

# Dynamic distribution of angle kappa and its biomechanical relationships in population who are suitable for excimer laser refractive surgery

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## Research article

**Keywords:** angle kappa, pupil center, coaxially sighted corneal light reflex, ablation centration

**Posted Date:** May 21st, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-23243/v1>

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# Abstract

**Background** To explore the dynamic distribution of pupil size and center, the eccentricity distribution of angle kappa, and its correlation with other biomechanics about suitable for excimer laser refractive surgery.

**Methods** Randomly selected 225 patients (407 eyes) who underwent femtosecond laser combined with excimer laser in situ keratomileusis, preoperative use of Wavelight Allegro Topolyzer Corneal Topography (Wavelight Laser Technologies AG, Erlangen, Germany) to measure the pupil size and center position, the German Wavelight EX500 excimer Laser (500Hz) records the deviation between the pupil center and the coaxially sighted corneal light reflex when the patient is supine.

**Results** The average displacement distribution of P-Dist (the eccentricity between the pupil center and the coaxially sighted corneal light reflex point) is  $0.225 \pm 0.102$  mm, and 80% of the eyes are  $\leq 0.30$  mm. The coaxially sighted corneal light reflex point is mainly deviated to the superior temporal side of the corneal center (34%). Under the dark light condition, the x-axis of the left eye was:  $-0.046 \pm 0.091$  mm, the x-axis of the right eye was:  $-0.152 \pm 0.084$  mm, with statistical difference ( $P = 0.015$ ) (the right eye shifted to the temporal side), the y-axis direction had no statistical change ( $P = 0.062$ ). The WTW was positively correlated with changes of pupil diameter (dark pupil diameter-bright pupil diameter) ( $r = 0.270$ ,  $P < 0.001$ ). The SE and measured centroid shift was negative correlated ( $r = -0.214$ ,  $P = 0.002$ ).

**Conclusion** The pupil of the left eye becomes smaller, the anterior chamber becomes shallower, and the angle kappa increases relative to the right eye. In patients with large WTW, a darker light environment is maintained during the operation to improve the efficiency of pupil matching. The dynamic change of angle kappa in high myopia population is small.

## Background

The ideal excimer laser ablation centration should be completely overlapped with the visual axis, in corneal refractive surgery<sup>[1]</sup>. If the pupil positioning tracking scan does not take into account the adjustment of the angle kappa, the actual corneal cutting area is not consistent with the ideal cutting area, which will cause "surgical origin" eccentric cutting. Therefore, it is particularly important to adjust the angle kappa during surgery<sup>[2]</sup>. However, the visual axis is so difficult to determine that the eye tracking system usually locates and tracks the center of the pupil in actual surgery. Because the pupil center is different from the visual axis, it has become a consensus among corneal refractive surgeons to adjust the laser ablation centration from the pupil center to the visual axis, compensate for the offset effect of angle kappa, and reduce higher-order aberrations after surgery<sup>[3,4]</sup>.

The coaxially sighted corneal light reflex point is the corneal entry point of the visual axis<sup>[5]</sup>. Studies have shown that coaxially sighted corneal light reflex point is the ideal ablation centration point, because coaxially sighted corneal light reflex point is the closest point to the visual axis and is not affected by

changes of pupil size and center position, with an average of 0.02 mm<sup>[6]</sup>. Therefore, the angle kappa can be understood as *P-Dist*<sup>[7]</sup>. However, the angle kappa is not a fixed value, and changes with the dynamic change of the pupil center position<sup>[8, 9]</sup>. That is why it is necessary to further explore the dynamic changes of the pupil size and center position suitable for excimer laser surgery, *P-Dist* and its correlation with other biomechanics. The related research at home and abroad hasn't been reported.

This study analyzes the *P-Dist*, and researches its correlation with other biomechanics to explore the dynamic changes of pupil size and center position suitable for excimer laser surgery. It provides a reference for the surgical solution design about how to optimize the femtosecond laser combined with excimer laser in situ keratomileusis with the angle kappa compensation in accordance with the optical characteristics of individual human eyes.

