Corneal biomechanical effects: Small-incision lenticule extraction versus femtosecond laser–assisted laser in situ keratomileusis

Di Wu, PhD, Yan Wang, MD, PhD, Lin Zhang, MD, Shengsheng Wei, MD, Xin Tang, MD, PhD

PURPOSE: To compare the biomechanical properties of the cornea after small-incision lenticule extraction (lenticule extraction group) with those after femtosecond laser–assisted laser in situ keratomileusis (femtosecond LASIK group).

SETTING: Tianjin Eye Hospital & Eye Institute, Tianjin Key Laboratory of Ophthalmology and Visual Science, Tianjin Medical University, Tianjin, China.

DESIGN: Prospective comparative case series.

METHODS: Corneal hysteresis (CH), the corneal resistance factor (CRF), and 37 other biomechanical waveform parameters were quantitatively assessed with the Ocular Response Analyzer preoperatively and 1 week and 1, 3, and 6 months postoperatively.

RESULTS: Each group comprised 40 eyes. The decrease in CH and the CRF was statistically significant 1 week postoperatively compared with preoperatively in both groups (P<.0001). However, the CH and CRF values in the lenticule extraction group were significantly higher than those in the femtosecond LASIK group 3 months and 6 months postoperatively (P<.032). The residual stromal thickness index versus the CRF and CH and the planned lenticule thickness versus the change in central corneal thickness were statistically significant in the lenticule extraction group ($r = 0.388$ to 0.950, P<.018); no significant correlation was found in the femtosecond LASIK group. In the waveform analysis of the lenticule extraction group, 28 of the 37 biomechanical waveform parameters differed significantly between preoperative values and postoperative values (P<.035).

CONCLUSIONS: Both small-incision lenticule extraction and femtosecond laser–assisted LASIK can cause biomechanical changes in the cornea. However, changes in the cornea's viscoelastic properties were less after lenticule extraction than after LASIK.

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The femtosecond laser has rapidly become accepted as a safe and effective technology to create flaps for laser in situ keratomileusis (LASIK)[1] by delivering precise laser pulses at a predetermined depth in the cornea. Although early studies of femtosecond laser–assisted LASIK have shown good results and quick visual recovery, the creation of a corneal flap in a typical LASIK procedure has been shown to weaken the cornea's biomechanical strength[2,3] and may result in an increased risk for keratectasia postoperatively.[4,5]

Recently, a new corneal refractive procedure, refractive lenticule extraction to correct myopia, has emerged. Small-incision lenticule extraction is a technique of refractive lenticule extraction. Small-incision lenticule extraction, characterized by performing lenticule extraction through a small incision (Figure 1),[6] is expected to offer better biomechanical stability than procedures that involve flap creation, such as LASIK. Although this new technique has provided satisfactory early refractive outcomes, predictability, and stability in most published reports,[6,7] information is lacking about the biomechanical effects and differences in the cornea compared with other flap-creation procedures (eg, refractive lenticule extraction, femtosecond lenticule extraction, and LASIK).

The commercially available Ocular Response Analyzer (Reichert Technologies), a dynamic bidirectional applanation device, has been used in refractive

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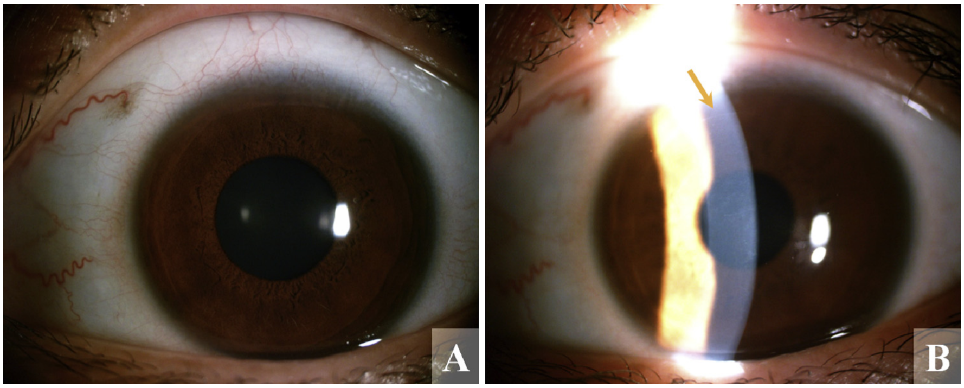

Figure 1. Slitlamp photographs 1 day after small-incision lenticule extraction. *A:* Overview in diffuse illumination. *B:* A small incision at the 12 o'clock position (*orange arrow*).

