• Clinical Research •

Comparison of visual effects of FS-LASIK for myopia centered on the coaxially sighted corneal light reflex or the line of sight

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Abstract

● AIM: To compare visual quality after femtosecond laser *in situ* keratomileusis (FS-LASIK), between the coaxially sighted corneal light reflex (CSCLR) group and conventional ablation line of sight (LOS) group.

● METHODS: In total, 243 eyes (122 patients) were treated with centration on the CSCLR (visual axis) and 238 eyes (119 patients) treated with centration on the pupil center (LOS). Postoperative outcomes [uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA)], safety index, efficacy index, refractive outcome, ablation center distance from the visual axis, corneal high-order aberrations, subjective discomfort glare and shadowing incidence rate, and contrast sensitivity at 1, 3, and 6mo were measured and compared.

● RESULTS: The mean age was 27.77±7.1y in the CSCLR group and 26.03±7.70y in the LOS group. Preoperatively, the manifest refraction spherical equivalent (MRSE) was -6.68±2.60 D in the CSCLR group and -6.65±2.68 D in the LOS group. The postoperative UCVA, BSCVA, MRSE (-0.03±0.263 D in the CSCLR group, -0.05±0.265 D in the LOS group), efficacy index (1.04, 1.03), and safety index (1.09, 1.08) were not significantly different between the groups (all *P*>0.05). In total, 3% lost one line and more of BSCVA in the CSCLR group, as 9% in the LOS group postoperatively (*P*<0.05). The ablation center deviation was 0.20±0.15 mm from the visual axis (Pentacam system default setting; range, 0-0.75 mm) in the CSCLR group, and 0.43±0.22 mm (range, 0-1.32 mm) in the LOS group (*P*<0.0001). Statistically significant greater augmentation of total corneal higher-order aberrations (0.15±0.10 μm and 0.20±0.12 μm respectively, *P*=0.03) and vertical and horizontal coma (*P*<0.0001) were noted in the LOS group. Subjective discomfort glare and shadowing incidence rates were 8.59% and 17.5% in the CSCLR and LOS groups, respectively (*P*<0.05). The 1-month postoperative contrast sensitivity visual acuity in the CSCLR group was significantly higher than that in the LOS group on contrast (100%, 25%, 10%) with a dark background, but there was no significant difference between the groups at 3 or 6m.

● CONCLUSION: Myopic LASIK centered on the CSCLR achieves significantly lower induction of loss of BSCVA, corneal high-order aberrations, and lower risk of subjective discomfort glare and shadowing, and lower decline in early contrast sensitivity by comparison with centration on the LOS, giving advantages in visual quality postoperatively.

● KEYWORDS: laser *in situ* keratomileusis; ablation center; line of sight; coaxially sighted corneal light reflex

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INTRODUCTION

With the development of corneal refractive surgery and the introduction of wavefront-guided ablation and aspheric ablation, visual quality has become an increasingly important criterion. However, correct alignment of the corneal ablation is crucial to achieving good visual results because decentered optical zones can lead to a significant increase in higher-order aberrations[1], with a decrease in quality of vision, diplopia[2], decreased contrast sensitivity, and night vision disturbances[3]. There are three common choices for corneal ablation centration: centration of the pupil [line of sight (LOS)], the geometric center of the cornea (cornea vertex, CV), and the visual axis of the cornea reflex points [coaxially sighted corneal light reflex (CSCLR), also referred to as the "visual axis" in some studies][4-5]. The LOS is defined as the line joining the fixation point with the center of the entrance pupil[6]. The visual axis is defined as the line joining the fixation point and the fovea[6].

Early refractive outcomes of laser *in situ* keratomileusis (LASIK) centered on the CSCLR or the LOS showed that both strategies were safe and effective[7-8]. However, there is still some controversy as to where it is best to center the corneal ablation: on the entrance pupil center (LOS) or on the corneal vertex (an approximate proxy for the visual axis). The LOS is based on the theory that only the bundle of rays of light delimited by the entrance pupil enters the eye, and the LOS represents the chief ray of that bundle of light reaching the fovea[9]; thus, the intersection of the LOS with the cornea should be the desired centration point. In contrast, CSCLR supporters propose that the best optical results are achieved by centering corneal ablation on the corneal vertex, which best approximates the corneal intercept of the visual axis[10].

