·Clinical Research·

Analysis of changes in crystalline lens thickness and its refractive power after laser *in situ* keratomileusis

Liang Wang [1,2], *Hai-Ke Guo* [1], *Jing Zeng* [1], *Hai-Ying Jin* [1]

[1]Department of Ophthalmology, Guangdong General Hospital Affiliated to Southern Medical University, Guangzhou 510515, Guangdong Province, China
[2]Department of Ophthalmology, Wuhu Second People's Hospital Affiliated to Wannan Medical College, Wuhu 241001, Anhui Province, China
Correspondence to: Hai-Ke Guo. Department of Ophthalmology, Guangdong General Hospital Affiliated to Southern Medical University, Guangzhou 510515, Guangdong Province, China. guohaike@hotmail.com
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Abstract

• AIM: To evaluate changes in the anterior chamber depth (ACD), crystalline lens thickness (LT) and its refractive power after laser in situ keratomileusis (LASIK).

• METHODS: In all cases, the preoperative and postoperative central ACD which were measured with Pentacam, Orbscan, IOL-Master and A-scan ultrasonography, central corneal true net power which was measured with the Pentacam, Orbscan and IOL-Master, axial length (AL) which was measured with IOL-Master and LT which was measured with the A-scan ultrasonography were compared using the paired sample *t* test. Ocular refractive errors and lens refractive power at corneal plane were calculated and their correlations were also evaluated before and after LASIK.

• RESULTS: At 1 week after LASIK, LT and crystalline lens refractive power at corneal plane (Dlens) which were associated with the IOL-Master and Pentacam increased significantly ($P \leqslant 0.005$), ACD decreased significantly ($P \leqslant 0.001$), but no significant increase was observed in the Dlens which was associated with the Orbscan(P=0.261). Significant correlations between the changes in the ocular refractive errors and Dlens which were associated with the Pentacam were observed at 1 week and 6 months after LASIK (P=0.028; P=0.001).

• CONCLUSION: LT increased significantly after LASIK, and this might partially lead to ACD decrease, Dlens increase and a small quantity of myopic regression.

• KEYWORDS:anterior chamber depth; crystalline lens thickness; refractive power
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INTRODUCTION

Excimer laser surgery has for years been a routine procedure for the correction of myopia. Corneal laser *in situ* keratomileusis (LASIK) intends to change the shape of the anterior surface of the cornea, thus changing its refractive power, 1 but refractive outcomes are subject to some variability because of regression,2 hydration,3 and other factors that lead to empiric adjustments of the ablation nomogram.4,5 Myopic regression can affect the predictability, efficiency, and long-term stability of keratorefractive surgery, and lead to deterioration in visual performance, but the mechanism for myopic regression still remains to be further elucidated. Greater understanding of the mechanism for myopic regression that take place in the ocular after surgery would help to improve the predictability and stability of achieved corrections. The incidence of regression toward myopia after LASIK varies across studies, ranging from 5.5% to 27.7% .6-10 Most of the previous studies in which investigators identified clinical correlates responsible for myopic regression after LASIK focused on cases involving cornea, rather than on crystalline lens thickness and its refractive power, 11-16 although both the Orbscan17 and the Pentacam18 had been used to detect a statistically significant amount of decrease in the anterior chamber depth (ACD), which may lead to total ocular refractive change and deterioration in visual performance, after laser refractive surgery.

The purpose of this paper was to evaluate the changes in ACD, LT and its refractive power after LASIK, and to explore whether these changes affect total ocular refraction and myopic regression.

PATIENTS AND METHODS

Patients This retrospective study included 66 eyes from 66 patients undergoing LASIK. Inclusion criteria included preoperative examination with the Pentacam and Orbscan IIz Placido and slit-scanning topography systems. All patients provided informed consent. There were 37 females (56%) and 29 (44%) males. The mean patient age was 27.2±4.8 years (range, 20-40). The preoperative refraction (spherical equivalent [SE]) was -5.02±1.68 diopters (range, -1.0- -8.5). The preoperative corneal thickness was 554.9± 24.7μm (range, 512-619). In general, no LASIK procedure was performed when the preoperative thinnest pachymetry reading was less than 500μm. The minimum residual bed allowance was 250μm. Corrections were typically limited to a maximum spherical correction in negative cylinder form of 10.00 diopters or less.