corneal surgery to follow intraocular pressure (IOP) and biomechanical property changes during clinical studies over the past few years.[2,3,8,9] The device completes measurements by applanating the cornea with a puff of air. Two applanation pressure measurements (P1 and P2) are recorded by an infrared signal. In multiple previous studies, the most analyzed parameters from this noncontact instrument have been corneal hysteresis (CH) and the corneal resistance factor (CRF). Briefly, CH represents the ability of the cornea to absorb or dampen an applied force and can be calculated as the difference between P1 and P2, while the CRF is a viscoelastic parameter expressed by the following equation: $CRF = k1 \times (P1 - 0.7 \times P2) + k2$, where k1 and k2 are constants.[8,10]

Our study monitored 37 additional biomechanical waveform parameters, each of which describes a morphologic feature of the waveform, to obtain clinical information and details about the corneal deformation signal waveform.[11,12] The information obtained may distinguish the corneal biomechanical effects of small-incision lenticule extraction from those of femtosecond laser–assisted LASIK. To our knowledge, this is the first study reporting biomechanical changes and outcomes of small-incision lenticule extraction. The purpose was not only to assess the biomechanical changes after small-incision lenticule extraction procedure in the early postoperative period but also to compare the changes between flapless surgery (lenticule extraction) and femtosecond laser–assisted LASIK.

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From Tianjin Eye Hospital & Eye Institute, Tianjin Key Laboratory of Ophthalmology and Visual Science, Tianjin Medical University, Tianjin, China.

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Corresponding author: Yan Wang, MD, PhD, Tianjin Eye Hospital & Eye Institute, Tianjin Key Laboratory of Ophthalmology and Visual Science, Tianjin Medical University, Number 4, Gansu Road, Heping District, Tianjin 300020, China. E-mail: wangyan7143@vip.sina.com.

PATIENTS AND METHODS

This prospective study was performed at Tianjin Eye Hospital, Tianjin Medical University, China, from August 2011 to March 2012. It enrolled right eyes with myopia or myopic astigmatism scheduled to have femtosecond laser–assisted LASIK (femtosecond LASIK group) or small-incision lenticule extraction (lenticule extraction group). The Institutional Review Board, Tianjin Eye Hospital, approved the study protocol, which adhered to the tenets of the Declaration of Helsinki. All patients provided informed consent for surgery.

Inclusion criteria were 18 years or older, no ocular or systemic disease that could affect the biomechanical properties of the cornea, and a stable refraction (change of $\pm$0.50 diopter or less) in the previous 2 years. Patients discontinued soft contact lens wear at least 2 weeks before surgery.

Measurements

Patients had a full eye examination as part of a routine preoperative assessment. The assessment included uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest and cycloplegic refractions, IOP, slitlamp microscopy, and dilated indirect fundoscopy. The preoperative keratometry and anterior and posterior corneal elevation were measured using a Scheimpflug tomography system (Pentacam, Oculus GmbH).

The Ocular Response Analyzer was used to measure CH and CRF values and 37 other biomechanical waveform parameters preoperatively and at all postoperative visits. Three measurements with consistent signal quality were obtained, and the CH and CRF values were averaged for statistical analysis. The measurement with the highest waveform score was used for analysis. Anterior segment optical coherence tomography (Visante, Carl Zeiss Meditec AG) was used to evaluate the thickness of the preoperative and postoperative central cornea, flap (or cap), and residual stromal thickness (RST). Imaging and measurements of each eye were repeated 3 times by the same technician, and the average of the 3 measurements was used for analysis.

Postoperative follow-up took place at 1 week and 1, 3, and 6 months. In addition to the biomechanical waveform parameters, the IOP, CDVA, and UDVA were measured at each visit. Each visit also included a slitlamp examination. Anterior segment OCT was performed 6 months postoperatively.

Surgical Technique

The same surgeon (Y.W.) performed all surgeries using the same femtosecond laser platform (Visumax, Carl Zeiss Meditec AG) with a 500 kHz repetition rate.

During the small-incision lenticule extraction procedure, 4 cleavage planes were created, including 2 surfaces of the refractive lenticule, a 360-degree chordal length vertical edge of the refractive lenticule, and a single side-cut incision with a circumferential length of 4.0 mm at the 12 o'clock position. In all cases, the predicted depth of the anterior surface of the lenticule (ie, cap) was 110 μm and the diameter of the optical zone size was 6.0 mm. All side-cut angles were 90 degrees.