## Methods

Randomly selected 225 (407 eyes) myopia patients who underwent femtosecond combined excimer laser in situ keratomileusis at the Ophthalmology Department of the Affiliated Hospital of Yanbian University from January to May in 2019, aged from 18 to 40. Preoperative central corneal thickness  $\geq 480$   $\mu\text{m}$ , Postoperative residual corneal stromal bed thickness  $\geq 280$   $\mu\text{m}$ . Preoperative spherical lenses (-0.50 D to -9.50 D), cylindrical lenses (0 to 1.50 D), anisometropia  $\leq 2.50$  D, corneal contact lens discontinued  $> 2$  weeks. No complications occurred when they are followed-up during and after surgery. Recently, there is no history of taking drugs (glucocorticoids, contraceptives, etc.); Women are not pregnant or lactating. To eliminate corneal diseases, keratoconus, cataract, glaucoma, uveitis, retinal diseases and other eye diseases. The whole body is in good condition, excluding diabetes, hypertension, rheumatism, hyperthyroidism and other systemic diseases. Informed consent was obtained from all subjects using a consent form approved by the Institutional Review Board of the Affiliated Hospital of Yanbian University.

All patients were examined for naked eye vision, best corrected vision, slit lamp examination, comprehensive optometry, intraocular pressure, corneal thickness, axial length, ACD, fundus examination, and the size and central position of pupil were measured by Wavelight Allegro Topolyzer Corneal Topographic (*Wavelight Laser Technologies AG, Erlangen, Germany*) before operation.

Wavelight Allegro Topolyzer Corneal Topographic measures pupil size and central position under bright and dark conditions. All subjects were measured and recorded by the same physician under dark room conditions for 60 seconds. Red and green dots showed pupil center and corneal apex. Records the distance between the pupil center and the corneal apex in bright light and dark light. Provides the calculated pupil center offset in horizontal X and vertical Y directions. Take the average value of pupil diameter measured three times.

Excimer laser cutting was carried out using the wavefront optimized cutting procedure of the German Wavelight FS200 (200 KHz) femtosecond laser and the Wavelight EX500 excimer Laser (500 Hz), with the target refraction set to 0 D and no residual refraction. Surgical steps: Routine preoperative

preparations, disinfection of operative eye, open eyes by eyelid opener, take the supine position; ask the patient to look at the upper indicator lamp before lifting the flap after making the corneal flap. The patient can see the reflective point of the corneal vertex (coaxially sighted corneal light reflex point) and red reflection (visual axis center). By adjusting the illuminance to keep the pupil size to match the preoperative examination, the Wavelight EX500 excimer laser system's x and y-axis eye-tracking adjustment program is started to make the two reflection points coincide. The reference system displays the corneal horizontal and vertical adjustments, and records the *P-Dist* when the patient is in the supine position.

## Statistical Methods

All statistical analysis were performed using SPSS software (version 19.0, SPSS, Inc.). The data of each group were tested for normality and homogeneity of variance. When pairwise comparison was performed, LSD-t test was used. Paired t test was used for right and left eyes. The biomechanical correlation was analyzed by Pearson correlation. when  $P < 0.05$ , it was considered statistically significant.

## Results

Randomly selected 225 patients (407 eyes) who underwent femtosecond laser combined with excimer laser in situ keratomileusis at Yanbian University Hospital. There were 115 males (51%) and 110 females (49%), average aged  $24.58 \pm 6.84$  years. The average corneal curvature  $42.62 \pm 1.23$  D (Range: 39.32 to 48.91 D), The average SE is  $-4.62 \pm 1.24$  D (Range: -0.50 to -9.50 D), The average corneal astigmatism is  $-0.79 \pm 0.81$  D (Range: 0 to -1.50 D), The average eye axis is  $26.51 \pm 1.49$  mm (Range: 23.09 to 30.85 mm) (Table 1).

