Objective Evaluation of Planned Versus Achieved Stromal Thickness Reduction in Myopic Femtosecond Laser-assisted LASIK

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ABSTRACT

PURPOSE: To evaluate corneal stromal thickness reduction and compare to attempted and achieved ablation depth in a consecutive case series study of myopic LASIK.

METHODS: Stromal thickness reduction was retrospectively evaluated in 205 consecutive eyes of 205 patients undergoing myopic and myopic astigmatic LASIK. Anterior segment optical coherence tomography was performed preoperatively and 3 months postoperatively. Epithelial thickness remodeling was also accounted for to achieve objective stromal thickness reduction. The derived maximum stromal thickness reduction was then compared to the programmed (planned) maximum ablation depth. Deviation of planned versus achieved maximum stromal thickness changes was correlated with residual refractive error.

RESULTS: The 3-month stromal reduction was 86.01 ± 28.28 μm, compared to the average programmed maximum ablation depth of 88.48 ± 26.05 μm. The attempted versus achieved thickness outliers correlated with deviations in achieved refractive correction.

CONCLUSIONS: Actual objective stromal thickness reduction following myopic LASIK correlates well with the attempted versus achieved refractive change.

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LASIK correction accuracy may depend on many variables, such as preoperative refractive error assessment, corneal pachymetry, biomechanical corneal changes induced by the procedure, and refraction fluctuation. Another variable may be the excimer laser output consistency, which is related to the volume of ablated tissue. Consistency of this variable may be evaluated by comparing attempted to achieved tissue thickness reduction, in a similar manner to the refractive predictability, in which the attempted versus achieved refractive correction is compared.[1]

Therefore, corneal pachymetry is a factor that affects preoperative refractive evaluation, and may also provide a method for the evaluation of excimer laser-induced tissue removal assessment. Improved accuracy and precision of pachymetry measurement has gained increased significance in the design and outcome evaluation of a successful refractive correction such as myopic LASIK.[2] Continuous and notable improvement in corneal thickness evaluation modalities has led to the clinical acceptance of corneal pachymetry maps[3] as an indispensable prescreening and evaluation element in corneal refractive surgery.[4,5]

The purpose of this study was to evaluate stromal thickness changes in eyes undergoing myopic LASIK and compare to the intended (planned) maximum stromal ablation.

PATIENTS AND METHODS

The study received approval by the Ethics Committee of the LaserVision Clinical and Research Eye Institute and adhered to the tenets of the Declaration of Helsinki. Signed

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informed consent was obtained from all adults participating in the investigation.

This is a single-center, single-intervention case series performed from January 2012 to June 2014 involving retrospective data review of 205 consecutive eyes of 205 patients subjected to myopic LASIK from September to December 2014. One eye was randomly selected from each patient in case of bilateral surgeries. All of the eyes included in the study had undergone successful myopic femtosecond laser-assisted LASIK. The same surgeon (AJK) performed all operations. The FS200 femtosecond and the EX500 excimer laser, both by WaveLight (Alcon Laboratories, Inc., Ft. Worth, TX), had been employed. Inclusion criteria for the procedure were healthy unoperated eyes with no ocular pathology other than refractive error and patient age between 18 and 65 years. A complete ocular preoperative evaluation was performed to screen for corneal abnormalities. Refractive error was up to -12.00 diopters (D) of sphere and up to -6.00 D of astigmatism, and preoperative central corneal thickness was at least 480 µm. Flap diameter was 8.00 mm and thickness was 110 µm, using the clear-cone applanation interface.[6] Surgical details of the refractive procedure are provided in a previous publication.[7] Exclusion criteria for the procedure were clinically significant corneal abnormalities including scar in the visual axis, basement membrane dystrophy, significant superficial punctuate keratitis, keratoconus, or other abnormalities that in the surgeon's opinion would have negatively affected safety of the procedure and the potential for maximum visual outcomes.