In the femtosecond LASIK group, flap creation was performed using a 100 to 110 μm flap thickness setting and programmed flap diameters of 7.9 to 8.0 mm. The corneal stroma was ablated with a scanning-spot excimer laser (Allegretto, Wavelight Laser Technologie AG). The repetition frequency of the laser was 400 Hz, and the ablation diameter of the Gaussian spot profile was 1.0 mm. All eyes had ablations using an optical zone diameter of 6.0 mm surrounded by a transition zone of 1.0 mm.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows software (version 13.0, SPSS, Inc.). All changes were calculated as follows: 6-month postoperative value − preoperative value; in this paper, changes are preceded by the Δ symbol. An RST index was calculated to account for preoperative central corneal thickness (CCT) as follows: RST/preoperative CCT.[2] The ΔCCT index was calculated as follow: ΔCCT/preoperative CCT. The correlation between ΔCCT and predicted tissue removal was assessed. The thickness of tissue removal was expressed as the lenticule thickness in the lenticule extraction group and as the ablation depth (provided by excimer laser computer) in the femtosecond LASIK group.

The normality of all data samples was checked with the Kolmogorov-Smirnov test. The means of CH and CRF at different examination points within a group were compared by repeated-measures analysis of variance. The Greenhouse-Geisser correction was applied to the degrees of freedom if sphericity was violated. The statistical significance of differences between the 2 groups and between preoperative and postoperative waveform parameters was evaluated using post hoc testing. The Pearson correlation coefficient (*r*) was used to evaluate the correlations between variables. A *P* value less than 0.05 was considered statistically significant.

RESULTS

The study enrolled 80 patients (80 right eyes), 40 in the femtosecond LASIK group and 40 in the lenticule extraction group. Table 1 shows the baseline (preoperative) characteristics of patients by group.

Table 1. Baseline characteristics of eyes by group.

	Mean ± SD		
Parameter	Lenticule Extraction	Femto LASIK	*P* Value
Sex (n)			.502
Male	15	18	
Female	25	22	
Age (y)	25.75 ± 5.40	24.25 ± 6.02	.244
MRSE (D)	−5.71 ± 1.19	−5.80 ± 1.14	.728
Mean K (D)	44.31 ± 1.02	43.96 ± 1.23	.597
CCT (μm)	554.15 ± 24.77	556.70 ± 30.60	.683

CCT = central corneal thickness; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; K = Scheimpflug keratometry; Lenticule Extraction = small-incision lenticule extraction; MRSE = manifest refraction spherical equivalent

In the lenticule extraction group, 40 eyes completed the postoperative examinations at 1 week and 1 and 3 months; 37 eyes completed the 6-month follow-up visit. In the femtosecond-LASIK group, 40 eyes completed postoperative examinations at 1 week and 1 month; 38 eyes and 34 eyes completed the 3-month and 6-month follow-up visits, respectively.

Corneal Hysteresis and Corneal Resistance Factor

Figure 2 and Figure 3 show the CRF values and CH values, respectively. At most timepoints, the postoperative CH and CRF values decreased statistically significantly in both groups over preoperative values ($P < .0001$).

In the lenticule extraction group, the CH values were lowest 1 week after surgery. However, there was an increase in CH at 3 months, at which time the value was statistically significantly higher than the 1-week and 1-month values ($P = .004$ and $P = .026$, respectively). There were no statistically significant differences in the CH value between 3 months and 6 months or in the CRF between any postoperative timepoints.

In the femtosecond-LASIK group, the CRF values 1 week after surgery were statistically significantly lower than those at 1 month ($P = .015$). The 6-month CRF values were lowest and statistically significantly lower than the values at 1 month and 3 months ($P < .0001$ and $P = .040$, respectively). The decrease in the CH value was statistically significantly lower than the preoperative values. However, there was no statistically significant difference in the CH values between any postoperative timepoints.

Between-Group Comparisons

There was no statistically significant difference between the 2 groups in baseline CH and CRF

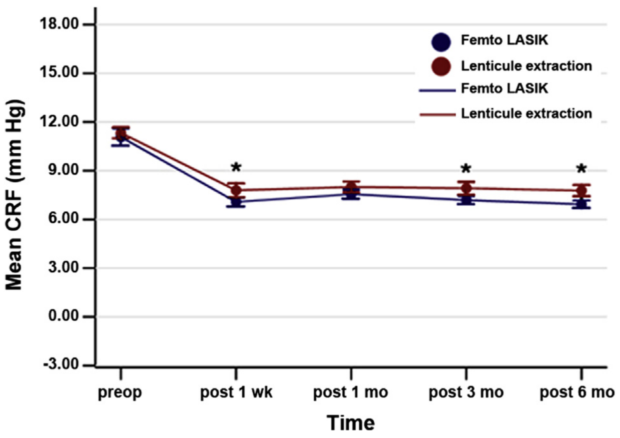

Figure 2. Change in the CRF over time. An asterisk denotes a significant difference between the 2 groups ($P<.05$) (CRF = corneal resistance factor; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule extraction = small-incision lenticule extraction).

