·Clinical Research·

Corneal white-to-white distance and mesopic pupil diameter

Hasan Basri Cakmak[1], *Nurullah Cagil*[1], *Huseyin Simavli*[2], *Sabri Raza*[3]

[1]Yıldırım Beyazıt Universitesi, Ataturk Egitim ve Arastırma Hastanesi, Bilkent yolu No: 3 Bilkent, Ankara, Turkey
[2]Bolu State Hospital, Bolu, Turkey
[3]Ankara Atatürk Education and Research Hospital, Ankara, Turkey
Correspondence to: Nurullah Cagil. Yıldırım Beyazıt Universitesi, Ataturk Egitim ve Arastırma Hastanesi, Bilkent yolu No: 3 Bilkent, Ankara, Turkey.drcagil@gmail.com
Received: 2011-06-21 Accepted: 2012-05-26

Abstract

• AIM: To study the relationship between corneal white-to-white (WTW) distance and mesopic pupil diameter.

• METHODS: This study is composed of 30 cases that underwent photorefractive keratotomy (PRK). Pupil size measurements were performed with Schwind ORK wavefront analyzer in mesopic conditions. WTW distance was measured with a measuring caliper. Also, A-scan ultrasound examination was performed in all patients. The relationship among the mesopic pupil diameter and age, sex, axial length, lens thickness, anterior chamber depth (ACD), horizontal WTW distance, vertical WTW distance, spherical equivalent, and average keratometry were analyzed with univariate and multivariate regression analysis.

• RESULTS: Mean pupil diameter was (6.39 ± 0.80)mm (range: 3.70mm to 7.73mm. Horizontal WTW distance measurements were between 11.00mm and 12.50mm and mean horizontal WTW distance was (11.79± 0.43)mm. On the other hand, vertical WTW distances ranged between 10.00mm and 13.00mm, and their mean was (11.42± 0.72)mm. Bivariate correlation between pupil diameter and other variables showed that the axial length, ACD, spherical equivalent, and horizontal WTW distance had a moderate correlation with mesopic pupil diameter. Multiple regression analysis revealed that spherical equivalent and horizontal WTW distances were significantly associated with mesopic pupil diameter (R=0.598, R^2=0.358 P=0.02).

• CONCLUSION: This study shows that mesopic pupil diameter is closely related to horizontal WTW distance. These two factors must be taken in consideration together in preoperative ablation zone planning.

• KEYWORDS: mesopic pupil diameter; photorefractive keratectomy; white-to-white distance

DOI:10.3980/j.issn.2222-3959.2012.04.19

Cakmak HB, Cagil N, Simavli H, Raza S. Corneal white-to-white distance and mesopic pupil diameter. *Int J Ophthalmol* 2012;5(4): 505-509

INTRODUCTION

Many clinical studies have reported a relationship between the ablation zone and mesopic pupil size with night vision problems after laser vision correction[1]. For instance, Holladay and Janes[2] and Boxer Wachler[3] in their studies showed the critical effect of mesopic pupil size on night vision and visual acuity. Before refractive surgery most of the surgeons plan the effective ablation zone taking into account the mesopic pupil size. The incompatibility between the mesopic pupil size and effective optical zone on the cornea causes troublesome symptoms such as ghost images, blurred vision, and especially glare and haloes at low illumination levels after refractive surgery.

Previous studies have shown that mesopic pupil size is related to the dimensions of other ocular structures. It is a possibility that mesopic pupil size may also have a relationship with corneal diameters. The corneal diameter has been used in the diagnosis of many eye malformations such as microcornea and also to detect and monitor congenital or infantile glaucoma [4]. Also, with the introction of IOLs into the clinical practice, corneal diameters are used to assess the size of intraocular spaces (i.e., chamber or ciliary sulcus diameter) and to determine the adequate IOL size[5,6].

The relationship between the mesopic pupil size and corneal diameters has not been studied yet. To the best of our knowledge, this study is the first that attempts to analyze this relationship between mesopic pupil size and corneal diameters.