For the evaluation of stromal thickness reduction, we employed the OptoVue RTVue-100 (OptoVue, Inc., Fremont, CA), a Fourier-domain AS-OCT system,[8] using the L-Cam accessory lens. Pachymetry maps extended over a 6-mm diameter corneal area and were obtained and processed via the examination software A6 (9,0,27). The default setting of eight meridional B-scans, consisting of 1,024 A-scans each, was used. Data with 'good' measurement reliability, as reported in green color in the system report, and quantified by a signal strength index greater than 30, have been considered.

Preoperative and postoperative (1-week and 3-month) corneal thickness maps were obtained from each eye. From each map, the value of the central corneal thickness (CCT) was recorded, which in the myopic ablations examined coincides with the maximum ablation depth.

To account for differences in total corneal thickness due to epithelial remodeling, as a result of the LASIK procedure, the AS-OCT system was also employed to measure central epithelial thickness[8] preoperatively and 3 months postoperatively.[9] The difference between postoperative and preoperative central epithelial thickness (typically, an increase) was subtracted from the respective postoperative to preoperative CCT difference. Thus, the actual difference in stromal thickness was calculated in each eye employing the formula: difference in stromal thickness = (postoperative – preoperative CCT) – (postoperative – preoperative central epithelial thickness).

The intended (planned) maximum ablation depth, to which these stromal reduction values were compared, was provided by the Aqua planning software incorporated in the refractive laser platform. Statistical data analysis was performed by SPSS version 21.0 (IBM Corporation, New York, NY). Statistical significance was assessed employing Student's *t* tests. *P* values less than .05 were indicative of statistically significant results in this study. Results are reported as mean ± standard deviation (range).

RESULTS

Demographic and preoperative data of the patient pool included in the study are reported in **Table 1**. Corneal epithelial thickness, planned maximum ablation depth, and measured stromal thickness differences preoperatively and postoperatively are reported in **Table 2**.

Figure 1 illustrates all 3-month stromal reduction data points in the form of Bland–Altman plots (ie, the stromal reduction data compared to the planned central ablation data). We note that the mean of the differences is nearly constant (ie, not dependent on the magnitude of the measurement [the mean line has slope -0.054 per average µm]) and is close to the identity line (ie, the line in which the differences between measured and planned is zero).

The detailed epithelial thickness increase with spherical equivalent corrected is illustrated in **Figure 2**. The epithelium remodels, increasing its central thickness, depending on the amount of myopia corrected. Thus, an average of +3 µm may be considered as a representative average central epithelial thickness, which has been subtracted from the noted 'corneal' (ie, stromal + epithelial thickness measured postoperatively). In this study, we subtracted this central epithelial thickness increase per eye from the individual CCT reduction to obtain the true stromal reduction.

To further investigate the visual and refractive outcomes in these outlier cases, we identified the cases in which the difference of planned to actual stromal reduction was equal to or larger by 2× standard deviation. We evaluated the uncorrected distance visual

TABLE 1

Demographic and Preoperative Baseline Data of the Study Group

Parameter	No.
No. of eyes	205
Gender (female:male)	84:121
Eye laterality (right:left)	102:103
Patient age (y)	32.3 ± 8.8 (19 to 60)
Preoperative refractive error (D)[a]	
Sphere	-5.06 ± 2.36 (-0.25 to -11.25)
Cylinder	-0.90 ± 0.83 (0.00 to -5.25)

D = diopters
[a]Data are presented in the form of mean ± standard deviation (range).

TABLE 2

Preoperative and 3 Months Postoperative Data

Parameter	Mean ± SD (Range)
Preoperative CCT	539.93 ± 26.70 (489 to 625)
3-month CCT	451.31 ± 34.98 (375 to 550)
Difference in CCT	88.62±31.15 (18 to 163)
Preoperative CET	52.32 ± 3.34 (43 to 62)
3-month CET	55.03 ± 3.82 (45 to 66)
Difference in CET	+2.71 ± 2.68 (-3 to +12)
Calculated stromal thickness difference	86.01 ± 28.28 (17 to 161)
Planned central ablation depth	88.48 ± 26.05 (21.39 to 155.11)
Planned to calculated	+2.19 ± 6.82 (-16.94 to +18.38)

CCT = central corneal thickness; CET = central epithelial thickness; SD = standard deviation

acuity (UDVA) and manifest refraction spherical equivalent (MRSE) in these cases, as measured clinically 3 months postoperatively.