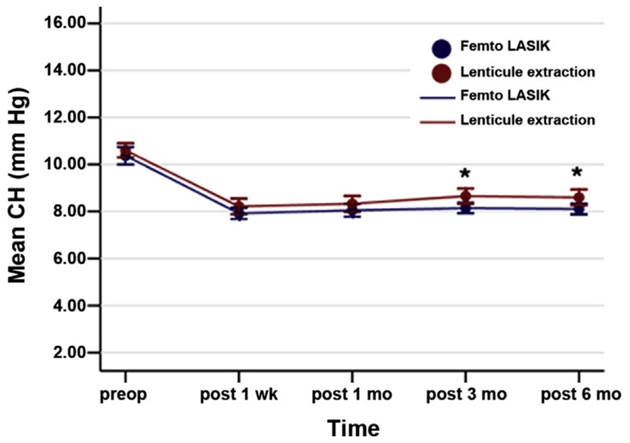

Figure 3. Change in CH over time. The asterisk denotes a significant difference between the 2 groups ($P<.05$) (CH = corneal hysteresis; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule extraction = small-incision lenticule extraction).

preoperatively. The CH and CRF values in the lenticule extraction group were higher than those in the femtosecond-LASIK group at each postoperative timepoint. Furthermore, the mean CRF was statistically significantly higher in the lenticule extraction group than in the femtosecond-LASIK group 1 week, 3 months, and 6 months after surgery (Table 2). The CH also was significantly higher in the lenticule-extraction group than in the femtosecond-LASIK group 3 months and 6 months after surgery (Table 3).

Table 4 compares the characteristics and measurements 6 months after surgery between groups. The ΔCRF was significantly smaller after lenticule extraction than after femtosecond laser–assisted LASIK ($P=.025$). The difference in ΔCH between the 2 groups approached significance ($P=.083$). No other measured parameter was statistically significantly different between the 2 groups.

Correlation Analysis

ΔCentral Corneal Thickness Versus Ablation Depth/Lenticule Thickness The correlation between the lenticule thickness and ΔCCT (r = 0.950, $P<.0001$) was higher than between the ablation depth and ΔCCT (r = 0.577, $P<.0001$). The measured ΔCCT was very close to the planned value in the lenticule extraction group (Figure 4). However, the deviation between the predicted ΔCCT and the measured ΔCCT was greater with the increase in the planned ablation depth in the femtosecond LASIK group.

ΔCentral Corneal Thickness Index and Residual Stromal Thickness Index Versus ΔCorneal Resistance Factor and ΔCorneal Hysteresis Figure 5 shows the correlation of the RST index and the ΔCCT index with ΔCRF and ΔCH. In the lenticule extraction group, there was a statistically significant correlation between the RST index and ΔCRF (r = 0.517, $P=.001$) and between the RST index and ΔCH (r = 0.412, $P=.011$). However, the correlations between the RST index and ΔCRF (r = −0.008, $P=.965$) and between the RST index and ΔCH (r = 0.196, $P=.267$) were not statistically significant in the femtosecond LASIK group. There was a higher correlation between the ΔCCT index and ΔCRF in the lenticule extraction group (r = −0.473, $P=.003$) than in the femtosecond

Table 2. Statistically significant differences in the postoperative CRF values between groups.

	Mean CRF (mm Hg) ± SD		
Postop Exam	Lenticule Extraction	Femto LASIK	P Value
1 week	7.89 ± 1.31	7.21 ± 0.83	.011
1 month	7.98 ± 1.24	7.29 ± 0.75	.006
6 months	7.78 ± 1.03	6.94 ± 0.66	<.0001

CRF = corneal resistance factor; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule Extraction = small-incision lenticule extraction

Table 3. Statistically significant differences in the postoperative CH values between groups.

	Mean CH (mm Hg) ± SD		
Postop Exam	Lenticule Extraction	Femto LASIK	P Value
3 months	8.64 ± 1.03	8.17 ± 0.71	.032
6 months	8.59 ± 1.00	8.11 ± 0.66	.019

CH = corneal hysteresis; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule Extraction = small-incision lenticule extraction

Table 4. Characteristics and measurements at 6 months postoperatively.

Parameter	Mean ± SD		P Value
	Lenticule Extraction (n = 37)	Femto LASIK (n = 34)	
Postop CCT (μm)	456.49 ± 29.40	459.65 ± 29.53	.653
FT (μm)	104.54 ± 2.98	104.76 ± 2.80	.745
RST (μm)	351.95 ± 29.60	354.88 ± 29.32	.676
RST index	0.64 ± 0.03	0.63 ± 0.03	.593
ΔCCT	95.43 ± 13.12	100.24 ± 14.02	.140
ΔCCT index	0.17 ± 0.03	0.18 ± 0.02	.328
ΔCH	−1.94 ± 0.82	−2.34 ± 1.08	.083
ΔCRF	−3.59 ± 0.91	−4.29 ± 1.60	.025*

Δ = 6-month postoperative − preoperative; ΔCCT index = Δcentral corneal thickness/preoperative central corneal thickness; CCT = central corneal thickness; FT = flap thickness; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule Extraction = small-incision lenticule extraction; RST = residual stromal thickness; RST index = residual stromal thickness/preoperative central corneal thickness
*Statistically significant (*t* test)

LASIK group ($r = -0.241$, $P = .169$). The correlation of the ΔCCT index with ΔCH was similar between the 2 groups ($r = -0.350$, $P = .034$, lenticule extraction group; $r = -0.416$, $P = .014$, femtosecond LASIK group).