Table 1  
General information of patients

	Mean ± SD	Range
Age (years)	24.58 ± 6.84	18 to 45
SE (D)	-4.62 ± 1.24	-0.50 to -9.50
Sphere(D)	-5.74 ± 1.91	0 to -10.00
Cylinder (D)	-0.79 ± 0.81	0 to -1.50
Corneal K-value (D)	42.62 ± 1.23	39.32 to 48.91
Corneal thickness(μm)	526.72 ± 33.26	496.00 to 646.00
IOP (mmHg)	13.60 ± 1.32	12.4 to 20.5
Pupil diameter (mm)		
Photopic	3.29 ± 0.49	2.25 to 5.48
Mesopic	6.09 ± 0.74	3.71 to 7.99
Axial length (mm)	26.51 ± 1.49	23.09 to 30.85

Figure 1 shows the average distribution of the eccentricity between the corneal center and the pupil center under bright light conditions, which is  $0.322 \pm 0.194$  mm (Range: 0.005 to 0.956 mm), 21% of the eyes are  $\leq 0.20$  mm, 64% are  $\leq 0.40$  mm, 89% are  $\leq 0.60$  mm, and 100% are  $\leq 1.00$  mm. Figure 2 provides the average distribution of *P-Dist* is  $0.225 \pm 0.102$  mm (Range: 0.010 - 0.580 mm), 30% of the eyes are  $\leq 0.15$  mm, 80% are  $\leq 0.30$  mm, 98% are  $\leq 0.45$  mm, and 100% are  $\leq 0.60$  mm. Fig 3 shows the distribution characteristics of the corneal quadrants of the coaxially sighted corneal light reflex point. The coaxially sighted corneal light reflex point are mainly biased towards the upper temporal side of the corneal center. 34% above temporal, 29% below temporal, 22% above nasal and 15% below nasal.

The dynamic change of pupil center position of left and right eyes showed that the pupil center position of left and right eyes under bright light condition had no significant statistical change in the X-axis and Y-axis directions ( $P > 0.05$ ). Under dark light conditions, the left eye X-axis:  $-0.046 \pm 0.091$  mm, the right eye X-axis:  $-0.152 \pm 0.084$  mm, with statistical differences ( $P = 0.015$ ) (right eye offset to temporal side), and the Y-axis direction has no statistical changes ( $P = 0.062$ ). The Measured Centroid Shift (Scotopic-Photopic) for the left eye is  $0.127 \pm 0.103$  mm, and that for the right eye is  $0.176 \pm 0.139$  mm, with statistical difference ( $P = 0.034$ ) (Table 2, Fig. 4).

Table 2  
Changes in horizontal and vertical axes of pupil center under bright and dark light conditions of left and right eyes

	Right eyes	Left eyes	<i>t</i>	<i>P</i>
<b>Photopic</b>				
X Shift	-0.124 ± 0.104	-0.107 ± 0.132	1.068	0.092
Y Shift	0.010 ± 0.142	-0.023 ± 0.137	0.869	0.385
<b>Scotopic</b>				
X Shift	-0.152 ± 0.084	-0.046 ± 0.091	-2.448	0.015
Y Shift	-0.014 ± 0.132	-0.032 ± 0.191	1.929	0.062
<b>Measured Centroid Shift</b> ( Scotopic-Photopic)	0.127 ± 0.103	0.176 ± 0.139	-0.647	0.034

## Discussion

Although angle kappa compensation combined with personalized femtosecond laser combined with excimer laser in situ keratomileusis has a good theoretical basis, there is still a significant gap between the actual and ideal visual quality<sup>[10]</sup>. Factors influencing angle kappa include axial length, ACD and corneal curvature radius, but the proportion of each factor has not been confirmed<sup>[11, 12]</sup>. Moreover, the size and central position of the pupil in corneal refractive surgery cannot be ignored. In order to ensure the accuracy of surgical positioning, it is necessary to ensure the matching with the preoperative pupil size and position, iris texture recognition, corneal limbus recognition<sup>[13, 14]</sup>.

At present, the target of non-interference pupil center-corneal reflex line-of-sight tracking technology based on image processing is the pupil center of the operated eye, and the direction of the visual axis is estimated by calculating the vector between the pupil center and corneal reflex<sup>[15]</sup>. The laser cutting area is mostly centered on the coaxially sighted corneal light reflex point<sup>[16]</sup>. If the positions of the two are different, the locked pupil center needs to be adjusted accordingly<sup>[17]</sup>. The centrifugation used is a fixed value, but the ideal centrifugation should also change with the dynamic changes of the pupil. Therefore, according to the pupil size, center position and dynamic change of angle kappa of the patients who are suitable for excimer laser surgery, obtained the individualized pupil center displacement curve. During the operation, the pupil dynamics were monitored to adjust the angle kappa and calibrate the ablation centration in real time to ensure that each scanning-spot excimer laser was in the correct position<sup>[18]</sup>.