Methods LASIK was performed by the same surgeon (Jin Zeng). The preoperative central corneal thickness (CCT) had to be adequate to ensure a residual stromal bed of at least 250μm and above 55% of the total preoperative CCT after creation of a corneal flap with a superior hinge (160-μm head, Hansatome microkeratome; Chiron Vision, Claremont, CA, USA).Ablation of the appropriate cut depth was carried out using the Technolas Keracor 217z excimer laser (Bausch & Lomb Chiron Technolas GmbH, Munich, Germany).The mean optical zone diameter was 6.0±0.12mm (range, 5.7-6.4), and the mean maximum ablation depth was 82.9 ±19.6μm (range, 22-120). No case had clinically apparent iatrogenic keratectasia.

In all cases, the ACD, corneal thickness, and central corneal true net power were measured using a rotating Scheimpflug camera and Orbscan IIz Placido and slit-scanning topography systems before and 1 week and 1 ,3 ,6 months after surgery, and IOL-Master was used to measure the ACD, axial length (AL),and central corneal power. Simultaneously, the pupil was dilated with two drops of 0.5% tropicamide, after which the refractive error and astigmatism in the central zone of each eye was measured with a Topcon KR-3500 autokerato-refractometer, the ACD and lens thickness were detected with the A-scan ultrasonography. The mean ACD and central corneal thickness (CCT) were evaluated at the center, and the CCT was subtracted from the ACD. ACD changes were determined by subtracting the preoperative central ACD from the postoperative central ACD. The preoperative and postoperative central ACD which were measured with Pentacam, Orbscan, IOL-MASTER and A-scan ultrasonography, and crystalline lens thickness (LT) which was measured with the A-scan ultrasonography were compared. The correlation between the crystalline lens refractive power and ocular refractive error was also evaluated. All measurements were performed just after a blink to minimize the effect of tear film alteration on the data.

For the optical design, the total ocular refractive power at corneal plane (Fe/D_{total}) can be determined from the geometrical optics theory,

$V'-V=Fe$

$D_{total}=D_{cornea}+D_{lens}$

where V represents object vergence (ocular refractive errors at corneal plane, R), V' represents image vergence, D_{cornea} represents the refractive power of the cornea, and D_{lens} represents the refractive power of the lens at corneal plane.

The image vergence (V') can be determined from the Gullstrand's number 1 or "exact" eye model,

$V'=n/s=1.336\times1000/(L-1.602)$

where L represents AL and the refractive index for the aqueous and vitreous humors is 1.336 (n=1.336)[19].

Then Equations (1-3) can be applied to determine the refractive power of the lens at corneal plane (D_{lens}),

$D_{lens}=1336/(AL-1.602)-D_{cornea}-R$

where R represents ocular refractive errors at corneal plane.

Relations between the changes in lens refractive power (ΔD_{lens}) and the ocular refractive errors 1 week and 6 months after LASIK (ΔR^1, ΔR^2) were analyzed,

$\Delta D_{lens}^1=D_{lens}$(Pre-op)-$D_{lens}$(1 week after LASIK)

$\Delta D_{lens}^2=D_{lens}$(Pre-op) -Dlens(6 Months after LASIK)

ΔR^1=R(operation)-R(1 week after LASIK)

ΔR^1=R(operation) -R(1 week after LASIK)

where R(operation) represents the ocular refractive errors at corneal plane determined by the Lasik operation design.

Statistical Analysis A paired t test was used to compare the measured values before and after the laser refractive surgery. LT, AL, ACD, D_{cornea} and D_{lens} before surgery and at 1 week, 1 month, 3 months and 6 months after LASIK were compared by using two-tailed paired t-tests. Normal distribution was confirmed with the Shapiro-Wilk test. Spearman's correlation was used to investigate relationship between the changes in lens refractive power and the ocular refractive errors 1 week and 6 months after LASIK ($\Delta D_{lens}^1/\Delta R^1$, $\Delta D_{lens}^2/\Delta R^2$). All statistical analyses were performed using the Statistical Package for Social Science software version 13.0 (SPSS, Inc., Chicago, IL) and a P value ≤0.05 PubMed was considered statistically significant.