Waveform Analysis

Table 5 shows the waveform metrics that were statistically significantly different between preoperatively and postoperatively. (See descriptions of metrics in Table 5.) Compared with preoperative values, there were statistically significant reductions in p1area, p2area, w1, w2, p1area1, p2area1, w11, and w21 in both groups ($P < .035$, lenticule extraction group; $P < .020$, femtosecond-LASIK group), whereas an increase occurred postoperatively in aspect2, uslope1, uslope2, dslope2, path1, path2, mslew2, slew1, slew2, aspect11, aspect21, uslope21, dslope11, dslope21, path11, and path21 in both groups ($P < .021$, lenticule extraction group; $P < .042$, femtosecond-LASIK group). Significant variations were also found between the preoperative and postoperative h2, mslew1, uslope11, and h21 values in the lenticule extraction group ($P < .028$).

There were no statistically significant differences in the 37 biomechanical waveform parameters preoperatively or postoperatively between the lenticule extraction group and the femtosecond LASIK group. No between-group differences were found in the changes between preoperatively and postoperatively.

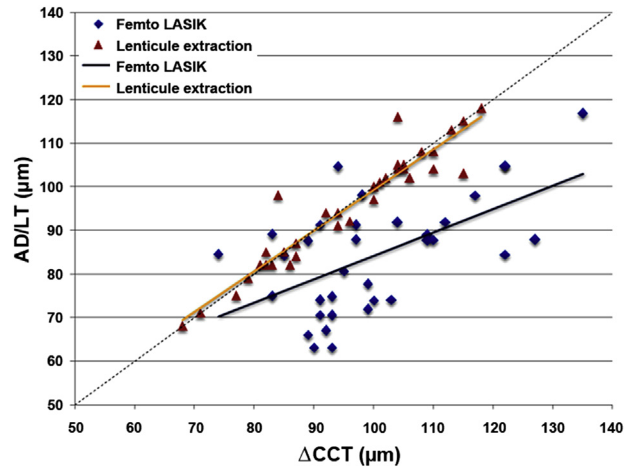

Figure 4. Relationship between predicted ablation depth (or lenticule thickness) and measured ΔCCT. The *dotted line* represents the intended outcome (ie, estimated ΔCCT and measured ΔCCT are identical). The *solid blue* and *yellow lines* represent the regression lines. The regression line formulas are $y = 0.93 \times +6.03$ ($r^2 = 0.901$) and $y = 0.54 \times +30.52$ ($r^2 = 0.332$) for the lenticule extraction group and femtosecond LASIK group, respectively (ΔCCT = change in central corneal thickness; AD/LT = ablation depth or lenticule thickness; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule extraction = small-incision lenticule extraction).

DISCUSSION

Since the first reports of corneal ectasia after LASIK published by Seiler et al.,[13] the profound impact of corneal biomechanical variation on the safety and efficacy of refractive surgery continues to be an increasing concern. It has been verified that flap creation and tissue removal can weaken the biomechanical properties of the cornea.[14,15] Small-incision lenticule extraction, a procedure combining the flapless technique with the new concept of tissue subtraction (which is different from tissue ablation with the excimer laser), was generated to some extent by the need for biomechanical protection. However, to our knowledge, the corneal biomechanical effects of this new surgical technique have not been reported.

In the current study, we found a noticeable decrease in the biomechanical parameters after both small-incision lenticule extraction and femtosecond laser–assisted LASIK. After small-incision lenticule extraction, corneal biomechanical parameter values were stable with no progressive deterioration during the 6-month follow-up. There was a positive recovery in CH 3 months and 6 months after surgery. The same recovery was not observed after femtosecond laser–assisted LASIK during the postoperative follow-up. In a study with a 1-year follow-up by Ryan et al.,[16] CH after epithelial LASIK decreased significantly, with a slight recovery between 1 month and 6 months. The