In this study, the average shift distribution between the center of the cornea and the center of the pupil was  $0.322 \pm 0.194$  mm (range: 0.005 to 0.956 mm), and 64% of the eyes were  $\leq 0.40$  mm. We also measured *P-Dist* during the operation, and showed that the average *P-Dist* = 0.225 mm, the minimum

0.010 mm and the maximum 0.580 mm, 80% of the eyes is  $\leq 0.30$  mm, and the coaxially sighted corneal light reflex point is mainly biased which is Upper temporal side of the pupil center (34%). The angle kappa is not a fixed value, which will change under different conditions<sup>[19]</sup>. Influenced by factors such as intraoperative illumination, surgical stimulation, eye type, emotional tension, and accommodation convergence caused by close gaze indicator lights, the dynamic changes of pupil size and central position can be caused<sup>[20, 21]</sup>. Theoretically, when the size and the center of pupil continuously change during surgery, the angle kappa also changes significantly<sup>[7, 22]</sup>. Therefore, we speculate that there is difference in diopter and visual quality after different angle kappa compensation percentage.

The results of this study indicate that the positions of the pupils' center of the left and right eyes were significantly different in low light conditions. The X axis of the left eye is  $-0.046 \pm 0.091$  mm, and the X axis of the right eye is  $-0.152 \pm 0.084$  mm. The right eye deviated from the left eye to the temporal side by  $0.106 \pm 0.095$  mm under dark light. The Measured Centroid Shift of the left eye is  $0.127 \pm 0.103$  mm, and that of the right eye is  $0.176 \pm 0.139$  mm, with statistical difference. We speculate that the majority of the population is right-handed, and the head deviates to the right side when working in close range. Due to the inconsistent gaze target distance, the left eye needs more accommodation force to achieve the same state as the right eye (the right eye is closer), causing smaller pupils, shallower anterior chambers and larger angle kappa relative to the right eye.

The changes in the pupil center positions of the left and right eyes guide us the left eye should adjust a larger proportion of angle kappa when positioning in excimer laser surgery. Because the angle kappa offset of the left eye is greater than that of the right eye. If positioned at the center of the cornea, the right eye can appropriately adjust the ablation centration at a position slightly within 0.152 mm from the corneal center to the temporal side to find the ablation centration point which is most closest to the visual axis<sup>[23]</sup>. To avoid the reduction of postoperative retinal imaging quality caused by unnecessary eccentric ablation<sup>[24, 25]</sup>.

Our results also show a positive correlation between lateral WTW and pupil diameter change. The related results have not been reported at home and abroad. This conclusion guides us to treat patients with large cornea during the operation to reduce the dynamic changes in pupil size with a darker environment as much as possible in order to improve the efficiency of pupil matching<sup>[26]</sup>. There is no correlation between the SE and the change of pupil diameter, but there is a negative correlation between the SE and Measured Centroid Shift. It has been reported in the literature that the refractive state has a significant correlation with the angle kappa, which is consistent with the results of this study<sup>[15]</sup>. Therefore, We speculate that the dynamic change of pupil center of Measured Centroid Shift is small for people with high myopia. Therefore, it can be understood that the dynamic change of angle kappa is correspondingly reduced, and the efficiency of pupil matching is higher. It is suggested that the proportion of compensating angle kappa vector is higher during operation.

This study firstly explored the offset distribution between the pupil center and the corneal co-reflective point, and its correlation with other biomechanical factors such as the eyeball. It further confirms the

importance of accurately locating the position of the ablation centration and the necessity to reasonably adjust the angle kappa vector ratio under different myopia degrees and eye type. This study also has limitations, the insufficient samples and the individual variability may affect the results. The relationship between angle kappa compensation and visual quality needs to be further studied. The digital relationship between various individualized cutting modes still needs further exploration.

## Conclusions

The pupil of the left eye becomes smaller, the anterior chamber becomes shallower, and the angle kappa increases relative to the right eye. In patients with large WTW, a darker light environment is maintained during the operation to improve the efficiency of pupil matching. The dynamic change of angle kappa in high myopia population is small. This study further confirmed the importance of accurately locating ablation centration and the necessity of rationally adjusting angle kappa ratio according to different myopia degrees and eye types.