SUBJECTS AND METHODS

Subjects This prospective study was performed in 1st Ophthalmology Clinic at Ankara Ataturk Training and Research Hospital. All subjects were patients who underwent PRK between March 1, 2008 and May 30, 2008. There were 30 subjects totally. Before the surgery, all cases underwent a detailed ophthalmological examination that included uncorrected visual acuity (UCVA), best corrected

Table 1 Clinical characteristics and statistics of parameters for the study population

Parameters	Min	Max	Mean	Std. Error	Std. Deviation
Age	20	48	29.41	0.90	7.01
Average keratometry (D)	40.05	47.75	43.40	0.08	2.12
Axial length (mm)	19.49	29.23	24.68	0.30	2.09
Anterior chamber depth (mm)	2.8	4.39	3.63	0.05	0.34
Lens thickness (mm)	3.15	4.27	3.75	0.04	0.28
Mesopic pupil diameter (mm)	3.7	7.73	6.39	0.10	0.80
Horizontal WTW (mm)	11	12.5	11.79	0.06	0.43
Vertical WTW (mm)	10	13	11.42	0.10	0.72
Spherical equivalent (D)	-11.5	11.25	-2.65	0.62	4.84

visual acuity (BCVA), manifest spherical refraction, cycloplegic refraction, ultrasonic pachymetry (B.V. International, Clermont-Ferrand, France), corneal topography (Keratron Scout, Optikon s.p.a, Rome, Italy), wavefront analysis (ORK Wavefront analyzer, Schwind eye-tech-solutions, Kleinostheim, Germany), slit-lamp examination of the anterior segment, and fundoscopy.

Methods Since the level of dark adaptation is difficult to standardize between subjects, all subjects were held in a waiting area under standard illumination for 15 and 30 minutes prior to examination. Wavefront and pupil examinations were then performed in a dimly lit adjacent room. Illumination level of the room was measured as 0.6 lux via a light meter (CEM DT-1301, Guangdong, China). Subjects were held in the examination room for approximately 5 minutes prior to wavefront measurement and pupil assessment while demographic data were entered into database.

The ORK wavefront analyzer uses a Hartmann-Shack sensor to measure the eye's aberrations. A hood projects around the subject's head to limit the effects of ambient light. Each eye is measured consecutively. The subject is asked to fixate on a red-light-emitting diode target (0.02lx). The operator manually focuses on the reflection pattern. The subject's refractive error is mapped using the wavefront analyzer, and the target light is "fogged" to infinity to relax accommodation. At the time of wavefront acquisition, a digital photograph of the iris and pupil is captured. The pupil size is determined manually fitting an onscreen circle to the pupil margin. If the pupil was not round, horizontal diameter was measured.

The same researcher (HBC) measured WTW distances by a measuring caliper. The measuring caliper has a scale in 1.0mm steps ranging from 0 to 20.0mm. After topical anesthesia, tips of the caliper were placed at the internal edge of the limbus horizontally and vertically, and the WTW distance measurement was read from the scale.

The A-scan ultrasound examination was performed after topical anesthesia with the patient in supine position. Anterior chamber depth, lens thickness, and total axial length were measured with Sonomed EZ Scan model AB5500+ (Sonomed Inc., Lake Success, New York) ultrasound device.

A computer database was established and measurements of each case were recorded. We considered the following nine possible significant factors to be related to pupil diameter: age, sex, axial length, lens thickness, anterior chamber depth, horizontal WTW distance, vertical WTW distance, spherical equivalent of refraction, and average keratometry. All the above variables were evaluated as continuous variables and gender as categorical variable.

Statistical Analysis The categorical variable was coded as either 1 or 0 depending on the presence or absence of the factor, respectively. Mean values were compared by the Student's t-test.ANOVA analysis was performed to compare two gender groups and spherical equivalent variable was taken as a covariate. Statistical analysis of individual factors' correlation with pupil diameter was done with Pearson correlation test. Multivariate regression was performed to calculate the coefficient of determination R^2 as an estimate of predicted pupil diameter. Only variables with $P<0.05$ were entered into or allowed to remain in the stepwise multivariate regression analysis. $P<0.05$ was considered to be statistically significant.

RESULTS

In this study, there were 30 subjects (60 eyes), 12 women and 18 men. Clinical characteristics and statistics of parameters belonging to whole study population were shown in Table 1.

Pupil diameter had a range between 3.70mm and 7.73mm. Mean pupil diameter was (6.39±0.80)mm. Horizontal WTW distance measurements were between 11.00mm and 12.50mm and mean horizontal WTW was (11.79±0.43)mm. On the other hand, vertical WTW distances were smaller, they ranged between 10.00mm and 13.00mm, and their mean was (11.42±0.72)mm.