Among the three ablation centers, the CSCLR distance to the visual axis is approximately 0.02 mm, whereas the other two ablation centers are relatively larger. Hence, practically, it is difficult to locate the optic axis at the intersection of the corneal surface, so that the CSCLR is the closest to the "ideal" anatomical point[11-12]. Theoretical modeling indicates that decentration of 0.10 mm can induce aberrations rather than reduce aberrations during myopic wavefront-guided treatments. Centration on the LOS is not ideal strategy, because it defaults the shift in pupil center with differing light conditions[13]. In the present study, we compared the postoperative outcomes with myopic LASIK centered on the LOS or the CSCLR. We evaluated the efficacy and safety indexes, refractive outcomes, postoperative wavefront aberrations, contrast sensitivity, and objective visual quality in eyes after femtosecond laser surgery.

SUBJECTS AND METHODS

General Information This randomized, double-masked study compared visual, refractive, and the corneal high-order aberrations, and contrast sensitivity outcomes of the LOS versus the CSCLR with myopic LASIK. In total, 481 eyes of 241 patients (131 males, 110 females), ranging in age from 18 to 35 years old, underwent LASIK surgery between March and September 2014 at Ruijin Hospital, affiliated with Shanghai Jiaotong University School of Medicine. Patients were divided into two groups depending on the different ablation centers: 122 patients (243 eyes) underwent treatment with centration on the CSCLR (CSCLR group) and 119 patients (238 eyes) underwent treatment with centration on the LOS (LOS group). The two ablation methods were randomized using a random-number table at the inclusion visit.

Inclusion criteria were as follows: age 18-35 years old, preoperative spherical refraction of -2.00 to -12.00 D, refractive cylinder of less than -3.00 D, a stable refractive state for 2y, an intraocular pressure (IOP) of <21 mm Hg, and at least 4wk or 2wk without hard or soft contact lenses, respectively. Exclusion criteria included the following: a history of systemic autoimmune disease, a history of diabetes, other ophthalmic disorders, a history of ocular trauma, and a surgical history. Prior approval by ethic committee of Ruijin Hospital (Shanghai Jiaotong University School of Medicine) was obtained according to the Declaration of Helsinki. All patients were informed of the surgical procedures and use of equipment, and all provided written informed consent.

Methods Patients underwent a full eye examination before LASIK surgery, including evaluations of their uncorrected visual acuity (UCVA), best-corrected visual acuity (BSCVA), IOP, corneal curvature, corneal diameter, corneal thickness, anterior and posterior corneal surface height, corneal topography, refraction and slit-lamp anterior segment, fundus examinations, contrast sensitivity measurement (CSV-1000, VectorVision), and corneal high-order aberrations measurement (Pentacam, Oculus, Germany).

Patients were divided into two groups based on the center of ablation. The surgery procedure was as follows. Topical anesthesia and 2% propoxyphene tetracaine eye drops were applied, along with routine disinfection and shop towels. An eyelid holder was used to open the eye. A suction ring was applied to the eye to hold it in place. Surgery using the femtosecond laser was used to create the corneal flap. Adjusted ablation was offset with the ESIRIS excimer laser software.

The femtosecond laser had a bed energy of 0.65 μJ, with a side-cut energy of 0.8 μJ and a repetition frequency of 200 kHz. Myopia stromal ablations were performed using an Allegretto Wave Eye-Q excimer laser (Wavelight Company, Germany). The wavelength and energy intensity of the excimer laser were 193 nm and 180 mJ/cm^2, respectively. The corneal ablation was centered on CSCLR or LOS. For the CSCLR group, during surgery the patient subject-fixated coaxially sighted corneal light reflex, the surgeon used left eye to view right corneal light reflex and removed the ablation center (red point) to fixation point (green point), whereas the opposite. The vector of pupil shift were calculated from the horizontal and vertical magnitude (X and Y value) according to the following formula.

Vector of pupil shift $=\sqrt{\text{X value}^2+\text{Y value}^2}$. For example, the ablation center was shifted nasoinferiorly on the *x* axis by 0.31 mm and 0.12 mm on the *y* axis, corresponding to an offset of 0.33 mm. For the LOS group, the centering procedure was entirely automated selecting the pupil center and did not rely on surgeon adjustment.

At 1, 3, and 6mo postoperatively, follow-up measurements included auto refractometry, manifest refraction, BSCVA, UCVA, Pentacam topography, and corneal high-order aberrations, as well as contrast sensitivity.

