ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

Assessment of Pupil Diameters of Emmetropes and Myopes under Photopic, Mesopic and Scotopic Conditions, Using the Infrared Pupillometer Integrated Within Schwind Sirius Multifunctional Diagnostic Device

Emetropların ve Miyopların Pupil Çaplarının Fotopik, Mezopik ve Skotopik Koşullarda Schwind Sirius Çok Amaçlı Tanı Aracı ile Entegre İnfrared Pupillometre Kullanılarak Değerlendirilmesi

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ABSTRACT Objective: To assess the pupil diameters of emmetropes and myopes in photopic, mesopic and scotopic conditions. **Material and Methods:** Pupil diameters of 49 emmetropic subjects [spherical equivalent (SE) values ±0.25 diopter (D) with a mean age of 31.0±10.5 years (range 17 to 58 years)], and 61 age-matched (mean age 31.3±8.9 years, range 17 to 52 years) myopic subjects (SE values ≥-1D) were measured with the infrared pupillometer integrated within Schwind Sirius Multifunctional diagnostic device (Eye-tech-solutions, Kleinostheim, Germany) in photopic (40 lux) condition simulating the day-time, in mesopic (4 lux) condition and in scotopic (0.04 lux) condition simulating the level of light encountered at night. All statistical analyses were performed according to two-sided hypothesis tests and a p-value of less than 0.05 was considered statistically significant. **Results:** The mean photopic pupil diameter was 3.62±0.73 mm (range 2.49 to 5.83) in the emmetropic group and 3.86±0.85 mm (range 2.06 to 6.67) in the myopic group. The mean mesopic pupil diameters were 4.68±0.78 mm (range 3.19 to 6.45) and 5.16±0.91 mm (range 3.23 to 7.46) and the mean scotopic pupil diameters were 5.63±0.70 mm (range 4.28 to 7.14) and 6.08±0.86 mm (range 4.30 to 7.95) in emmetropes and myopes, respectively. The mean pupil diameters of myopes were larger than emmetropes in all three light conditions ($p<0.001$). There was no interaction between patient group and light condition ($p>0.05$). **Conclusion:** The mean pupil diameters of myopic subjects were larger than the pupil diameter of emmetropes. Pupil diameter should be measured objectively under standardized illumination levels in order to minimize the risk of post-operative glare and halo formation in refractive surgery patients.

Key Words: Pupil; myopia; mesopic vision; night vision; refractive surgical procedures; glare

ÖZET Amaç: Emetropların ve miyopların pupil çaplarının fotopik, mezopik ve skotopik koşullarda değerlendirilmesi. **Gereç ve Yöntemler:** Ortalama yaşı 31,0±10,5 yıl (aralık 17-58 yıl) olan 49 emetropik olgunun [sferik eşdeğer (SE) değerleri ±0,25 diopter (D)] pupil çapları ile yaşa göre eşleştirilmiş (31,3±8,9 yıl; aralık 17-52 yıl) 61 miyopik olgunun (SE değerleri ≥-1D) pupil çapları Schwind Sirius Çok İşlevli tanı aracıyla (Eye-tech-solutions, Kleinostheim, Almanya) entegre infrared pupillometre ile gündüzü taklit eden fotopik koşullarda (40 lüks), mezopik (4 lüks) ve gece rastlanan ışık düzeyini taklit eden skotopik koşulda (0,04 lüks) ölçüldü. Tüm istatistiksel incelemeler iki taraflı hipotez testlerine göre yapıldı ve 0,05'den küçük p değeri istatistiksel olarak anlamlı kabul edildi. **Bulgular:** Ortalama fotopik çap emetropik grupta 3,62±0,73 mm (aralık 2,49-5,83) ve miyopik grupta 3,86±0,85 mm (aralık 2,06-6,67) bulundu. Ortalama mezopik pupil çapları emetroplarda ve miyoplarda sırasıyla 4,68±0,78 mm (aralık 3,19-6,45) ve 5,16±0,91 mm (aralık 3,23-7,46) ve ortalama skotopik pupil çapları 5,63±0,70 mm (aralık 4,28-7,14) ve 6,08±0,86 mm (aralık 4,30-7,95) ölçüldü. Miyopların ortalama pupil çapları üç ışık durumunda da emetropların pupil çaplarından daha genişti ($p<0,001$). Hasta grubuyla ışık durumu arasında hiç etkileşim yoktu ($p>0,05$). **Sonuç:** Miyopik olguların ortalama pupil çaplarının emetroplardakinden daha geniş olduğu bulundu. Refraktif cerrahi hastalarında postoperatif göz kamaşması riskini ve halo formasyonunu en aza indirmek için pupil çapı standart aydınlatma düzeylerinde objektif olarak ölçülmelidir.