## Abbreviations

ACD: Anterior chamber depth (from endothelium); Std. Error: Standard error of the estimate; SE: Spherical equivalent; P-Dist: the distance (eccentricity) between the pupil center and the coaxially sighted corneal light reflex point; WTW: White-to-white corneal diameter  $\square$  the corneal transverse diameter  $\square$ .

## Declarations

### Ethics approval and consent to participate

The study protocol was approved by the Ethics Institutional Review Board of the Affiliated Hospital of Yanbian University ( No.2020032) and informed consent was obtained from all participants before enrollment.

### Consent for publication

Applicable.

### Availability of data and materials

The data will not be made public in order to protect the participant's identity.

### Competing interests

The authors declare that they have no competing interests.

### Funding

This study was supported by a grant of the National Natural Science Foundation of China (Project No. 81960182). The research is funded by the National Nature Fund (No. 81960182).

### **Authors' contributions**

Y-J L were responsible for the conception and design of this study. W-Q D and Y-J L and other authors collected and obtained data. W-Q D and Y-J L analyzed and interpreted the data. W-Q D drafted the manuscript. Y-J L revised the manuscript critically for important intellectual content. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

### **Acknowledgements**

Thank my colleagues and teachers for their guidance, and my colleagues for helping me organize the data.

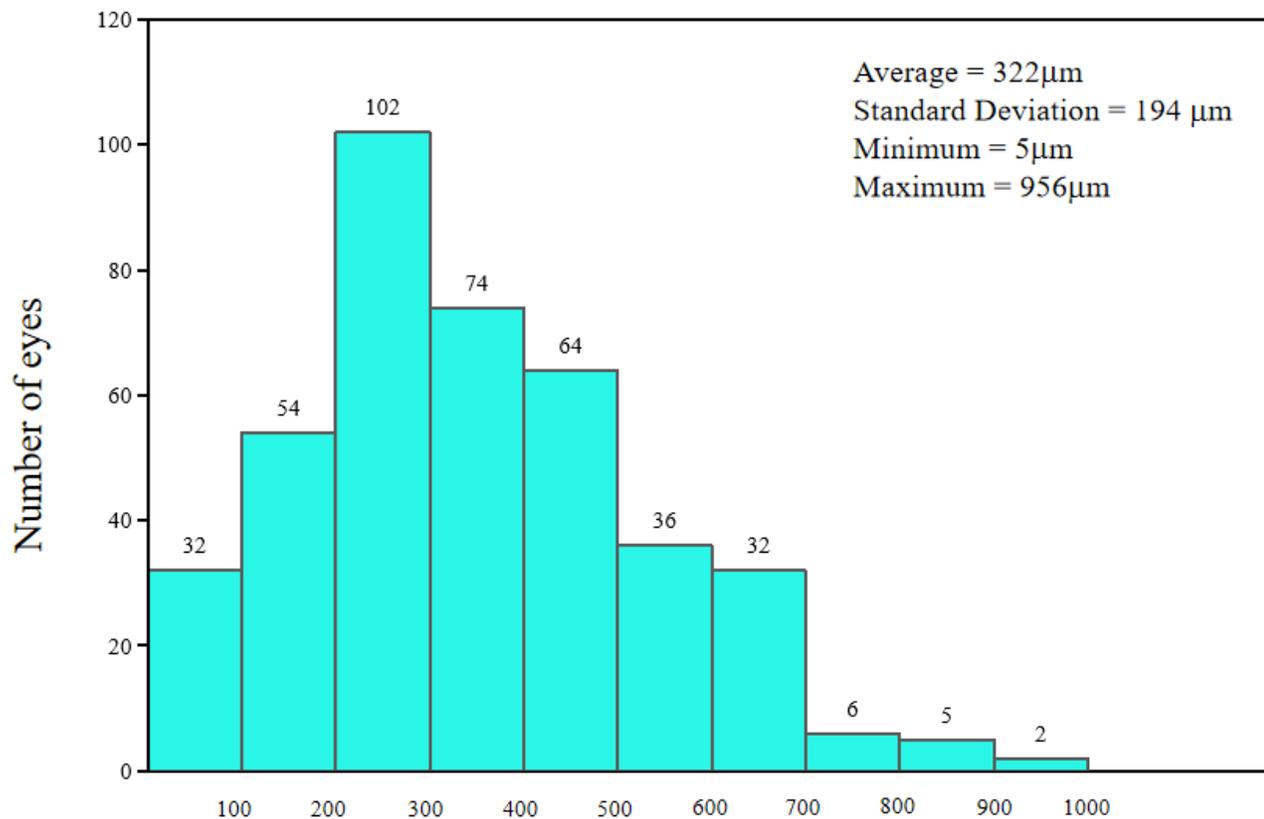
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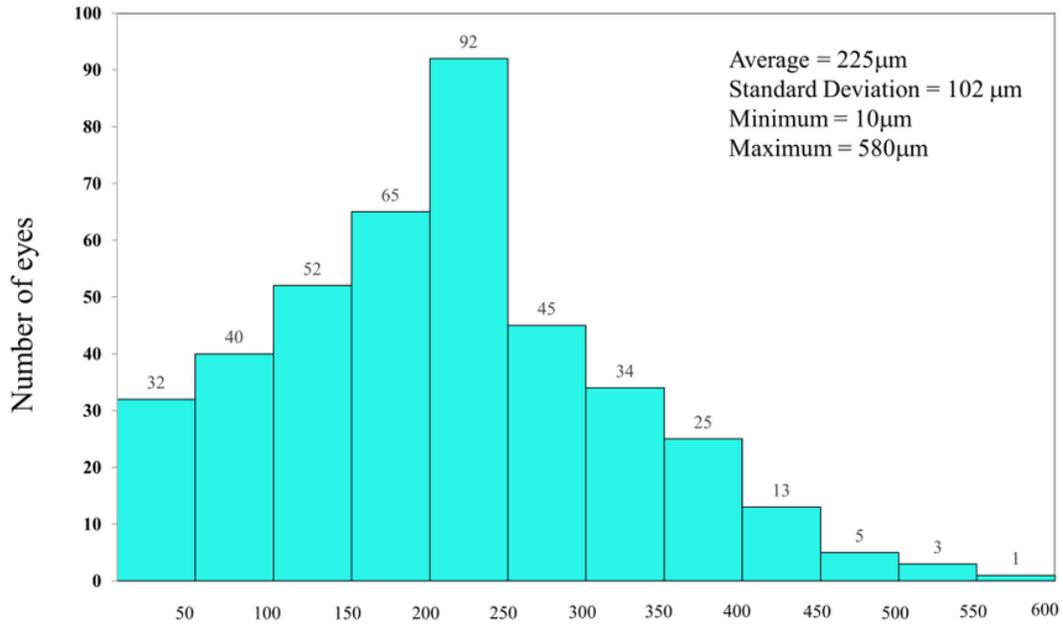
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## Figures



