<.0001$), and 7-mm ($r=0.502$, $P<.0001$) diameter regions.

Mean total cornea volumes preoperatively and postoperatively on days 1, 3, 7, 15, and 30 are shown in Table 2. Corneal volumes for the 3-, 5-, and 7-mm diameter regions significantly decreased over time postoperatively (one-way ANOVA, $P<.05$) (Fig 4).

**DISCUSSION**

Only a few studies in the literature report changes in corneal volume measured by Pentacam (Scheimpflug system). A strong linear relationship was present between ablation volume and change in volume in the 3-mm ($r=0.769$, $P<.0001$), 5-mm ($r=0.723$, $P<.0001$), and 7-mm ($r=0.502$, $P<.0001$) diameter regions.
by phacoemulsification and aspiration. Previous studies using this method demonstrated that corneal volume distribution and increase in volume were different among keratoconic corneas and normal corneas, and therefore these data can serve as guidelines for diagnosis of keratoconus and/or screening of refractive surgery candidates.

Additionally, statistically significant differences in corneal volume measurements are present between mild keratoconus and severe keratoconus, and corneal volume readings are significantly different between control groups and all keratoconus groups. Analysis of the anterior segment of refractive surgery candidates shows that patients with myopia have a lower mean corneal volume than hyperopic patients. On the other hand, comparison of pre- and postoperative anterior segment measurements with Pentacam in horizontal muscle surgery reveals insignificant changes in keratometry readings, including corneal volume.

To our knowledge, no reports have yet to determine corneal volume after LASIK using a Scheimpflug system. In the present study, we found a strong linear relationship between the spherical equivalent refraction to be corrected and laser ablation volume (r=−0.931). Confirming the previously established accuracy of the Scheimpflug system, our results also indicated a strong linear correlation (r=0.894) between the planned and achieved thicknesses.

To assess whether the Pentacam system can be used to detect changes in corneal volume after LASIK, correlation tests were performed between the differences in pre- and postoperative corneal volumes and laser ablation volume. This analysis demonstrated that it is possible to assess the amount of volume change in the 3-, 5-, 7-, and 10-mm diameter regions based on the apex of the cornea.

Within the 3-, 5-, and 7-mm diameter regions, the correlation was high (r=0.769, r=0.723, r=0.502, respectively), which can be explained by the type of myopic treatment performed, according to the work of Munnerlyn et al., in which maximal depth of ablation occurs at the center of the treatment zone. An

![Figure 4. Corneal volume before and over time after LASIK. Asterisks mark the statistical significance of the difference between groups (*P<.05, one-way analysis of variance).](image-url)
explanation for the weak correlation of corneal volume in larger diameter regions (within 10 mm, r=0.314) is the fact that due to the angle of incidence, the light of the laser beam is oval-shaped towards the periphery, resulting in less fluence and suboptimal ablation (ie, removes less tissue in the periphery). We must also consider that keratocytes mediate the production of a variably thick lamellar corneal stromal scar, resulting in a greater thickness at the periphery of the flap.12

Previous histologic, ultrastructural, and immunofluorescent evaluation of human LASIK corneal wounds12 showed that the flap wound margin, which is adjacent to the epithelium, heals by producing an approximately 8-μm-thick hypercellular fibrotic stromal scar, whereas the central and paracentral wound regions heal with a thinner (approximately 5-μm) hypocellular primitive stromal scar. Immunohistochemistry studies identified an increase in type 3 collagen and myofibroblasts in the hypercellular fibrotic scar regions and a decrease or absence of all corneal stromal components other than type 1 collagen in the hypocellular primitive scar regions.12

Durairaj et al13 reported that hydration of the cornea changes during LASIK. After flap creation, dehydration of the cornea is expected due to microkeratome suction and compression. The increase in central corneal thickness or volume can be explained by dehydration of the cornea, which causes edema. The increased corneal hydration seems to occur early during surgery. Edema is greatest after repositioning the flap, then decreases slightly. Some pachymetry studies revealed that transient swelling disappears on the first postoperative day14 and edema continues to decrease during the early postoperative period, disappearing by the fifth day after LASIK.15

The findings of the present study indicate the usefulness of the Scheimpflug system for evaluating corneal volume after LASIK. The changes in corneal volume were consistent with laser ablation volume when the diameter considered was within a 3-, 5-, or 7-mm area from the apex of the cornea. This system may be useful for monitoring postoperative results and for detecting discrete changes in corneal volume and should contribute to the early detection of complications such as corneal ectasia.

AUTHOR CONTRIBUTIONS
Study concept and design (C.D., M.C.); data collection (C.D., E.Y., C.M., F.M.); analysis and interpretation of data (C.D., R.H., M.C.); drafting of the manuscript (C.D., R.H.); critical revision of the manuscript (C.D., R.H., E.Y., C.M., F.M., M.C.); statistical expertise (R.H.); supervision (M.C.)

REFERENCES