Anahtar Kelimeler: Göz merceği; miyopi; mezopik görüş; gece görüşü; refraktif cerrahi işlemler; parıltı

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Refractive surgery has become a widely used and effective technique in treating a variety of refractive errors. While improved technology seems to have increased the patient's and the physician's satisfaction and expectation, the success criteria became more complicated and varied for each patient. Some annoying visual disturbances such as halos, starbursts, and glare may happen even after a successful refractive surgery, with an incidence of 2% to 31.5%.[1-3] Pupil diameter (PD) is considered an important factor in the development of such problems.[4,5] Not only the size, but also the relationship between the location of the optical zone and the pupil is critical for a successful surgical outcome.[5-8] The diameter of the cornea that receives the full intended correction by the laser should be at least as large as the patient's pupil in dim light. Although milimetric rulers, handheld pocket charts and photographic cameras are commonly used methods, they are not reliable and objective due to non-standardized intensity and duration of light entering the pupil as well as their dependence to the examiner.[9-13] The infrared (IR) pupillometers and wavescan wavefront units provide more accurate measurements under different light conditions as well as capturing the pupil diameter either dynamically or statically according to the defined lighting conditions.

Some techniques described to simulate a scotopic illuminance level while measuring the pupil size, such as 'opening the examination room door 1 to 2 inches to create an ambient illumination of 0.5 to 0.6 lux may not be accepted as an exact simulation of night illuminance.[11,14,15] As International Commission on Illumination defines the scotopic condition as <0.05 lux and mesopic as 0.05-50 lux (National Physical Laboratory, London, UK), it is obvious that the pupil diameter measurements obtained in non-standardized conditions may not be real scotopic sizes.[16]

In this study, we measured the pupil diameters of age and sex-matched emmetropic and myopic subjects under three standardized light conditions using the IR pupillometer integrated within Schwind Sirius Multifunctional diagnostic device (Eye-tech-solutions, Kleinostheim, Germany) to compare the two groups as well as the pupil diameters in 3 light conditions within each group.

MATERIAL AND METHODS

Fourty-nine emmetropic (SE±0.25 D) and 61 age-matched myopic (SE over-1 D) subjects were included in the study. After the subjects were kept in a dark room for 5 minutes for dark adaptation; pupil diameters of both eyes were measured with the IR pupillometer integrated within the Schwind Sirius Multifunctional diagnostic device (Eye-tech-solutions, Kleinostheim, Germany) in photopic (40 lux) condition simulating day-time, in mesopic (4 lux) condition and in scotopic (0.04 lux) condition simulating the level of light encountered at night. All measurements were made between 8.00 and 9.00 am. The pupil diameters of both eyes were recorded but only the measurement of one eye (randomized right or left) was included in the study. Visual acuities were 20/20 or better in all subjects with spectacles or contact lenses. The study was conducted under the standards of 'Decleration of Helsinki' and written informed consents were obtained from all participants. Subjects with a history of any eye disease, eye surgery, eye trauma, systemic disease such as diabetes mellitus, neurological or psychiatric disease, history of uveitis, glaucoma and subjects under a systemic or topical treatment as well as any subject with a pupil or iris abnormality were excluded.

The Schwind Sirius (Eye-tech-solutions, Kleinostheim, Germany) diagnostic device consists of a 3-D rotating Scheimpflug camera, a Placido disc topographer system and an integrated IR pupillometer. Pupillometer measures the size and the position of the pupil in several light conditions, and fixates to corneal vertex as a reference point. It uses a binocular photomotor stimulus, necessitating that both eyes perceive the same luminosity. Visible light is used for the stimulus and the infrared light for capturing. Since the infrared light emitting diods (LEDs) illuminates the eye tangentially and is not visible for the human eye, it does not influence the photomotor stimulus. Dynamic pupillometry is used to evaluate the pupil movements through illumination levels of 500 to 0.04 lux.

Each pupil was measured three times by the same examiner and an average of the 3 measurements was obtained.