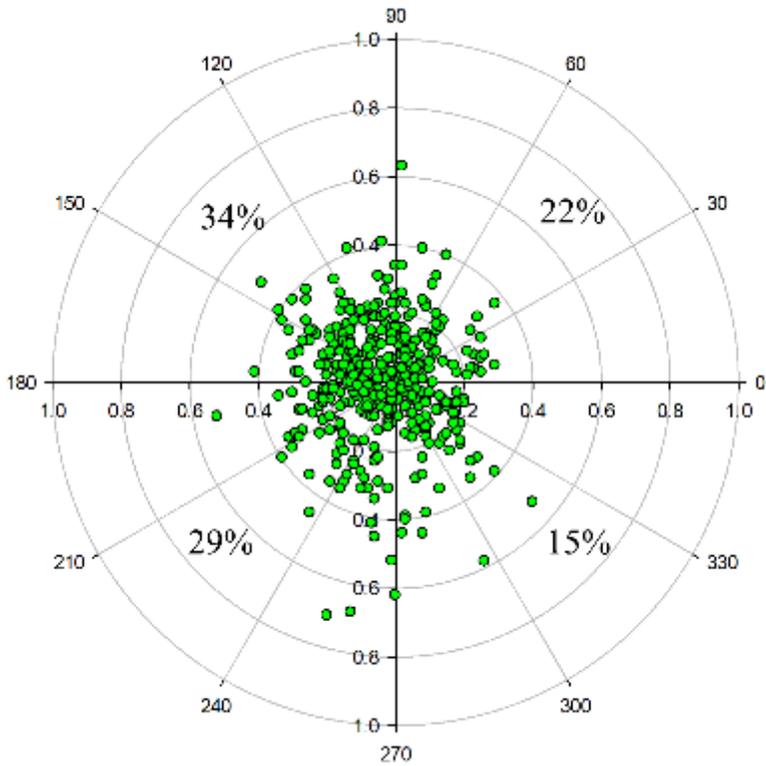
**Figure 1**

Offset distribution between corneal center and pupil center under bright light suitable for corneal refractive surgery patients