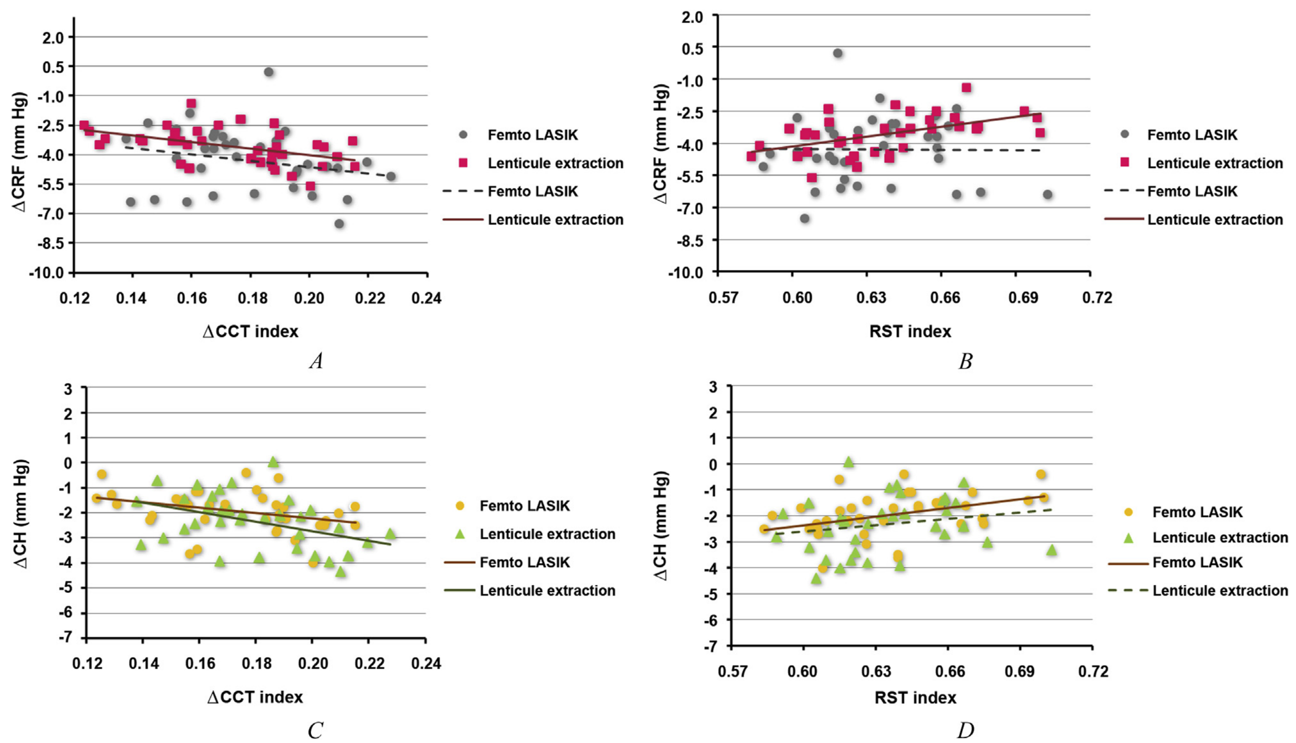

Figure 5. Correlation between ΔCRF and ΔCCT index (*A*), between ΔCRF and RST index (*B*), between ΔCH and ΔCCT index (*C*), and between ΔCH and RST index (*D*) (ΔCCT index = change in central corneal thickness/preoperative central corneal thickness; ΔCH = change in corneal hysteresis; ΔCRF = change in corneal resistance factor; RST index = residual stromal thickness/preoperative central corneal thickness; Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule extraction = small-incision lenticule extraction).

value stabilized by 1 year postoperatively. Another 6-month follow-up study of the time course of corneal biomechanics after LASIK by Kamiya et al.[17] found that after the most significant changes occurred within 1 week after surgery; the CH value was relatively stable. We speculate that different responses between small-incision lenticule extraction and femtosecond laser–assisted LASIK are the result of differences in the wound-healing reaction. The CH value is thought to correlate with the viscous dampening inherent in the corneal tissues; the dampening is created by the viscosity of glycosaminoglycans, proteoglycans, and the collagen matrix interaction.[18] Theoretically, the viscosity of the ground substance, which includes all the components of the extracellular matrix (ECM) except collagen and elastic fibers, is the main factor that determines CH.[10] Therefore, the wound repair that occurs in the ECM may affect CH to a degree. An in vivo animal study that compared corneal wound healing and inflammatory responses after refractive lenticule extraction and LASIK[19] found that refractive lenticule extraction might result in less inflammation and early ECM deposition than LASIK, especially when there is a high refractive correction. However, further studies of wound-healing reactions after femtosecond laser treatment are required.