Comparison of males to females showed that mean mesopic pupil diameter was (6.60±0.64)mm in males and (6.07±0.93)mm in females and the difference was statistically significant (P=0.011). Vertical WTW distances were

Table 2 Correlations between mesopic pupil diameter and other factors

Parameters		Age	AL	ACD	LT	PD	HWTW	VWTW	SE	KER
Age	*R*	1.000	0.049	-0.104	0.514	-0.032	0.071	0.146	-0.003	0.040
	P	-	0.371	0.242	0.000	0.405	0.301	0.140	0.492	0.385
AL	*R*	0.049	1.000	0.396	0.046	0.436	0.268	0.435	-0.871	-0.402
	P	0.371	-	0.003	0.380	0.001	0.038	0.001	0.000	0.001
ACD	*R*	-0.104	0.396	1.000	-0.036	0.513	0.407	0.123	-0.445	0.115
	P	0.242	0.003	-	0.405	0.000	0.003	0.211	0.001	0.265
LT	*R*	0.514	0.046	-0.036	1.000	0.100	-0.076	0.239	-0.105	0.038
	P	0.000	0.380	0.405	-	0.252	0.311	0.057	0.242	0.402
PD	*R*	-0.032	0.436	0.513	0.100	1.000	0.236	0.184	-0.480	-0.031
	P	0.405	0.001	0.000	0.252	-	0.039	0.085	0.000	0.416
HWTW	*R*	0.071	0.268	0.407	-0.076	0.236	1.000	0.646	-0.102	0.256
	P	0.301	0.038	0.003	0.311	0.039	-	0.000	0.225	0.031
VWTW	*R*	0.146	0.435	0.123	0.239	0.184	0.646	1.000	-0.247	0.384
	P	0.140	0.001	0.211	0.057	0.085	0.000	-	0.032	0.003
SE	*R*	-0.003	-0.871	-0.445	-0.105	-0.480	-0.102	-0.247	1.000	-0.435
	P	0.492	0.000	0.001	0.242	0.000	0.225	0.032	-	0.001
KER	*R*	0.040	-0.402	0.115	0.038	-0.031	0.256	0.384	-0.435	1.000
	P	0.385	0.001	0.265	0.402	0.416	0.031	0.003	0.001	-

R: Regression coefficient, *P*: *P* value, AL: Axial length (mm), ACD: Anterior chamber depth (mm), LT: Lens thickness (mm), PD: Mesopic pupil diameter (mm), HWTW: Horizontal WTW (mm), VWTW: Vertical WTW (mm), SE: Spherical equivalent (D), KER: Keratometry (D).

(11.63±0.67)mm in males and (11.03±0.66)mm in females and there was a significant difference between males and females (P= 0.002). However, horizontal WTW distances were not different between males (11.85±0.40) and females (11.68±0.47) (P=0.115). There was a significant difference between two gender groups in mean spherical equivalent (P=0.004). Therefore, an ANOVA analysis was performed to compare these two gender groups and the spherical equivalent variable was taken as a covariate. ANOVA analysis showed that these two groups were not significantly different in terms of mesopic pupil diameter (P=0.194) and horizontal WTW distance (P=0.230). However, mean vertical WTW distance measurements were found to be significantly different in these two groups (P=0.011) after ANOVA analysis.

Univariate correlates between pupil diameter and other variables such as age, sex, axial length; lens thickness, anterior chamber depth, horizontal WTW distance, vertical WTW distance, spherical equivalent, and average keratometry were performed *via* Pearson correlation analysis. Correlation coefficients and P values were shown in Table 2. Axial length, anterior chamber depth, spherical equivalent, and horizontal WTW distance had a moderate correlation with mesopic pupil diameter. On the other hand, there was no significant correlation between pupil diameter and age, lens thickness, vertical WTW, and keratometry values.

To assess whether any of the variables that showed a significant association with pupil diameter in univariate analysis contributed independently to the variability of these measures, multiple regression analyses were performed stepwise, entering anterior chamber depth, spherical equivalent, and horizontal WTW distance as variables. Stepwise multiple regression resulted that spherical equivalent was taken as the single variable in step 1. In this step, R^2 was 0.268 and standardized Beta of spherical equivalent was -0.52. In the second step, spherical equivalent and horizontal WTW distance were taken into analysis and anterior chamber depth was excluded. Second step showed that spherical equivalent and horizontal WTW distance were significantly associated with mesopic pupil diameter (R=0.598, R^2=0.358, P=0.02). Detailed data about the results of multivariate regression analysis were shown in Table 3.

DISCUSSION

The present study attempts to evaluate the relationship between the mesopic pupil size and WTW distance. There was a strong correlation between WTW distance and mesopic pupil size. In addition, bivariate correlation analysis among the mesopic pupil size and axial length, anterior chamber depth, and the spherical equivalent showed statistically significant correlation. Furthermore, multiple regression analysis revealed that the most significantly correlated factors with the mesopic pupil size were spherical equivalent and horizontal WTW distance.

In the literature macrocornea is usually regarded as corneal diameter greater than 12.5mm[7]. Large corneal diameters are found in keratoconus, lattice and granular dystrophies,

Table 3 Results of multiple regression analysis.