Statistical Analysis Data analyses were performed using SAS software (version8.2, SAS Institute, Inc.). Normality of all data samples was first checked using the Kolmogorov-Smirnov test. When parametric analysis was possible, the

Table 1 Preoperative parameters

Parameters	CSCLR (*n*=243)	Min	Max	LOS (*n*=238)	Min	Max	*P*
Age (a)	27.774±7.093	18	34	26.025±7.700	18	35	0.073
BSCVA (logMAR)	0.021±0.038	-0.032	-0.085	0.015±0.035	-0.076	0.058	0.060
MRSE (D)	-6.684±2.596	-11.25	-0.50	-6.645±2.676	-12.13	-1.50	0.231
totHOA (μm)	0.113±0.033	0.061	0.393	0.107±0.028	0.059	0.241	0.064
totZ40 (μm)	0.174±0.114	-0.045	1.092	0.152±0.073	-0.170	0.346	0.013[a]
totComa (μm) $Z3^{-1}$	0.158±0.117	0.001	0.498	0.140±0.1151	0	0.621	0.099
totComa (μm) $Z3^{1}$	0.091±0.065	0.001	0.318	0.103±0.072	0	0.337	0.052
froHOA (μm)	0.116±0.034	0.053	0.378	0.112±0.028	0.058	0.243	0.077
fro$Z4^{0}$ (μm)	0.230±0.096	0.031	1.068	0.211±0.017	-0.071	0.416	0.014[a]
froComa (μm) $Z3^{-1}$	0.153±0.115	0	0.509	0.134±0.111	0.001	0.595	0.064
froComa (μm) $Z3^{1}$	0.099±0.063	0	0.307	0.103±0.069	0	0.324	0.023[a]

CSCLR: Coaxially sighted corneal light reflex; LOS: Line of sight; UCVA: Uncorrected visual acuity; BSCVA: Best spectacle-corrected visual acuity; MRSE: Manifest refraction spherical equivalent; HOAs: Higher-order aberrations, whole corneal spherical aberration (totHOA), corneal anterior surface aberration (froHOA). [a]Statistically significant difference using the Wilcoxon rank-sum test with continuity correction, *P*<0.05.

Table 2 Contrast sensitivity data (cd/m^2) preoperatively in the two groups in different environments (100%, 25%, 10%, and 5%)

Parameters	CSCLR (*n*=243)	Min	Max	LOS (*n*=238)	Min	Max	*P*
Contrast A (5%)	5.915±0.915	2	7	5.983±0.812	2	7	0.393
Contrast B (10%)	6.093±1.118	1	8	6.162±1.072	1	8	0.468
Contrast C (25%)	6.194±1.590	0	8	6.291±1.550	0	8	0.498
Contrast D (100%)	5.524±1.756	0	8	5.633±1.703	0	8	0.498

CSCLR: Coaxially sighted corneal light reflex; LOS: Line of sight. Statistically significant (*P*<0.05).

Student's *t*-test for paired data was performed for all parameter comparisons. When parametric analysis was not possible, the Wilcoxon rank-sum test was applied to assess the significant of differences. For all statistical tests, a *P* value less than 0.05 was considered statistically significant.

RESULTS

The preoperative parameters for both groups are shown in the Table 1. Preoperatively, the mean age was 27.77±7.1y in the CSCLR group and 26.03±7.70y in the LOS group; Preoperatively the MRSE was -6.68±2.60 D in the CSCLR group and -6.65±2.68 D in the LOS group.

The two groups showed differences in preoperative corneal anterior surface and corneal spherical aberration with MRSE (-0.25 to -0.29 D, -0.30 to -0.59 D, -0.60 to -0.89 D, -0.90 to -12.00 D).

Table 2 shows the preoperative contrast sensitivity function was no statisticaly significant difference in the two groups.

Regarding the distance between the pupil center point and the visual axis preoperation in the two groups, in the CSCLR group, the preoperative distance between the pupil center and the visual axis was 0.1867±0.0925 (0.0141-0.5701) mm, whereas in the LOS group, it was 0.2029±0.109 (0.01-0.5235) mm. There was no significant difference between the groups (*P*=0.0801; Figure 1).

Postoperative Variables

Postoperative uncorrected visual acuity At 1mo postoperatively, UCVA was 0.009±0.007 in the CSCLR group and 0.001±0.007 in the LOS group (*P*=0.22). There was no significant difference at 3 or 6mo postoperatively (Figure 2).

Postoperative best spectacle-corrected visual acuity At 1mo postoperatively, BSCVA was -0.007±0.045 in the CSCLR group and -0.012±0.045 in the LOS group (*P*=0.23). Moreover, 117 eyes showed no change in either group. However, in the CSCLR group, 119 eyes gained one line and six eyes lost one line, and one eye lost two lines. In the LOS group, 104 eyes gained one line and 14 eyes lost one line, and six eyes lost two lines. There was no change at 1, 3, or 6mo postoperatively (Figure 3).