In this study, the CRF values changed less after small-incision lenticule extraction than after femtosecond laser–assisted LASIK. The cornea is a highly complex anisotropic tissue with more extensive interlamellar branching in the periphery than in the center. The cohesive tensile strength testing of corneas directly showed that the stronger regions were located anteriorly and peripherally.[20] Biomechanically, the flapless lenticule extraction technique maximally protects the structural integrity of the cornea and causes less disruption of the peripheral collagen fibers than LASIK. Regarding the Ocular Response Analyzer methodology, the CRF is calculated by proprietary algorithms that place greater weight on P1; thus, this parameter is more reflective of the initial applanation event. The anterior cornea with integrated peripheral collagen fibers might provide stronger resistance than the cornea after flap creation.

A limitation of the current study is the short follow-up. The change trends should be followed longer to allow conclusions about the characteristics of the corneal biomechanical properties after a new type of surgery. In addition, although the CH and CRF parameters are intended to quantify the viscoelastic nature of the cornea, their validity has not been convincingly confirmed. Comprehensive methods

Table 5. Biomechanical waveform parameters that were statistically significantly different between preoperatively and postoperatively. Parameters 1–15 are analyzed from upper 75% of the applanation peak. Parameters 16–28 parameters are analyzed from upper 50% of the applanation peak.

			Mean ± SD			
			Lenticule Extraction		Femto-LASIK	
No.	Parameter	Description	Preop	Postop	Preop	Postop
1	p1area	Area under the curve of peak1 (sum of values)	2859.74 ± 745.79	2243.15 ± 735.27*	2905.36 ± 720.42	2151.21 ± 479.11†
2	p2area	Area under the curve of peak2 (sum of values)	2026.60 ± 639.86	1709.20 ± 439.97*	2037.09 ± 639.98	1718.09 ± 442.43†
3	aspect2	Aspect ratio (height/width) of peak2	14.71 ± 6.92	22.56 ± 8.74*	13.91 ± 6.69	18.84 ± 6.99†
4	uslope1	Rate of increase from base to peak value of peak1	61.69 ± 27.47	78.01 ± 26.52*	58.08 ± 29.17	74.20 ± 28.89†
5	uslope2	Rate of increase from base to peak value of peak2	68.02 ± 35.12	108.02 ± 38.81*	73.60 ± 40.69	105.99 ± 43.00†
6	dslope2	Rate of decrease from peak to base value of peak2	19.49 ± 9.68	29.06 ± 12.71*	17.69 ± 8.87	22.88 ± 8.60†
7	w1	Width of peak1 at base of peak1 region	21.84 ± 3.78	20.00 ± 3.59*	23.71 ± 3.89	20.59 ± 2.68†
8	w2	Width of peak2 at base of peak2 region	19.62 ± 4.47	15.00 ± 4.00*	20.59 ± 4.85	16.53 ± 3.54†
9	h2	Height of peak2 (from lowest to highest value) of peak2	263.78 ± 75.24	311.14 ± 65.63*	261.15 ± 81.56	292.25 ± 77.49
10	path1	Absolute value of path length around peak1	23.35 ± 5.13	30.10 ± 4.93*	22.60 ± 4.13	28.63 ± 5.61†
11	path2	Absolute value of path length around peak2	25.03 ± 6.84	32.59 ± 7.07*	25.12 ± 6.20	29.89 ± 7.37†
12	mslew1	Maximum single-step increase in rise of peak1	102.06 ± 31.09	119.76 ± 36.51*	103.10 ± 32.31	105.15 ± 30.98
13	mslew2	Maximum single-step increase in rise of peak2	104.28 ± 41.49	152.22 ± 55.34*	109.55 ± 47.06	150.69 ± 53.84†
14	slew1	Aspect ratio of dive1‡	63.48 ± 28.25	80.49 ± 26.55*	61.10 ± 28.29	75.31 ± 28.22†
15	slew2	Aspect ratio of dive2§	68.98 ± 34.07	108.02 ± 38.81*	75.38 ± 38.96	105.26 ± 44.34†
16	p1area1	Area under the curve of peak1 (sum of values)	1197.51 ± 366.91	912.64 ± 439.98*	1189.87 ± 341.10	833.94 ± 308.66†
17	p2area1	Area under the curve of peak2 (sum of values)	865.04 ± 322.87	717.59 ± 216.65*	853.27±320.66	697.66 ± 203.90†
18	aspect11	Aspect ratio (height/width) of peak1	20.96 ± 10.65	28.87 ± 11.92*	19.85 ± 7.58	26.54 ± 10.30†
19	aspect21	Aspect ratio (height/width) of peak2	20.93 ± 11.10	35.28 ± 14.31*	19.71 ± 8.74	30.41 ± 12.85†
20	uslope11	Rate of increase from base to peak value of peak1	56.82 ± 25.72	74.13 ± 25.83*	59.24 ± 29.74	69.50 ± 25.75
21	uslope21	Rate of increase from base to peak value of peak2	59.92 ± 32.11	85.12 ± 31.40*	60.01 ± 32.97	81.20 ± 44.01†
22	dslope11	Rate of decrease from peak to base value of peak1	35.03 ± 24.51	48.47 ± 24.46*	30.87 ± 14.67	44.16 ± 26.86†
23	dslope21	Rate of decrease from peak to base value of peak2	31.44 ± 19.48	56.36 ± 25.63*	29.34 ± 14.46	45.70 ± 22.58†
24	w11	Width of peak1 at base of peak1 region	11.35 ± 2.71	8.05 ± 2.20*	11.47 ± 2.80	8.24 ± 2.09†
25	w21	Width of peak2 at base of peak2 region	9.70 ± 3.33	6.43 ± 1.83*	9.91 ± 3.33	7.12 ± 2.23†
26	h21	Height of peak2 (from lowest to highest value) of peak2	175.85 ± 50.16	207.40 ± 43.78*	174.10 ± 54.38	194.83 ± 51.66
27	path11	Absolute value of path length around peak1	34.14 ± 10.01	44.86 ± 10.04*	32.93 ± 7.60	42.17 ± 10.93†
28	path21	Absolute value of path length around peak2	34.89 ± 10.12	45.58 ± 11.51*	35.98 ± 8.70	42.72 ± 10.66†