STATISTICAL ANALYSIS

A complete analysis was performed using SPSS 18.0 version for Windows (SPSS Inc., Chicago, IL, USA). Total number of subjects analyzed were 49 and 61 for emmetropic and myopic groups, respectively. Continuous variables were presented as mean±standard deviation (SD) and as median (range; min.-max.) where necessary. Categorical variables were presented as frequencies. Continuity correction Chi-square test was used in the comparison of categorical variables between patient groups. Student's t-test and when necessary Mann–Whitney U-test were used for the comparison of continuous variables between the patient groups. Correlations of the analytic variables were investigated with Pearson's correlation analysis; when necessary Spearman's correlation analysis was used. After the assessment of normality assumption, repeated measures ANOVA with between subjects factors (with independent measures on patient groups and repeated measures on the different light conditions) were performed with Greenhouse-Geisser adjustment and Bonferroni post-hoc test. All statistical analyses were performed according to two-sided hypothesis tests and a p-value of less than 0.05 was considered statistically significant.

RESULTS

The emmetropic group consisted of 11 males and 38 females with a mean age of 31.0±10.5 (range 17 to 58 years) and the myopic group consisted of 23 males and 38 females with a mean age of 31.3±8.9 (range 17 to 52 years). The median SE was-0.13 D (ranged -0.25 to +0.25 D) in the emmetropic and-2.25 D (ranged, -7.00 to -1.00 D) in the myopic group (p<0.001).

There were no statistically significant differences in sex and age between groups, respectively (p>0.05; p>0.05) (Table 1).

TABLE 1: Data of emmetropic and myopic patients.

Variables	Emmetropic (n=49)	Myopic (n=61)	p-value
Sex			
Male/Female	11/38	23/38	[a]p=0.130
Age (years)			
Mean±SD	31.0±10.5	31.3±8.9	[b]p=0.883
SE (Diopter)	-0.05±0.21	-2.68±1.47	[c]p < 0.001
Mean±SD	-0,13	-2,25	
Median (min.-max.)	(-0.25-0.25)	(-1.0 - -7.0)	

[a]p- Continuity Correction Chi-square test; [b]p- Student's t-test; [c]p- Mann-Whitney U test.
SE: Spherical equivalance; SD: Standard deviation.

Repeated measures ANOVA with Greenhouse-Geisser adjustment for pupil diameters revealed significant effect of the patient groups [$F_{(1;105)}$=8.722 (p<0.01)] and light conditions [$F_{(1.673;175.684)}$=714.741 (p<0.001)]. Mean pupil diameters were significantly higher in the myopic group than in the emmetropic group for all measurements. Mean pupil diameters were significantly different for each of the light conditions in both groups. Comparisons between mesopic and scotopic, mesopic and photopic, and scotopic and photopic conditions revealed significant diferences (Bonferroni tests p<0.001, p<0.001, and p<0.001, respectively). No interaction effect was observed between the light conditions and the patient groups [$F_{(1.673;175.684)}$=2.008 (p>0.05)] (Table 2) (Figure 1).

Correlation analysis revealed strong correlation between pupil diameters in 3 light conditions both in myopes and emmetropes. Myopes had a weak-moderate negative correlation in terms of age and pupil diameters while emmetropes showed no correlations between age and pupil diameters (Table 3).

In photopic conditions, no pupil had a diameter over 7 mm in any group (Figure 2). In mesopic conditions, none of the 49 pupils was over 7 mm in emmetropes and only one pupil (1.6%) was over 7 mm in myopes (Figure 3). However, in scotopic conditions, one pupil (2.1%) had a diameter over 7 mm in the emmetropic group while 11 pupils (18%) were over 7 mm in the myopic group (Figure 4).

TABLE 2: Results of the Repeated Measures Analysis of Variance for the mean pupil diameters in the three different light conditions of myopes and emmetropes.

	Light Condition			
Mean Pupil Diameter (mm) Mean±SD	**[1]Photopic**	**[2]Mesopic**	**[3]Scotopic**	**p-value**
Emmetropes (n=49)	3.63±0.73	4.68±0.78	5.63±0.70	[a]p<0.001
Myopes (n=61)	3.86±0.85	5.16±0.91	6.08±0.86	[b]p<0.001
p-value	[1,2]p<0.001	[1,3]p<0.001	[2,3]p<0.001	

[a]p- for the light conditions; [b]p- for the patient groups.

[1,2]p- for the between Photopics and Mesopics; [1,3]p- for the between Photopics and Scotopics; [2,3]p- for the between Scotopics and Mesopics.

SD: Standard deviation.