Postoperative manifest refraction spherical equivalent Regarding postoperative MRSE, at 1mo postoperatively, the MRSE values of 232 eyes (95%) were within ±0.5 D in the CSCLR group, and 224 eyes (94%) in the LOS group, respectively. There was no significant difference at 3 or 6mo postoperatively (Figure 4).

Table 3 shows the postoperative parameters for both groups. No statistically significant differences were noted between groups in the UCVA, BSCVA, SI, EI and MRSE.

Regarding the postoperative distance between the pupil center and the visual axis, in the CSCLR group, it was 0.20±0.15 (0-0.75) mm, and for 69.5% (169/243) of the eyes, it was less than 0.25 mm, and for 20.6% (50/243), it was more than

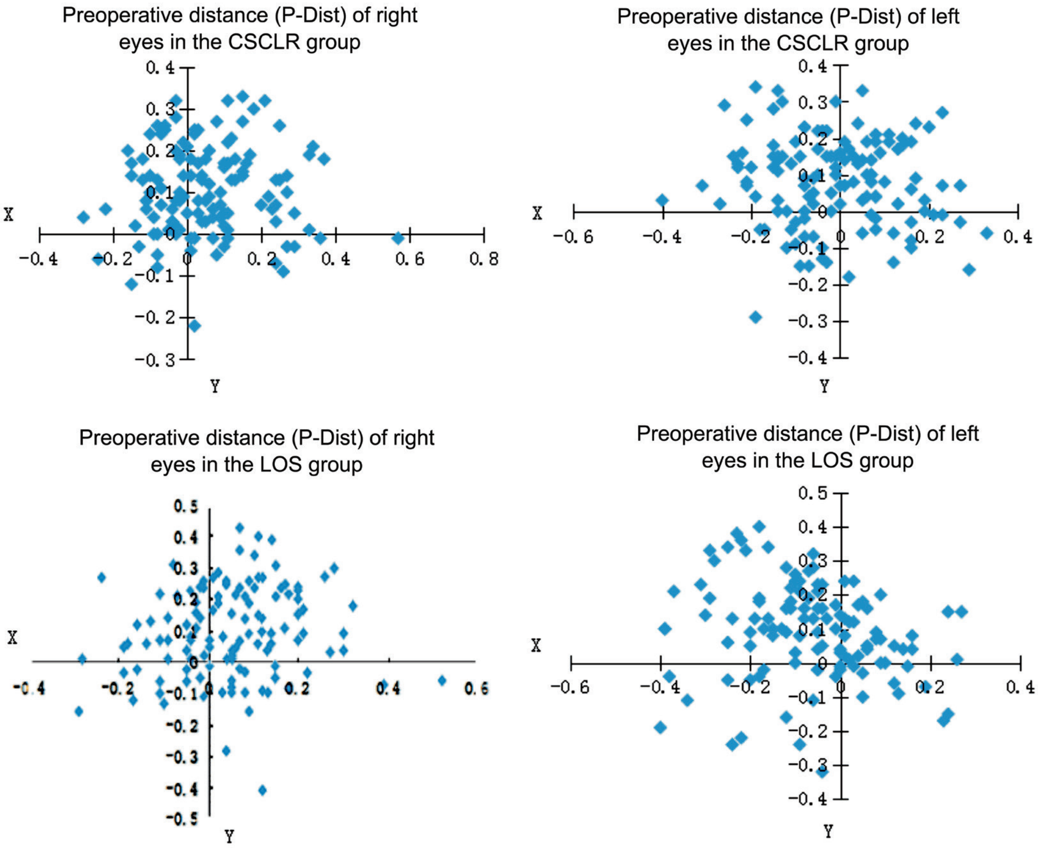

Figure 1 Preoperative scatterplots of the location of the pupil center relative to the visual axis between the CSCLR group and the LOS group.

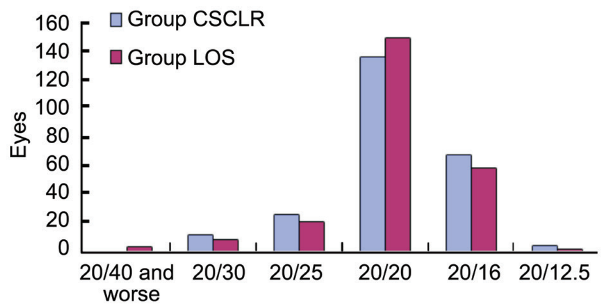

Figure 2 Change in UDVA in the two groups 6mo postoperatively.