		Unstandardized coefficients		Standardized coefficients	
		B	Std. Error	Beta	*t*
Step 1	Constant	6.10	0.13	-	48.72
	Spherical equivalent	-0.08	0.02	-0.52	-3.97
Step 2	Constant	-1.56	3.17	-	-0.49
	Spherical equivalent	-0.08	0.02	-0.49	-3.97
	Horizontal WTW	0.66	0.27	0.30	2.42

Step 1: R=0.518, R^2 =0.268, P=0.001; Step 2: R=0.598, R^2=0.358, P=0.020.

whereas smaller diameters are present in Fuchs` and macular corneal dystrophies [8]. The definition of microcornea in the literature varies in horizontal diameters between less than 10.0mm to 11.0mm [9,10]. Similarly, normal range of horizontal corneal diameter is controversial and is reported to be between 11.5mm and 12.5mm [11-14]. In this study, horizontal WTW distance measurements were between 11.00mm and 12.5mm and the mean horizontal WTW distance was (11.79±0.43)mm. These results are in accordance with other previous reported studies.

The correlation between WTW distance and mesopic pupil size was significant. Although this correlation, having a correlation coefficient of 0.23, was accepted as a moderate correlation, its clinical implications deserve an importance. It means that every increase in corneal diameter is associated with an increase in mesopic pupil size. On the other hand, this moderate correlation points to other factors remaining undiscovered, determinative on mesopic pupil size. In quest of these factors, a multivariate correlation analysis was performed to elucidate inconspicuous relationships.

Multivariate analysis showed that the relationship between the spherical refractive error and pupil size was found to be significant as well. Pupil size is inversely proportional to algebraical value of spherical refractive error. As the spherical equivalent increases, the pupil size decreases.

Axial length, WTW distance, and anterior chamber depth appeared to be other significant factors. The relationship between pupil size and the dimensions of other ocular structures might be supported by clinical studies on children. During the development of the anterior chamber structures, the change in pupil size has been well documented. MacLachlan and Howland[15] investigated normal values and standard deviations for pupil diameter and interpupillary distance in subjects aged 1 month to 19 years. They reported the second order regression equation for average pupil size as a function of age.

Similarly Thunyalukul *et al* [16] measured pupil sizes and interpupillary distances of 970 infants and children. They reported that the pupil diameter and the axial length of the eye increase gradually in the first few years of life. We found that there is a relationship between axial length and pupil size. The correlation coefficient between pupil size and axial length was 0.436. Axial length also has a very close relationship with spherical equivalent (r=-0.871). All these support the claim that as the size and dimensions of the eye increase, mesopic pupil diameter increases.

We found that vertical WTW distances were larger in males than females however; horizontal WTW distances were not different between two genders. There was a significant difference between two gender groups in mean spherical equivalent (P=0.004). Therefore, an ANOVA analysis was performed to compare these two gender groups and spherical equivalent variable was taken as a covariate. ANOVA analysis showed that the mean vertical WTW distance measurements were larger in males. Difference between male and female was not reported as an important variable for mesopic pupil size in previous studies in contrast to this study, using strict and elaborate analysis. A close attention must be paid to the sexual differences in making surgical decision planning.

In this study, mesopic pupil size measurements were performed via a wavefront aberrometer. Mesopic pupil size could be measured by a variety of methods such as: Colvard pupillometer, Procyon pupillometer, Rosenbaum scales etc. Although measuring pupil size with wavefront aberrometer is not a standard method; previous studies reported that pupil size measurements with wavefront aberrometer were comparable with Colvard and Procyon pupillometers[17-19].

Another important issue that has to be discussed is that WTW distances were measured by a measuring caliper. Several methods are used to measure WTW distance such as: the Holladay-Godwin gauge, a measuring caliper, Zeiss IOLMaster, Orbscan II topography system, pentacam topography system, high-speed optical coherence tomography, and ultrasound biomicroscopy [7-14]. In one study, the WTW distance was measured using the following techniques: the Holladay-Godwin gauge, a measuring caliper, Zeiss IOLMaster, and Orbscan II topography system [13]. It was concluded that measurements with automated devices were comparable to manual methods. For this reason we consider that our measurements with measuring caliper are commensurable and pertinent.

The peripheral cornea works to decrease wavefront aberrations, especially spherical aberrations. In clinical practice the ablation zone is planned according to the mesopic pupil size [20]. In large corneas planning the ablation zone just using the mesopic pupil size may not cause significant problems. On the other hand, surgery planning not taking into consideration the corneal diameters may increase the wavefront aberrations significantly in cases having small corneas. According to the results of this study, not only the mesopic pupil but also corneal diameters must be considered in the planning of the ablation zone.