DISCUSSION

Pupil size is influenced by many factors such as characteristics of the light stimulus and the stimulated eye, retinal illumination, accommodative state of the eye, sensory and emotional state, various neuro-psychiatric diseases, drugs, as well as the age and diabetes.[17-23] The recent technological developments in refractive surgery as well as the widespread notion of 'no pain, nearly no complication and a momentary surgery resulting with an eagle sight', raised the degree of expectations of patients and even the doctors. Patients may complain about problems such as glare, halos, ghost images, poor contrast sensitivity and monocular double vision especially at night or in dim-light condition, which they may describe as 'devastating' even if they achieved visual acuity of 20/20 and over. These disturbances may be related to incoordination of scotopic pupil diameter with ablation diameter as well as to incoordination of optical zone and pupil location.[24] Patients with pupils that dilate larger than the effective optical zone of the LASIK treatment are at increased risk for debilitating visual aberrations and loss of contrast sensitivity.[25,26] Even patients with normal pupil sizes are at risk, as the laser loses efficacy on the slope of the cornea resulting in an effective optical zone that is smaller than intended.[27] Large pupil diameters are not the only cause but are considered an important predictor of night-vision disturbances. Therefore, the exact measurement of the pupil diameter is essential before refractive surgery to avoid such postoperative problems and to determine if a patient is suitable for refractive surgery. The techniques commonly used are subjective methods such as a millimeter ruler or a Rosenbaum Pocket Vision Screen card which may have some handicaps such as difficulty in measuring pupils in dim light, not considering the dynamic structure of the pupil, non-standardized intensity and duration of light exposed and have high inter-observer and intra-observer variation, with greater inter-examiner variation compared to infrared systems.[16,28]

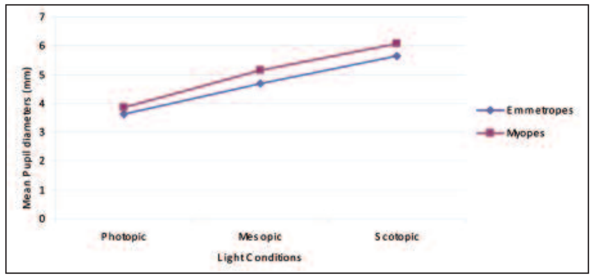

FIGURE 1: Mean pupil diameters in photopic, mesopic and scotopic conditions for the emmetropes and myopes.
(See for colored form http://tipbilimleri.turkiyeklinikleri.com/)

In this study, the light stimulus and the light adaptation of the stimulated eye were constant. The mean scotopic pupil diameter was 6.08±0.86 mm in myopes and 5.63±0.70 mm in emmetropes. Many other studies have evaluated pupil diameters using different devices in various patient and age groups, with different light intensities, resulting with a wide range of pupil diameters and most of these studies have included both eyes of the patients.[11,13,15,16,27,29-31] Shallenberg et al, measured pupil diameters in 92 eyes of 46 healthy individuals with a mean age of 25.7 years, with Colvard, Neuroptics and Procyon IR pupillometers in scotopic condition (0.04 lux) and found a mean PD of 6.63±0.68 (5.0-8.0) mm for Colvard, 6.99±0.67 (5.3-8.6) mm for Neuroptics and 6.73±0.74 (3.6-8.1) mm

TABLE 3: Results of the correlation analysis between pupil diameters in three different light conditions, SE and age of myopes and emmetropes.

Emmetropes					Myopes				
	Age	†SE	Scotopic	Mesopic		Age	†SE	Scotopic	Mesopic
Photopic	NS	NS	0.530**	0.804**	Photopic	-0.478**	NS	0.653**	0.825
Mesopic	NS	NS	0.734**		Mesopic	-0.405**	NS	0.846**	
Scotopic	NS	NS			Scotopic	-0.410**	NS		
† SE	0.370*				†SE	NS			

† Spearman correlation coefficients, and the others Pearson correlation coefficients.
NS, no significance; SE: Spherical equivalance; * p<0.01; **p ≤ 0.001.