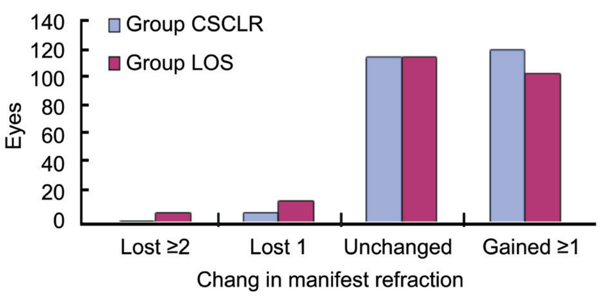

Figure 3 Change in BSCVA in the two groups 6mo postoperatively.

0.25 mm. In the LOS group, it was 0.43±0.22 (0-1.32) mm: 19.3% (46/238) of eyes were less than 0.25 mm, and 80.7% (192/238) of eyes were ≥0.25 mm. The difference between the two groups was statistically significant (*P*<0.0001; Figure 5).

Table 4 shows the postoperative TotHOA and DHOA were statistically significantly lower in the CSCLR group (*P*<0.05); the postoperative ComaZ3^{-1} ComaZ3^{1} were statistically significantly lower in the CSCLR group (*P*<0.05), but there

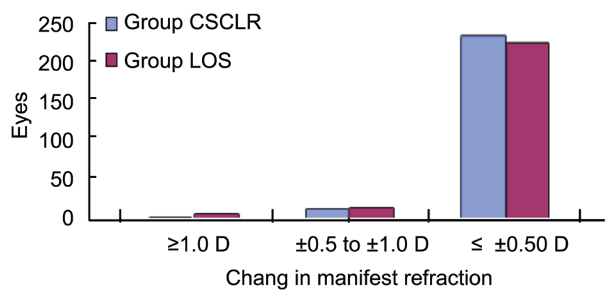

Figure 4 Change in MRSE in the two groups 6mo postoperatively.

was no statistically significant difference in the postoperative froZ4^{0} between the two groups (*P*>0.05).

Table 5 shows the contrast sensitivity function was statistically significantly different at low frequencies between the two groups at 1mo postoperatively (*P*<0.05), but there was no significant difference at any frequency at 6mo postoperatively (*P*>0.05).

DISCUSSION

Over the years, confusion and conflicting definitions over the various axes have been sources of much controversy surrounding the question of what is the appropriate centration technique in corneal refractive surgery. Many axes of the eye can be described, such as the optical axis, pupillary axis, line of sight, visual axis, and line of fixation. LOS is defined by the fixation point at one end and the center of the entrance pupil at the other[10,12]. The pupillary axis has been described as the line perpendicular to the cornea that passes through the center

Table 3 Postoperative parameters for both groups

Parameters	Postoperative one-month			Postoperative three-month			Postoperative six-month		
	CSCLR	LOS	*P*	CSCLR	LOS	*P*	CSCLR	LOS	*P*
UCVA	0.009±0.070	0.001±0.080	0.22	0.012±0.082	0.001±0.093	0.11	0.014±0.087	-0.002±0.093	0.06
BSCVA	-0.007±0.045	-0.012±0.045	0.23	-0.005±0.050	-0.012±0.060	0.18	-0.007±0.049	-0.014±0.062	0.17
SI	1.098±0.120	1.081±0.140	0.89	1.111±0.130	1.099±0.150	0.87	1.119±0.110	1.120±0.120	0.88
EI	1.045±0.140	1.031±0.160	0.40	1.052±0.130	1.040±0.180	0.41	1.061±0.120	1.049±0.150	0.39
MRSE	-0.030±0.263	-0.050±0.265	0.31	-0.030±0.330	-0.040±0.196	0.73	-0.090±0.360	0.010±0.332	0.71

CSCLR: Coaxially sighted corneal light reflex; LOS: Line of sight. Statistically significant (P<0.05).