Within these cases in which the planned minus the actual difference was positive (positive outliers, n = 5), indicating that the achieved stromal thickness reduction was less than planned, the difference was +9.55 ± 2.55 µm (range: +4.77 to +23.43 µm). Mean UDVA was 0.98 ± 0.16 (20/20 Snellen) (range: 0.60 to 1.20 [20/40 to 20/10 Snellen]), reported decimally, and mean MRSE was -0.75 ± 0.43 D (-1.75 to -0.25 D). We therefore indicate an 'undercorrection' in these cases.

In the cases in which the planned minus the actual difference was negative (negative outliers, n = 7), indicating that the achieved stromal thickness reduction was more than planned, the difference was -12.75 ± 11.21 µm (range: -38.81 to -14.75 µm). Mean UDVA was 0.99 ± 0.17 (20/20 Snellen) (range: 0.65 to 1.20 [20/30 to 20/10 Snellen]), reported decimally, and mean MRSE was +0.42 ± 0.62 D (range: -0.50 to +1.75 D). We therefore indicate an 'overcorrection' in these cases.

DISCUSSION

The recent entry of OCT technology in the domain of anterior segment imaging is supported by several different OCT systems commercially available today. These include not only the OptoVue RtVue, but also the SS-1000 CASIA (Tomey Corp., Nagoya, Japan),[10] the Copernicus SOCT (OptoPol Technology S.A., Zawiercie, Poland),[11] and the Spectralis OCT (Heidelberg Engineering GmbH, Heidelberg, Germany).[12] Typically, these systems provide corneal pachymetric maps (via interpolation of thickness profile calculated from each meridional scan) and high-resolution cross-sectional images along select meridians. Acquisition is fast, and, due to the rotating slit-like beam, there is a common point (eg, the pupil center) of reference for all sequential scans.

The lack of an absolute metric by which to objectively compare the reported pachymetry values has been an obvious limitation to determining accuracy. Device accuracy may be evaluated with calibration targets graduated with accepted standards, which are lacking in the case of a live tissue such as the cornea.

In the case of myopic LASIK, an objective assessment between preoperative and postoperative corneal pachymetry reduction may be facilitated by comparing the maximum stromal thickness reduction to the ablation depth, which can be either calculated by formulae,[13-15] or directly provided by planning software embedded in the refractive platform.[6]

The current study introduces a novel objective analysis to address this issue. We employ a 'reference' to which to compare, and indirectly to deduct accuracy of measurement, to the planned maximum ablation depth, provided by the refractive laser planning software documentation. Thus, we compared the measured differences in postoperative to preoperative stromal reduction to this value for each eye.

In addition to this, the study employs a correction factor to increase objectivity, which is the difference in total corneal thickness attributed to postoperative epithelial remodeling. Our team has investigated this aspect after LASIK[8,16]; employing the same OCT system, we reported a statistically significant increase in epithelial thickness following myopic LASIK, which correlates to the amount of refractive error corrected. The detailed epithelial thickness increase with spherical equivalent corrected, as illustrated in **Figure 2**,

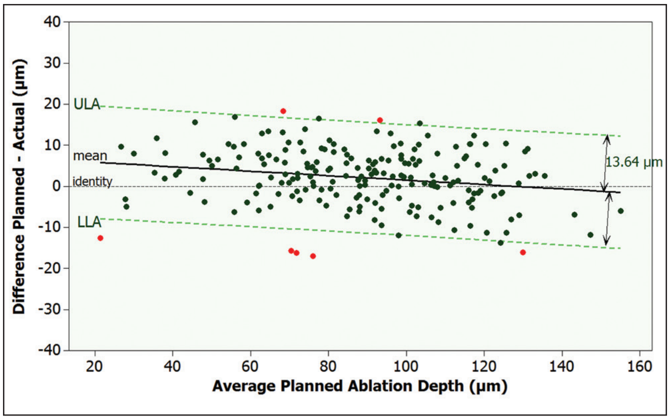

Figure 1. Bland–Altman plots comparing planned to measured stromal thickness reduction with mean difference and 95% upper (defined as mean + 2× standard deviation) and lower (defined as mean – 2× standard deviation) limits of agreement. Positive difference indicates achieved stromal thickness reduction was less than planned. All units are expressed in microns.