In conclusion, it might be stated that the mesopic pupil diameter is closely related to the horizontal WTW. Therefore, cases with large horizontal WTW distance deserve more careful and stringent approach in preoperative evaluation for ablation zone planning.

REFERENCES

1 Villa C, Gutierrez R, Jimenez JR, Gonzalez-Meijome JM. Night vision disturbances after successful LASIK surgery. *Br J Ophthalmol* 2007;91(8): 1031-1037

2 Holladay JT, Janes JA. Topographic changes in corneal asphericity and effective optical zone after laser in situ keratomileusis. *J Cataract Refract Surg* 2002;28(6): 942-947

3 Boxer Wachler BS. Effect of pupil size on visual function under monocular and binocular conditions in LASIK and non-LASIK patients. *J Cataract Refract Surg* 2003;29(2):275-278

4 de Silva DJ, Khaw PT, Brookes JL. Long term outcome of primary congenital glaucoma. *J AAPOS* 2011;15(2):148-152

5 Allemann N, Chamon W, Tanaka HM, Mori ES, Campos M, Schor P, Baïkoff G. Myopic angle-supported intraocular lenses: two-year follow-up. *Ophthalmology* 2000;107(8):1549-1554

6 Rosen E, Gore C. Staar Collamer posterior chamber phakic intraocular lens to correct myopia and hyperopia. *J Cataract Refract Surg* 1998,24(5): 596-606

7 Hashemi H, KhabazKhoob M, Yazdani K, Mehravaran S, Mohammad K, Fotouhi A. White-to-white corneal diameter in the Tehran Eye Study. *Cornea.* 2010; 29(1):9-12

8 Seitz B, Langenbucher A, Zagrada D, Budde W, Kus MM. Corneal dimensions in various types of corneal dystrophies and their effect on penetrating keratoplasty. *Klin Monatshl Augenheilkd* 2000;217 (3): 152-158

9 Wang L, Auffarth GU. White-to-white corneal diameter measurements using the eyemetrics program of the Orbscan topography system. *Dev Ophthalmol* 2002;34(1):141-146

10 Rüfer F, Schröder A, Erb C. White-to-white corneal diameter: normal values in healthy humans obtained with the Orbscan II topography system. *Cornea* 2005;24(3):259-261

11 Salouti R, Nowroozzadeh MH, Zamani M, Ghoreyshi M, Salouti R. Comparison of horizontal corneal diameter measurements using Galilei, EyeSys, and Orbscan II systems. *Clin Exp Optom* 2009; 92(5):429-433

12 Fotedar R, Wang JJ, Burlutsky G, Morgan IG, Rose K, Wong TY, Mitchell P. Distribution of axial length and ocular biometry measured using partial coherence laser interferometry (IOL Master) in an older white population. *Ophthalmology* 2010; 117(3): 417-423

13 Baumeister M, Terzi E, Ekici Y, Kohnen T. Comparison of manual and automated methods to determine horizontal corneal diameter. *J Cataract Refract Surg* 2004;30(2):374-380

14 Khng C, Osher RH. Evaluation of the relationship between corneal diameter and lens diameter. *J Cataract Refract Surg* 2008;34(3):475-479

15 MacLachlan C, Howland HC. Normal values and standard deviations for pupil diameter and interpupillary distance in subjects aged 1 month to 19 years. *Ophthalmic Physiol Opt* 2002;22(3):175-182

16 Thunyalukul V, Peck L, Howland HC. Pupil sizes and interpupillary distances of 970 infants and children measured in 2800 visits. *Invest Ophthalmol Vis Sci* 1996;37(Suppl) :7

17 Schmitz S, Krummenauer F, Henn S, Dick HB. Comparison of three different technologies for pupil diameter measurement. *Graefes Arch Clin Exp Ophthalmol* 2003;241(6):472-477

18 Wickremasinghe SS, Smith GT, Stevens JD. Comparison of dynamic digital pupillometry and static measurements of pupil size in determining scotopic pupil size before refractive surgery. *J Cataract Refract Surg* 2005; 31(6):1171-1176

19 Kohnen T, Terzi E, Bühren J, Kohnen EM. Comparison of a digital and a handheld infrared pupillometer for determining scotopic pupil diameter. *J Cataract Refract Surg* 2003;29(1):112-117

20 Schallhorn SC, Kaupp SE, Tanzer DJ, Tidwell J, Laurent J, Bourque LB. Pupil size and quality of vision after LASIK. *Ophthalmology* 2003;110 (8):1606-1614