Table 4 Postoperative aberrations changs between the two groups

Parameters	Postoperative one-month			Postoperative three-month			Postoperative six-month		
	CSCLR (*n*=243)	LOS (*n*=238)	*P*	CSCLR (*n*=243)	LOS (*n*=238)	*P*	CSCLR (*n*=243)	LOS (*n*=238)	*P*
TotHOA	0.265±0.102	0.297±0.125	0.0021[b]	0.265±0.102	0.295±0.123	0.0041[b]	0.264±0.101	0.295±0.122	0.0030[b]
DHOA	0.152±0.102	0.190±0.125	0.0004[b]	0.159±0.103	0.196±0.128	0.0007[b]	0.150±0.101	0.192±0.123	0.0006[b]
TotZ40	0.563±0.270	0.580±0.275	0.4851	0.554±0.267	0.566±0.273	0.6300	0.552±0.266	0.556±0.275	0.8600
DZ40	0.389±0.279	0.428±0.276	0.1246	0.389±0.279	0.428±0.276	0.1240	0.380±0.278	0.426±0.273	0.1270
totComaZ3^{-1}	0.314±0.251	0.451±0.345	<0.0001[b]	0.321±0.260	0.452±0.336	<0.0001[b]	0.325±0.261	0.461±0.347	<0.0001[b]
totComaZ3^{1}	0.238±0.205	0.349±0.288	<0.0001[b]	0.249±0.205	0.355±0.289	<0.0001[b]	0.245±0.203	0.356±0.281	<0.0001[b]
froHOA	0.249±0.091	0.289±0.119	0.0029[b]	0.259±0.090	0.286±0.117	0.005[b]	0.259±0.090	0.285±0.115	0.0050[b]
froZ4^{0}	0.596±0.257	0.601±0.251	0.6526	0.582±0.254	0.588±0.248	0.6200	0.581±0.253	0.580±0.248	0.9540
froComaZ3^{-1}	0.301±0.234	0.423±0.315	<0.0001[b]	0.303±0.238	0.422±0.304	<0.0001[b]	0.302±0.235	0.425±0.315	<0.0001[b]
froComaZ3^{1}	0.223±0.188	0.325±0.262	<0.0001[b]	0.232±0.186	0.330±0.256	<0.0001[b]	0.230±0.188	0.330±0.256	<0.0001[b]

CSCLR: Coaxially sighted corneal light reflex; LOS: Line of sight. [b]Statistically significant difference using the Student's *t*-test (P<0.05).

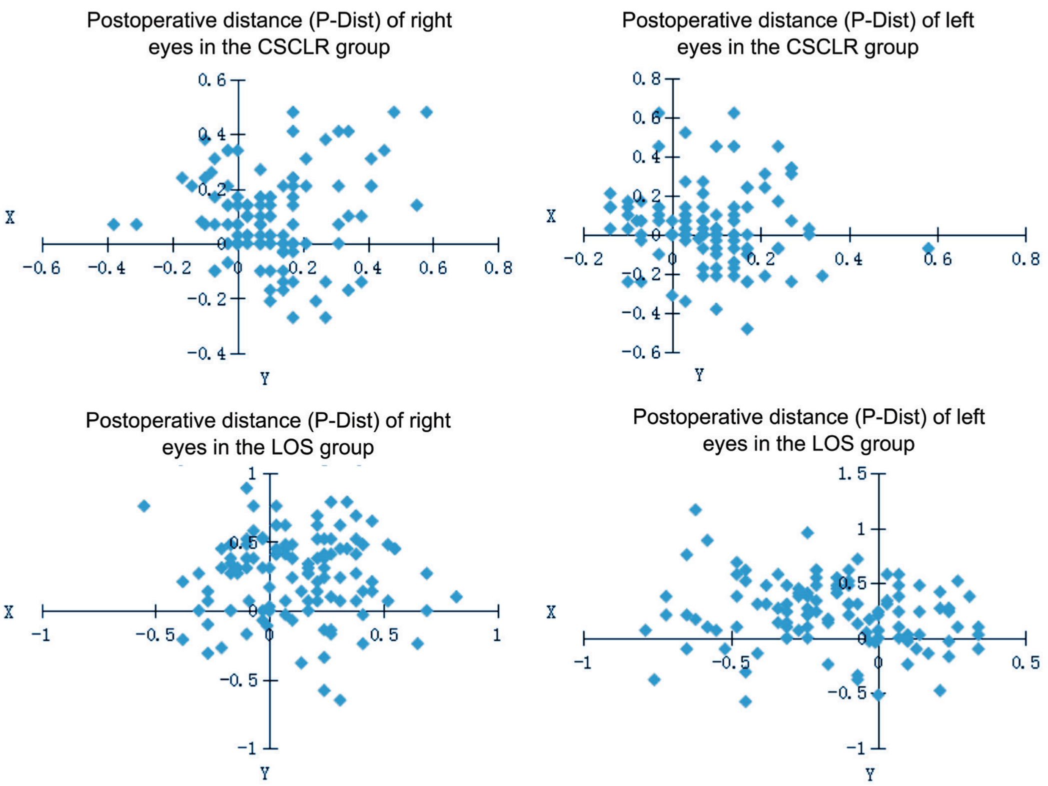

Figure 5 Scatterplots of pupil center shifts relative to the visual axis between the CSCLR and the LOS group postoperatively.