RESULTS

At 1 week, 1 month, 3 months and 6 months after LASIK, ACD which was measured with A-scan, IOL-master, Orbscan and Pentacam decreased significantly (P<0.001). In addition, ACD which was measured with A-scan, Pentacam, IOL-master, and Orbscan decreased gradually in order after LASIK, and there was significant correlation among these four measurements (P<0.001, Table 1). After LASIK, LT increased 0.098±0.137mm at 1 week, 0.111± 0.116mm at 1 month, 0.112±0.126mm at 3 months and 0.107±0.118mm at 6 months (t=5.805, P<0.001; t=7.799; P<0.001; t=7.203; P<0.001; t=7.375; P<0.001, Table 2).

Table 1 Changes in ACD before and after LASIK

Paired differences	ACD (Mean±SD, mm) (*P* Value)			
	A-scan	Pentacam	IOL-master	Orbscan
Pre-op	3.404±0.220	3.317±0.219	3.247±0.246	3.100±0.223
1 week	3.330±0.233 (0.001)	3.257±0.227 (0.000)	3.207±0.244 (0.009)	0.047±0.239 (0.000)
1 month	3.344±0.224 (0.009)	3.256±0.226 (0.000)	3.213±0.243 (0.002)	3.052±0.242 (0.000)
3 months	3.331±0.219 (0.001)	3.252±0.230 (0.000)	3.207±0.238 (0.001)	3.047±0.237 (0.000)
6 months	3.330±0.233 (0.001)	3.251±0.229 (0.000)	3.211±0.238 (0.003)	3.049±0.242 (0.000)

Table 2 Changes in LT before and after LASIK

Paired differences	LT (Mean±SD, mm)	Diference(Mean±SD, mm)	*t* Value; *P* Value
Pre-op	3.606±0.218	/	/
1 week	3.704±0.234	0.098±0.137	5.805; 0.000
1 month	3.717±0.222	0.111±0.116	7.799; 0.000
3 months	3.719±0.222	0.112±0.126	7.203; 0.000
6 months	3.714±0.215	0.107±0.118	7.375; 0.000

Table 3 Changes in AL and AL* before and after LASIK

Paired differences	AL(mm) Mean±SD (t Value; P Value)	AL*(mm) Mean±SD (*t* Value; *P* Value)
Pre-op	25.845±1.029	25.762±1.017
1 week	25.754±1.021(-15.893; 0.000)	25.754±1.021(-1.749; 0.085)
1 month	25.756±1.022(-15.845; 0.000)	25.756±1.022(-1.230; 0.223)
3 months	25.762±1.026(-5.508; 0.000)	25.762±1.026(-0.061; 0.952)
6 months	25.757±1.023(-14.625; 0.000)	25.757±1.023(-1.107; 0.272)

Table 4 Changes in ocular refractive errors at corneal plane (R) before and after LASIK

Paired differences	R (Mean±SD, D)	Diference(Mean±SD, D)	*t* Value; *P* Value
Pre-op	-4.709±1.496	/	/
1 week	0.366±0.622	5.075±1.662	24.809; 0.000
1 month	0.762±0.615	4.785±1.568	24.800; 0.000
3 months	-0.039±0.554	4.670±1.617	23.468; 0.000
6 months	-0.069±0.546	4.640±1.549	24.338; 0.000

The mean AL which was measured by the IOL-master was 25.845 ±1.029mm before LASIK, and it decreased significantly at 1 week, 1 month, 3 months and 6 months after LASIK (P<0.001,Table 3). However, there were no significant changes in AL between 1 week and 1 month, 1 month and 3 months, 3 months and 6 months postoperatively (P >0.05). Throughout the period of observation before and after LASIK, there were no significant difference in AL* (P >0.05), in which the planned photoablation depth was subtracted only from the ocular axial length before LASIK, but not the ocular axial length 1 week, 1 month , 3 months and 6 months after LASIK (Table 3).