Femto LASIK = femtosecond laser–assisted laser in situ keratomileusis; Lenticule Extraction = small-incision lenticule extraction
*Significant difference between preoperative and postoperative values in lenticule extraction group ($P < .05$, t test)
†Significant difference between preoperative and postoperative values in femto LASIK group ($P < .05$, t test)
‡dive1 represents absolute value of monotonic decrease on downslope part of peak1 starting at the peak value
§dive2 represents absolute value of monotonic decrease on downslope part of peak2 starting at the peak value

may be required to evaluate the biomechanical properties of corneas in future studies.

It is widely acknowledged that the RST plays an important role in maintaining the biomechanical stability of the cornea after refractive surgery. In our study, the stronger correlation between lenticule thickness and ΔCCT than between ablation depth and ΔCCT indicates that the estimation of the thickness of the material removed is more accurate with a femtosecond laser than an excimer laser. Estimating ablation depth with an excimer laser is difficult due to surgical swelling and an estimated ablation rate, among other factors. However, it is easy to precisely estimate the thickness of a femtosecond laser–created lenticule. In addition, we also analyzed the correlation between the change in biomechanical properties and the RST index. We found a positive correlation between the RST index and the ΔCRF and between the RST index and ΔCH in the lenticule extraction group. In our study's femtosecond LASIK group, which involved tissue ablation and a flap cut, the correlation between the RST index and ΔCRF and between the RST index and ΔCH was not significant. It has been shown that flap creation also can affect biomechanical properties. The flap effect may be the factor that weakens the correlation between biomechanical changes and the RST index.

A recent study[11] differentiated post-femtosecond LASIK eyes from keratoconic eyes by analyzing biomechanical waveform parameters obtained by the Ocular Response Analyzer after controlling for potential confounding factors. Six waveform parameters were found to discriminate between the 2 groups, even though the clinical significance of these parameters remains unknown. In our study, however, no significant difference was found between the lenticule extraction group and the femtosecond LASIK group. This shows that the biomechanical waveform parameters may be more useful in distinguishing between corneas with pathology (eg, keratoconus) and the postoperative normal cornea.

In summary, the present study evaluated the in vivo corneal biomechanical properties to improve the safety of contemporary femtosecond laser refractive treatments, in particular small-incision lenticule extraction. Although both procedures in the study decreased the biomechanical properties of the corneas, the change in the biomechanical parameters was smaller and showed better predictability after small-incision lenticule extraction than after femtosecond laser–assisted LASIK. Further studies are required to evaluate the long-term impact of corneal biomechanical changes and the potential mechanisms after small-incision lenticule extraction.

WHAT WAS KNOWN

- The creation of a corneal flap in a typical LASIK procedure can weaken the cornea's biomechanical strength. Small-incision lenticule extraction is a new flapless corneal refractive procedure, and its biomechanical effects on the cornea have not been studied.

WHAT THIS PAPER ADDS

- The cornea's biomechanical changes after small-incision lenticule extraction showed good stability and predictability; there were fewer biomechanical changes than after femtosecond laser–assisted LASIK.

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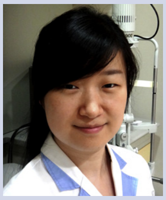

First author:
Di Wu, PhD

Tianjin Eye Hospital & Eye Institute, Tianjin Key Laboratory of Ophthalmology and Visual Science, Tianjin Medical University, Tianjin, China