of the entrance pupil, which also passes through the center of curvature of the corneal surfaces. The angle between the pupillary axis and the LOS is the angle lambda and has been clinically measured to be around 3°-6°[14-15]. Another angle that is frequently described, but is impossible to measure in the eye, is angle kappa, which is the angle between the pupillary axis and the theoretical visual axis[16-17]. The visual axis is defined as the line between the fixation point and the fovea

Table 5 Postoperative contrast sensitivity changs between the two groups

Parameter	Postoperative one-month			Postoperative three-month			Postoperative six-month		
	CSCLR (*n*=243)	LOS (*n*=238)	*P*	CSCLR (*n*=243)	LOS (*n*=238)	*P*	CSCLR (*n*=243)	LOS (*n*=238)	*P*
Contrast A (5%)	5.228±1.171	5.177±1.106	0.3930	5.250±0.820	5.200±1.114	0.5200	5.250±0.787	5.220±1.140	0.7500
Contrast B (10%)	5.138±1.472	4.650±1.486	<0.0001[c]	5.136±1.646	4.990±1.060	0.2540	5.136±1.646	4.993±1.060	0.2480
Contrast C (25%)	4.825±1.469	4.043±1.815	<0.0001[c]	4.800±1.310	4.816±1.949	0.9270	4.815±1.946	4.803±1.313	0.9260
Contrast D (100%)	4.322±1.516	3.771±1.829	<0.0001[c]	4.420±1.673	4.188±2.042	0.1240	4.423±1.067	4.188±2.043	0.1260

CSCLR: Coaxially sighted corneal light reflex; LOS: Line of sight. [c]Statistically significant difference using the Wilcoxon signed rank test ($P<0.05$).

but, in fact, it is difficult to locate the visual axis. The current study showed that the CSCLR is the ideal anatomical site, close to this intersection point on the corneal surface[17]. Chan and Boxer Wachler[7] also confirmed that the CSCLR was the closest approximation to the visual axis. Additionally, the CSCLR obtained from corneal topography may not accurately determine the location of the visual axis. Recent studies[18-19] have shown differences in the location of the visual axis, as estimated by the CSCLR and the LOS, in a population of myopic refractive surgery candidates, indicating that a precise and optimal definition of centration strategy is necessary.

A disadvantage of selecting the LOS is the documented change in the pupil center under different light conditions[20-21]. This change can result in relatively large changes in refraction because the curvature of the cornea changes with location. Yang *et al*[22] reported that they measured the pupil center of 70 eyes in dark and light environments and pharmacologically dilated conditions, and found that when the pupil diameter became larger, the pupil center continued to move the eye temporally, on average by 0.133 mm. Some scholars believe that the pupil center is a virtual image created by the bundle of rays of light across the aqueous humor and cornea refracted into the eye, so its reliability is questionable[23]. Thus, centering on the LOS maybe a greater risk for myopic LASIK. To center on the CSCLR may be preferable because it is not affected by pupil size. If the surgeon sights monocularly, directly behind the fixation light, the patient's corneal light reflex will appear to be decentered nasally in the pupil; the projection of the corneal light reflex onto the corneal surface will correspondingly be located nasal to the point where the line of sight and the cornea intersect. That is, the corneal light reflex will be located nasal to the optimal centration point for corneal surgical procedures. If the LOS is used to guide centration for a patient with a large kappa angle, there would be an error in marking the center.