Ocular refractive errors at corneal plane decreased significantly at 1 week, 1 month, 3 months and 6 months after LASIK (P<0.001). No further significant changes occurred in ocular refractive errors at corneal plane between 3 months and 6 months after LASIK (t=0.771, P =0.443) (Table 4). Cornea refractive power measured by IOL-master, Orbscan and Pentacam was 43.594 ±1.327D, 43.436±1.277D and 42.382±1.234D before LASIK, and it decreased significantly at 1 week, 1 month, 3 months and 6 months after LASIK (P<0.001). Between 3 months and 6 months after LASIK, no further significant changes occurred in cornea refractive power which was measured by IOL-master, Orbscan and Pentacam (t =1.223, P =0.226; t=1.200, P=0.0234; t =1.739, P=0.087) (Table 5).

At 1 week after LASIK, Dlens which was associated with the IOL-Master (t =2.881, P =0.005) and Pentacam (t= 5.537, P<0.001) increased significantly, but no significant increase was observed in the Dlens which was associated with the Orbscan(t=-1.134, P=0.261)(Table 6).There were statistically significant correlations between the $\triangle R^1$ and $\triangle D_{lens}{}^1$ which were associated with the Pentacam (r =0.271, P=0.028), Orbscan (r=0.266, P=0.031) and IOL-master (r= 0.270,P=0.028) measurement. Moreover, there was significant

Table 5 Changes in cornea refractive power (D_{cornea}) before and after LASIK

Paired differences	D_{cornea} (Mean±SD, D) (t Value; P Value)		
	Pentacam	IOL-master	Orbscan
Pre-op	42.382±1.234	43.594±1.327	43.436±1.277
1 week	37.014±2.036 (-26.997; 0.000)	38.486±2.086 (-25.443; 0.000)	38.675±1.917 (-25.706; 0.000)
1 month	37.323±2.026 (-25.896; 0.000)	38.792±2.046 (-24.244; 0.000)	38.947±1.922 (-24.162; 0.000)
3 months	37.526±2.036 (-24.749; 0.000)	38.984±2.084 (-22.945;0.000)	39.049±2.035 (-22.686; 0.000)
6 months	37.588±2.028 (-24.500; 0.000)	39.007±2.058 (-23.464; 0.000)	39.103±1.860 (-25.531; 0.000)

Table 6 Changes in D_{lens} at corneal plane before and after LASIK

Paired differences	D_{lens} (Mean±SD, D) (t Value; P Value)		
	Pentacam	IOL-master	Orbscan
Pre-op	17.531±1.211	16.319±1.189	16.476±1.255
1 week	18.031±1.414 (5.537; 0.000)	16.560±1.328 (2.881; 0.005)	16.372±1.405 (-1.134; 0.261)
1 month	18.008±1.280 (6.123; 0.000)	16.539±1.290 (2.955; 0.004)	16.384±1.273 (-1.216; 0.228)
3 months	17.909±1.260 (4.367; 0.000)	16.451±1.331 (1.336; 0.186)	16.387±1.322 (-0.795; 0.429)
6 months	17.887±0.256 (4.553; 0.000)	16.468±1.313 (1.812; 0.075)	16.372±1.194 (-1.405; 0.165)

correlation between $\triangle R^2$ and $\triangle D_{lens}^2$ which were associated with the Pentacam measurement (r=0.392, P=0.001), but none between the $\triangle R^2$ and $\triangle D_{lens}^2$ which were associated with the IOL-master(r=0.232, P=0.061), Orbscan (r=0.178, P=0.154) measurement. (Table 7).

Table 7 Correlations between $\triangle D_{lens}^1$ /$\triangle D_{lens}^2$ and $\triangle R^1$/$\triangle R^2$ 1 week and 6 months after LASIK

Spearman's rho		△Dlens (D)		
		IOL-Master	Orbscan	Pentacam
$\triangle R^1$	Correlation Coefficient	0.270	0.266	0.271
	P Value	0.028	0.031	0.028
$\triangle R^2$	Correlation Coefficient	0.232	0.178	0.392
	P Value	0.061	0.154	0.001