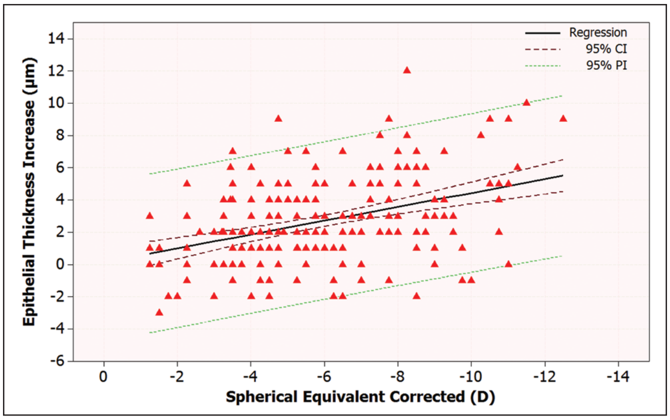

Figure 2. Scatter diagram showing the regression line of epithelial thickness increase (expressed in microns) versus attempted myopic spherical equivalent corrected (expressed in diopters [D]). Shown are regression line, the 95% confidence interval (CI), and the prediction interval (PI) lines.

supports our previous finding that there is an average epithelial thickness increase at the 1-month and up to 1-year postoperative interval; the increase depends on the amount of myopia corrected.[16] An average of +3 µm may be considered as a representative average epithelial increase, which must be subtracted from the noted 'corneal' (ie, stromal + epithelial thickness measured postoperatively). A more detailed approach, which was applied herein, involves specific evaluation of epithelial thickness increase in each eye, which is possible with the OCT device employed in this study.

A limitation of the study might arise from the fact that the recorded center(s) of the pachymetry maps, as obtained by the OCT device, may not coincide with the exact center of ablation. This is because the OCT pachymetry acquisition is centered manually by the investigator; caution is thus recommended for proper centration with the coaxial corneal light reflex (first Purkinje reflection), which in myopic eyes with small angle kappa nearly coincides with the corneal vertex.

The small percentage of outlier cases (12 of 205) illustrates that some excimer laser ablations may be either undercorrecting or overcorrecting. The correlation between the positive outliers and the residual MRSE indicates slight undercorrection, whose magnitude is in agreement with the Munnerlyn formula prediction[14]: the -0.75 D of MRSE is approximately associated with -12.50 µm for a 6.5-mm wide optical zone, and the +0.42 MRSE with +7.88 µm, respectively. Potential biomechanical influence in refractive correction achieved appears effectively neutralized by the nomogram used in these cases. These findings suggest that several variables may contribute in undercorrections and overcorrections, such as potential fluctuation in laser energy, operating room environmental conditions (temperature, humidity), intraoperative corneal dehydration, and potential patient-specific idiosyncratic variables that may influence these rare deviations from the predicted ablation depth and, consequently, refractive result.

Actual objective stromal thickness reduction following myopic LASIK correlates well with the attempted versus achieved refractive change. These findings may assist the clinicians in the quest for myopic LASIK precision and accuracy with the refractive error assessment methodology used and the specific surgical devices and technique employed.

AUTHOR CONTRIBUTIONS

Study concept and design (AJK, GA); data collection (AJK, SG, GA); analysis and interpretation of data (AJK, SG, GA); writing the manuscript (GA); critical revision of the manuscript (AJK, SG, GA); statistical expertise (AJK, GA); supervision (AJK)

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