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Relationships Between Haloes and Objective Visual Quality in Healthy Eyes

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Purpose: To determine the normal values and relationships between haloes and objective optical quality in healthy eyes.

Methods: In this cross-sectional study, haloes, pupillary responses to light, and objective optical quality were measured with the optical quality analysis system (OQAS) and a vision monitor (MonCv3) in 138 right eyes of 138 healthy young men with mean spherical equivalent of 0.32 ± 0.47 D.

Results: The mean disc halo size was 77.17 ± 25.03 arcmin. The mean objective optical quality values were as follows: objective scatter index (OSI), 0.58 ± 0.33; Strehl ratio (SR), 0.21 ± 0.05; modulation transfer function cutoff, 36.27 ± 7.98 cpd; OQAS value (OV)100%, 1.21 ± 0.27; OV20%, 0.91 ± 0.23; and OV9%, 0.59 ± 0.16. Disc halo size correlated independently with OSI ($P < 0.001$) and minimum pupil size ($P = 0.003$) by forward stepwise regression analysis (disc halo size = 16.60 + 26.24 × OSI + 11.34 × minimum pupil size; R^2 value = 17.7%; F = 14.52; $P < 0.001$).

Conclusions: Reference values for disc halo size and objective optical quality in healthy young subjects were established. Eyes with worse objective vision quality exhibited larger haloes.

Translational Relevance: The study provided the knowledge and the relationships of OQAS and halo measurements from a well-defined group of healthy young subjects. Both measurements are useful in clinical practice to help quantify the vision quality and complement each other.

Introduction

Haloes develop when a strong light source produces a veiling light over the retina.[1–3] Haloes can compromise aspects of daily life, such as driving, especially at night. Complaints about haloes commonly occur after cataract and refractive surgeries.[4–8] However, haloes exist before the surgeries without any complaints.[9] For refractive and cataract patients to be adequately informed about postoperative haloes, a preoperative haloes measurement may be an option. It has been previously suggested that haloes are ubiquitous among myopes before refractive surgeries with optical correction and vary with degree of myopia,[9] which raises the question about whether healthy young eyes also exhibit haloes.

Haloes are generated by forward scattering, which refers to the diffusion of light by the various components of the eye.[1–3] Theoretically, there is an association between haloes and forward scattering (objective optical quality). However, there is some controversy.[3,6] Whether there is a relationship between the widely used forward scattering measurement—the optical quality analysis system (OQAS) and the MonCv3 vision monitor, which is able to measure haloes objectively and accurately with good repeatability[10]—remains to be elucidated. Whether OQAS can replace MonCv3 in testing for haloes requires further investigation.

In the current study, we evaluated the normal halo values and relationships between disc halo size and objective optical quality in healthy young subjects.

Methods

Ethical Considerations

This study was conducted in accordance with the tenets of the Declaration of Helsinki and was approved by the ethics committee. Informed consent was obtained from all subjects.

Subjects

Subjects were enrolled in this cross-sectional study between April 2018 and June 2018 in the Air Force Medical Center. Inclusion criteria included an age of 17 to 20 years, men, spherical equivalent within ± 1.5 D, and a corrected distance visual acuity (CDVA) of 20/20 or better. Subjects with any systemic disease, a history of ocular surgery or trauma, or a history of any ocular disease other than refractive error were excluded.

Measurements

Haloes, pupillary responses to light, and the objective optical quality were measured using the MonCv3 vision monitor (Metrovision, Pérenchies, France) and the OQAS (OQAS-II, Visiometrics, Terrassa, Spain), which were operated by an experienced technician. OQAS is able to correct any spherical refractive errors less than 8.00 D automatically, whereas halo measurement uses optotypes corresponding to a visual acuity of 20/60. Because the use of lens can influence both measurements, refractive error was not corrected in this study.

During the measurements of haloes, the subjects were seated 2.5 m in front of the machine, as described previously.[11–13] A luminance of 5 cd/m^2, which is suitable for normal individuals, was chosen to test haloes in this study.[10] There were 3 radial lines of 10 letters appearing from the periphery toward the light source on the screen; 10 letters forming 10 rings at intervals of 30 arcmin. The subjects were instructed to read the letters, starting farthest from the light source to the nearest. The visual angle formed by the radius of the haloes was calculated in arcmin.