DISCUSSION

Previously, both the Orbscan and the Pentacam had been used to detect a statistically significant amount of decrease in ACD after LASIK, and the patient's accommodation was considered might to be the reason of ACD decrease after LASIK [17,18,20]. Nawa [21] suggested this decrease in the ACD was the result of the fact that the images of Orbscan are affected by the changes of the magnification effect of the post-LASIK corneas. In this study, A-scan was used to measure the ACD after the pupil was dilated with two drops of 0.5% tropicamide, thus the patient's accommodation and the changes of the magnification effect of the post-LASIK corneas were reduced. In this paper, the mean change in ACD before and after LASIK was measured by A-scan, IOL-master, Orbscan and Pentacam, which all showed a significant decrease in the ACD at one week and 6 months after LASIK ($P \leqslant 0.001$). Moreover, the ACD which was measured with A-scan, Pentacam, IOL-master, and Orbscan, decreased gradually in order, and significant correlation was detected among these four measurements (P<0.001) (Table 1). We assumed that the Orbscan and Pentacam measurements were both affected by the magnification effect of the post-LASIK corneas, and the orbscan measurement was affected more by the magnification effect of the post-LASIK corneas than the Pentacam measurement was.

LT increased significantly at 1 week, 1 month, 3 months and 6 months after LASIK which was measured by the A-scan (P<0.001) (Table 2), and this might partially lead to ACD decrease which was measured by the A-scan, Pentacam, IOL-master, and Orbscan after LASIK. However in this study, A-scan was used to measure the LT after the pupil was dilated with two drops of 0.5% tropicamide, thus the patient's accommodation was reduced. Hofmeister[22] reported that 1.0% cyclopentolate was more effective than 1.0% tropicamide in reducing accommodative amplitude in adult myopes (near-point testing). In addition, a reduced accommodative response has been found in myopia [23]. On average, during near-point induced accommodation in young myopic eyes, for each diopter of accommodation LT increased by 0.072mm [24]. During accommodation, the anterior lens pole moves forward by 0.3mm, and the posterior pole moves backward less than 0.1mm. LT increased by approximately 0.5mm in total [25]. In this paper, LT increased 0.098±0.137mm at 1 week after Lasik and 0.107±0.118mm by 6 months after Lasik. Thus, we assumed that residual accommodation may contribute to the LT increase in this paper. It can also be concluded that LT increase has no correlation with axial length, because there was no significant difference in AL* (P > 0.05) throughout the period of observation before and after LASIK (Table 3).

Ocular refractive errors at corneal plane decreased significantly at 1 week, 1 month, 3 months and 6 months after LASIK (*P* <0.001) (Table 4). Cornea refractive power which was measured by IOL-master, Orbscan and Pentacam was 43.594±1.327D, 43.436±1.277D and 42.382±1.234D before LASIK, and it decreased significantly at 1 week, 1 month, 3 months and 6 months after LASIK (*P*<0.001) (Table 5). Between 3 months and 6 months after LASIK, no further significant changes occurred in both the ocular refractive errors at corneal plane and cornea refractive power (Table 4,5), these outcomes agree with those in other studies[11-16].

D_{lens} after LASIK should be larger than D_{lens} before LASIK, because AL decreased significantly at 1 week after LASIK measured by the IOL-Master(*P*<0.001) (Table 3). However in this study, at 1 week after LASIK, only the D_{lens} which was associated with IOL-Master (*P*=0.005) and Pentacam (*P*<0.001) measurements increased significantly, D_{lens} which was associated with Orbscan (*P* =0.261) measurement showed no significant increase (Table 6). In another hand, no statistically significant correlations between the $\triangle R^2$ and $\triangle D_{lens}^2$ which were associated with the IOL-master (*P*= 0.061), Orbscan (*P*=0.154) measurement were observed, which were not coincident with the LT change in this paper (Table 7). So, based on the ACD and LT changes shown in this paper, a conclusion can be drawn that the lens refractive power calculated with the data measured with IOL-master and Orbscan is not accurate, Pentacam is a useful tool to detect cornea refractive power before and after LASIK.

In conclusion, LT increase significantly after LASIK because of the residual accommodation, and this might partially lead to ACD decrease, D_{lens} increase and a small quantity of myopic regression. Pentacam is a useful tool to detect central cornea refractive power and ACD before and after LASIK.

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