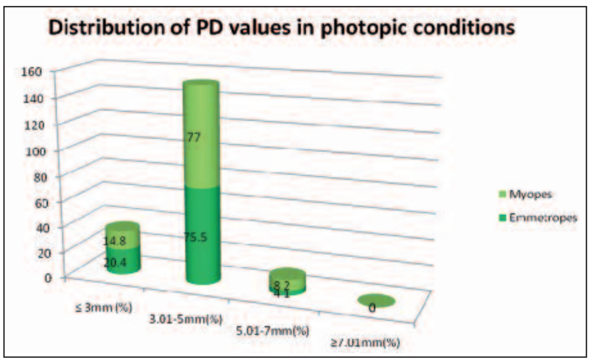

FIGURE 2: The distribution according to pupil diameters of emmetropes and myopes in photopic conditions.
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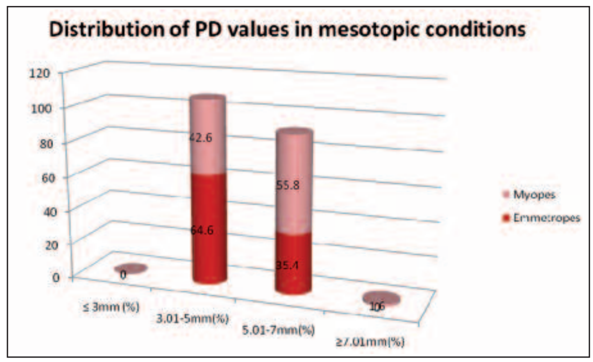

FIGURE 3: The distribution according to pupil diameters of emmetropes and myopes in mesopic conditions.
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for Procyon pupillometer. Their PD measurements are all larger than the emmetropic and even the myopic PDs in our study.[27] Colvard pupillometer was the first commercially available pupillometer, which used a horizontal milimetric ruler with 0.5 mm precision allowing the measurement of the pupil diameter directly by the examiner. The measurements in 0.1 mm steps is not possible, which causes the readings to be clustered to integer values.[27] Including both eyes of a participant which are clustered to an integer number may be the reason for the difference. Neuroptics pupillometer provides monocular measurement as Colvard pupillometer, since one eye is closed during the measurement of the pupil size. Boxer Wachler reports that monocular testing induces larger pupil diameter.[32] Although some features of Procyon IR pupillometer and Schwind Sirius IR pupillometer are similar in terms of binocularity, objectivity, standardization of illumination and dynamic measuring, the lack of automated outlier recognition of Procyon IR pupillometer as described by Schallenberg makes checking every measurement necessary to select the appropriate frames to be analyzed. The larger PD values compared to those in our study may be due to examiner bias toward the device.

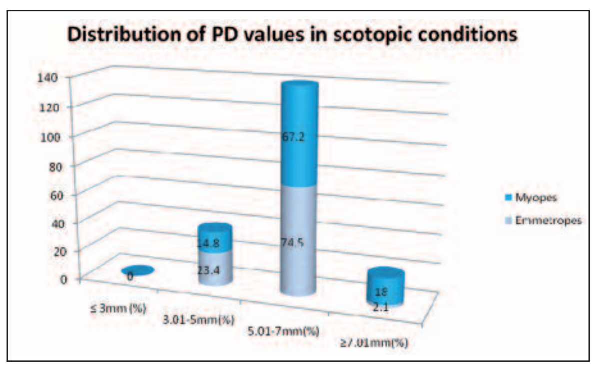

FIGURE 4: The distribution according to pupil diameters of emmetropes and myopes in scotopic conditions.
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Kohnen et al, also used Colvard and Procyon IR pupillometers with an illumination level of 0.07 lux in healthy individuals with a mean age of 38.8 years; the mean PD values were 5.78±0.98 (3-7.3) mm and 5.90±0.97 (3.24-7.91) mm respectively.[13]

Netto et al. used 0.04 lux illuminance with Procyon IR pupillometer in refractive surgery candidates with refractive error between -6.00 D to +5.00 D (mean age 43.4 years) and measured a mean PD of 6.6±0.9 in the right and 6.5±0.9 mm in the left eye where both PD measurements were larger those in our study.[29] However, the study differs from our study in terms of the wider range of refractive error and older mean age of the participants.

The relationship between refractive error and pupil size has not been well established. Some studies found no difference in pupil size between myopes and emmetropes, while others reported that myopes had larger pupils than emmetropes.[15,29,33-38] Tscherning states that the deeper anterior chamber in the myope makes the pupil appear larger.[39] Shaun et al. stated that myopes showed maximum values for anterior chamber depth (ACD) and PD than emmetropes and hyperopes in photopic and scotopic conditions.[40] Hosny at al found a correlation between the ACD and axial length (AL) as well as between the ACD and the level of myopia and an inverse correlation with age.[41] Freedman states that the real pupil diameters are calculated by the formula RP=EP(1-AK/1.3375). EP is entrance pupil and A is the ACD and K is the corneal refractive power.[42] The different corneal powers and the ACD values may be the reason for the difference in PD values of myopes and emmetropes.