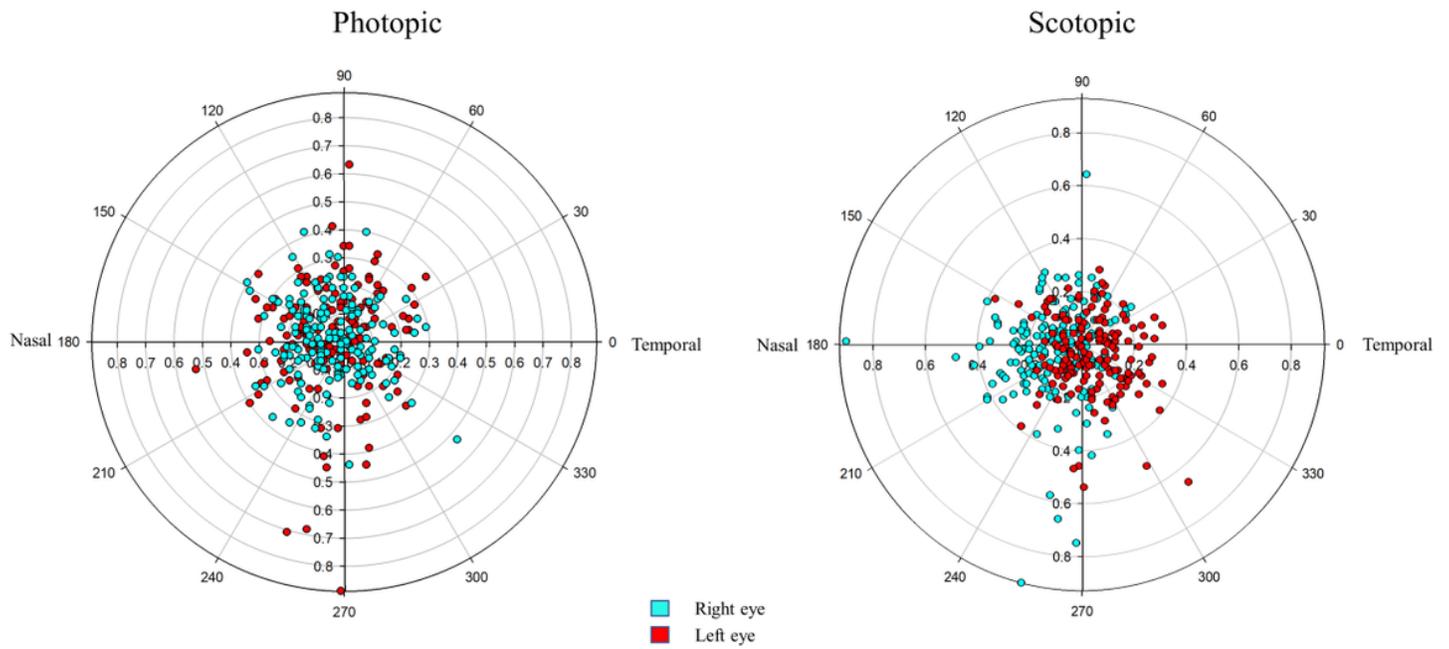
**Figure 2**

The shift distribution of P-Dist in patients with corneal refractive surgery



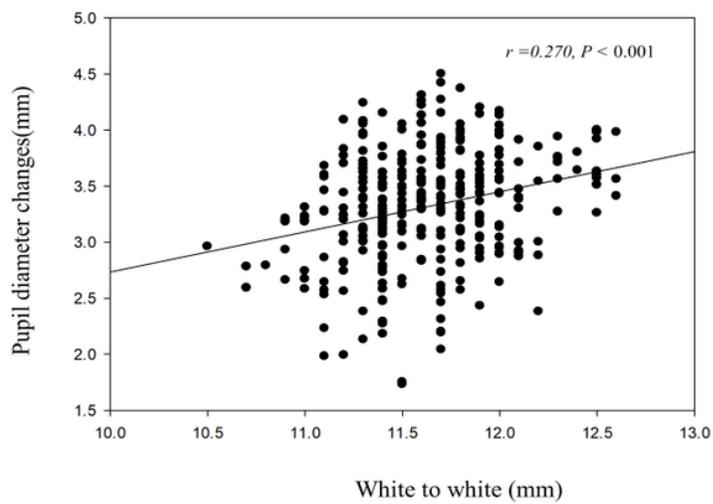
**Figure 3**

# Location and distribution of coaxially sighted corneal reflex point suitable for corneal refractive surgery patients



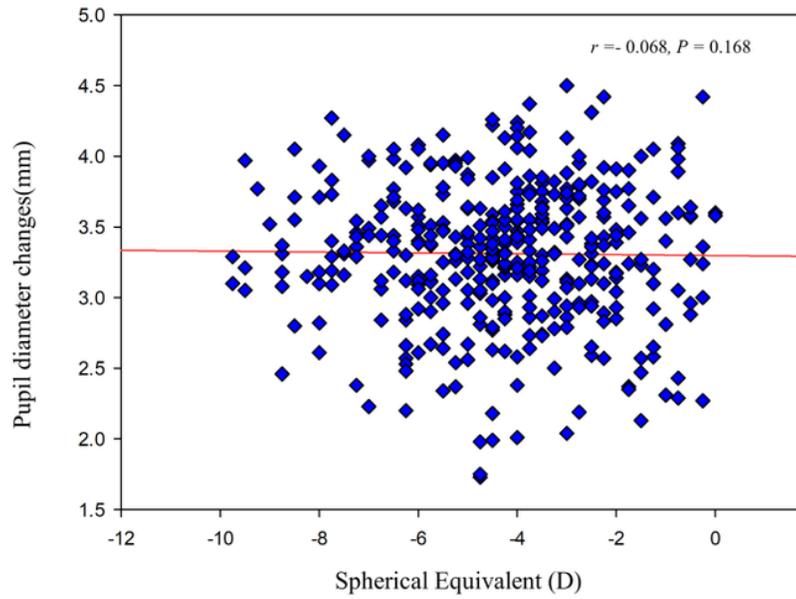