This study used topographical methods to measure centration of corneal procedures accurately from the pupil, and the surgeon removed the centration to the cornea reflex points of the visual axis during the LASIK procedure. The outcomes in this comparison indicated that both CSCLR and LOS centration are safe, accurate, and efficacious. Safety was indicated in this large cohort of 481 eyes by no loss of more than one line of vision. The loss of one line of CDVA falls within measurement variability and is considered clinically insignificant. In the CSCLR group, one eye lost more than one line of BSCVA and six eyes lost one line of BSCVA. In the LOS group, six eyes lost more than one line of BSCVA and 14 eyes lost one line of BSCVA. A UCVA of 20/20 or better was achieved in 84% of the CSCLR group and 86% of the LOS group; there was no statistically significant difference between the groups. The refractive outcomes in the current study were not statistically significantly different between the CSCLR and LOS groups. At postoperative 6mo, 95% of eyes in the CSCLR group and 94% of eyes in the LOS group were within ±0.50 D of the intended MRSE. Taken together, these outcomes indicate that a good safety index and an efficacy index could be achieved using both ablation strategies. Mrochen *et al*[3] compared myopic laser treatment, centering on the visual axis versus the line of sight. However, in that study, they performed comparisons on the early (1-month postoperative) data, which may not be accurate because refractive stability may not be achieved. In our study, we present longer term follow-up (6-month) data along with objective measures of the optical quality of the eye and visual quality; we also take comprehensive evaluation into consideration by treating closer to the visual axis rather than the line of sight.

In the current study, the pupil center distribution, angle kappa, ablation center and whole cornea, corneal anterior, and posterior surface of high-order aberrations were measured using a Pentacam, which is based on Scheimpflug imaging, and performed a Zernike analysis for the whole cornea by measuring height data. Using the topographic corneal vertex location has some advantages because this point is reliable and reproducible on topography. Because the CSCLR is the closest approximation to the visual axis, and it represents a stable preferable morphologic reference. Centration on the pupil poses a significant challenge because the pupil center changes with differing illumination and with age[13,24]. If patients possessing larger angle kappa can appear mildly exotropic while fixating on the LOS, it may be result in imprecise alignment of ablation. As this situation, centering on the

CSCLR is more beneficial and desirable strategy, which is not affected by pupil size[19]. The postoperative induction of HOAs in the CSCLR group was statistically significantly lower than in the LOS group. Increased magnitude of coma is indicative of decentration, subclinical or otherwise[21]. Postoperative coma was statistically significantly higher in the LOS group, as the P-distance increased from 0.15 mm to more than 0.25 mm (P<0.05). P-distance increases were less than 0.25 mm in 69.5% of the CSCLR group and in 19.3% in the LOS group; that is, the P-distance increased more than 0.25 mm in 20.6% of the former group and 80.7% of the latter group. The increased coma indicated greater ablation decentration in the LOS group. This outcome was consistent with Reinstein *et al*[18], who reported that small ablation decentration (P-distance<1 mm) showed no significant difference in UCVA or MRSE postoperatively, but it was a major cause in the induction of postoperative spherical aberrations and coma. Khakshoor *et al*[21] reported that centration on the CSCLR for myopic patients within high angle κ values may aid in providing better refractive outcomes and vision quality, which was consistent with our results. Our clinical outcomes indicated that there was no statistically significant difference in the increased magnitude of spherical aberrations postoperatively, but that postoperative coma was statistically significantly higher in the LOS group, and the increased magnitude of coma and the eccentric magnitude of the ablation were positively related (r=0.69, P<0.01). Postoperative spherical aberrations were not affected by decentration because the spherical aberrations were radially symmetric. Centration on the CSCLR reduced positioning errors made by the surgeon when estimating the visual axis and decreased the induction of coma postoperatively.

At 1mo postoperatively, the contrast sensitivity function was statistically significantly different at low frequencies between the two groups, but there was no significant difference at any frequency at 6mo postoperatively. This indicated that the ablation decentration was minor and did not lead to poor visual quality in either group. In the early stages of LASIK surgery, a decrease in CSF was related to factors such as corneal edema, irregularity of the corneal surface, light scattering of the corneal layer, central corneal flattening, ablation decentration, pupil size and optical zone matching, and haze, all of which can reduce the quality of vision. Our results were consistent with previous studies[21,25]; over time, the CSF returned to the preoperative level by 6mo after LASIK surgery.

A limitation of this study is that we did not choose to centrate on the LOS and the CSCLR on different eyes in the same candidate, which could demonstrate the greater strength of centering on the CSCLR. Another drawback is the follow-up of 6mo, which may not be long enough to identify changes that occur over a longer follow-up.

In conclusion, myopic LASIK centered on the CSCLR appears to represent a more preferable method, which is safe, accurate and efficacious, avoiding suboptimal refractive outcomes and induction of HOAs. Ablation centration closer to the CSCLR may achieve the best optical results and improve the postoperative vision quality. It is expected that larger studies with longer follow-up will further demonstrate the safety and efficacy of the procedure and validate the advantage of this centration technique in myopes.

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