The accomodative status of the eye when focusing a near target was taken into account in various studies.[34,35,43] Subbaram and Ballimore found no significant differences in the pupil diameters of age-matched myopes and emmetropes at different levels of accomodation.[43] He et al. stated that myopes had difficulty in accomodative relaxation, which resulted in accomodation lag.[44] Although this may produce an impression that a larger PD in myopes might be expected due to larger accomodation lag resulting in less accomodative miosis, it is difficult to draw a conclusion since the device and the illumination level used, the range of age and refractive error, accomodative status, anterior segment parameters and the ethnic origin of the participants included are quite different in each study.

Chaidaroon et al used Colvard IR pupillometer in 55 normal and 55 myopic subjects with a mean (+/- SD) age of 30.78 years +/- 10.03 (range, 18-54 years) and 27.35 years +/- 8.43 (range, 21-52 years), respectively. The mean (+/- SD) scotopic pupil diameter was 6.46 +/- 0.90 mm (range, 4.5-8.0 mm) in the emmetropic group and 6.98 +/- 0.67 mm (5.5-8.5 mm) in the myopic group.(p=0.0001).[15] The measurements in both studies were larger than the measurements in our study. This difference may be attributed to the hypothesis that monocular testing induces larger pupil diameter.[32] In addition, the illumination level used in Chaidaroon's study to create a scotopic condition was 0.5-0.6 lux and the participants were relatively younger, which makes it difficult to comment on.

In our study, in the emmetropic group, none of the 49 pupils had a diameter over 7 mm under mesopic conditions and only 1 pupil (2.1%) was over 7 mm under scotopic conditions. On the other hand, 1 (1.6%) and 11 (18%) of 61 pupils were over 7 mm in myopes, in mesopic and scotopic conditions, respectively. It is obvious that if we had measured the pupils under mesopic conditions, we might have overlooked 10 subjects who had pupil diameters over 7 mm under scotopic conditions and who would be probably candidates for postoperative glare and halo disturbances. It is very important to measure the largest diameter the pupil reaches, because our results revealed that the differences between mesopic and scotopic diameters of both emmetropic and myopic subjects were statistically significant (p<0.001).

Several studies reported that there was a significant reduction in pupil size in the elderly, in conjunction with comparative atrophy of the dilator muscle relative to the sphincter muscle, iris rigidity, decrease in sympathetic tone, reduction in parasympathetic inhibition, and chronic fatigue.[45-54] The age related decline in pupil size progresses linearly at an estimated rate of 0.4 mm/decade from the age of 20 years to 90 years.[51,55] However, Bernick suggests that pupillary activity (which is the standard deviation of the mean for each period of stimulation) and the range of pupillary response (which is the difference between the mean response levels in light and dark) may account for some of the relationship between age and pupil size.[56] In his study involving subjects aged between 19 and 49, the relationship between pupil size and age both in light and dark conditions was no longer significant when these two factors relating to the lability of the pupil were statistically partialled out.[56] In a recent study including a large cohort of myopic patients who were candidates for Implantable Collamer Lens (ICL) implantation showed that the average dynamic pupil range (mesopic PD-photopic PD) was constant between 18 and 62 years and photopic and mesopic pupil size or the difference between both were not correlated with age.[57]

The finding that there was no correlation in emmetropes and a weak-moderate negative correlation in myopes between pupil sizes and age may be due to the limited number and limited age range of patients (mean 31.3 years, ranged from 17 to 52 years in myopes and mean 31.0 years ranged from 17 to 58 years in emmetropes).

Some patients planned for refractive surgery may experience glare and halos due to bigger pupil sizes than the ablation zones and may not be good candidates for refractive surgery. Schwind Sirius Multifunctional diagnostic device allows standardized duration, power and intensity of illumination as well as providing and saving the dynamic and static movements of the pupil, helping to predict those patients at risk. This is the first study evaluating the pupil measurement results of Schwind Sirius Multifunctional diagnostic device, since the Pub-Med search did not reveal any other similar paper. Further controlled studies comparing the device with other infrared pupillometers in larger series along with its assessment of repeatability and reproducibility are required.

CONCLUSION

In this study, myopes were found to have larger pupil diameters than emmetropes. Mean pupil diameters were significantly different for each of the light conditions in both groups. Although it may not be considered the only or the primary factor for night induced vision problems encountered after refractive surgery, the importance of large pupil diameter is clear. Pupil diameter measurements obtained under standardized illumination levels are essential before refractive surgery in order to consider and eliminate the probability of night-vision problems related to pupil diameter.

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