**Figure 4**

Changes of pupil center position under light and dark light conditions in left and right eyes



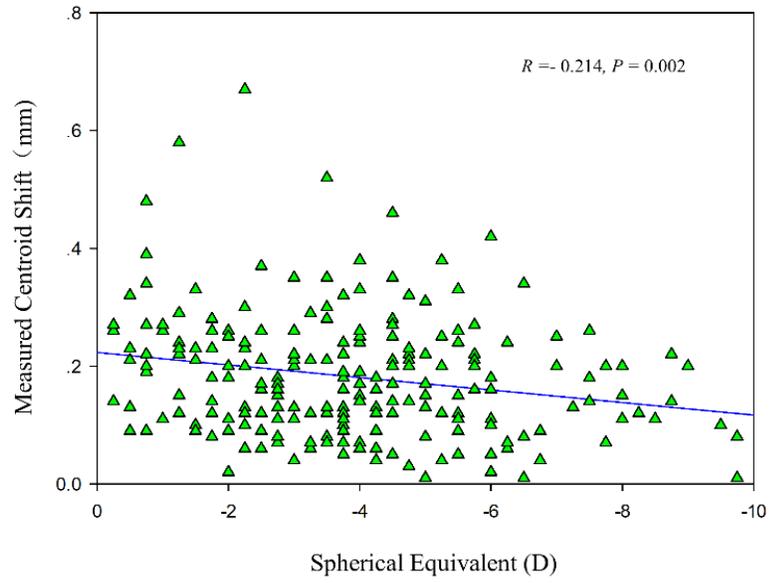
### Figure 5

Correlation between WTW and pupil diameter change (dark pupil diameter-bright pupil diameter)



### Figure 6

Correlation between SE and pupil diameter change (dark pupil diameter-bright pupil diameter)



**Figure 7**

Correlation between SE and Measured Centroid Shift