Dynamic responses to light flashes were automatically recorded by a high-resolution near-infrared sensor at a speed of 30 images/s. White light was flashed in both eyes for a duration of 90s (200 ms of stimulation on time, 3300 ms of stimulation off time, 100cd/m^2 of total luminance and 20cd·s/m^2 of total intensity). The parameters assessed were amplitude, latency, duration, and velocity of contraction; latency, dilation, and velocity of dilation; and initial, maximum, minimum, and average pupil sizes.

OQAS testing was performed as described by Miao et al.[11] The system directly provided objective scatter index (OSI), modulation transfer function cutoff frequency (MTFcutoff), Strehl ratio (SR), and the OQAS values (OV) at contrasts of 100%, 20%, and 9% (OV100%, OV20%, and OV9%) using the acquired double-pass retinal images.[12] These parameters provide the combined effect of light scatter and optical aberrations information about visual quality. OSI was computed as the ratio of the amount of light within an specific luminance level annular area of 12 to 20 arcmin and that recorded within 1 arcmin of the central peak of point spread function (PSF).[13] The OSI reflects the degree of scattering caused by the loss of transparency in the cornea or lens. The MTF cutoff was that corresponding to a modulation transfer function (MTF) value of 0.01, because there is a certain background noise in the MTF profile. SR is an expression of the ratio between the volume under the MTF curve of the measured eye and a corresponding aberration-free one. OV100%, OV20%, and OV9% are normalized values of spatial frequencies that correspond to MTF values of optical quality for three contrast conditions of 100%, 20% and 9%. Scotopic pupil size was measured to the nearest 0.1 mm using the auto-refractokeratometer (NIDEK ARK-510A) in a dark room.[14]

Statistical Analyses

All statistical analyses were performed using the Statistical Package for Social Sciences software (SPSS, Version 22; IBM, Armonk, NY, USA). Data derived from the right eye of each subject were used for analyses. The Spearman and Pearson tests were used to assess relationships between the variables. Forward stepwise regression analysis was used to assess the contributions of variables to disc halo size and OSI.

Table 1. Demographic Data (n = 138)

Parameters	Mean	SD	Min	Max
Age (years)	18.25	0.77	17.00	20.00
SE (retinoscopy) (D)	0.32	0.47	−0.50	1.50
SE (OQAS) (D)	−0.06	0.57	−1.50	1.25

D, diopters; SE, spherical equivalent.

In all tests, $P < 0.05$ was deemed to indicate statistical significance.

Results

The study included 138 right eyes of 138 healthy young subjects. The demographic characteristics of the subjects are shown in Table 1.

Table 2 shows the data of haloes, pupil parameters, and objective optical quality. The mean disc halo size was 77.17 ± 25.03 arcmin. In 60.9% (84/138) of eyes, disc halo size was > 60 arcmin. The mean objective optical quality values were as follows: OSI, 0.58 ± 0.33; SR, 0.21 ± 0.05; MTF cut-off, 36.27 ± 7.98 cpd; OV100%, 1.21 ± 0.27; OV20%, 0.91 ± 0.23; and OV9%, 0.59 ± 0.16.

The results of correlational analyses of age, spherical equivalent, pupillary response to light, and objective optical quality are shown in Table 3. Disc halo size correlated significantly with OSI ($r = 0.346$; $P < 0.001$), SR ($r = −0.314$; $P < 0.001$), MTF cutoff ($r = −0.313$; $P < 0.001$), and minimum pupil size in pupillary response to light ($r = 0.258$; $P = 0.002$). There were no significant associations between disc halo sizes, OSI, SR, or MTF cutoff and pupil parameters (scotopic pupil; amplitude, latency, duration, and velocity of contraction; latency, duration, and velocity of dilation; initial, minimum, average, and maximum pupil sizes) ($P > 0.05$).

Independent variables for multiple linear regression analysis were identified by forward stepwise regression. Disc halo size correlated independently with OSI ($P < 0.001$) and minimum pupil size ($P = 0.003$) (disc halo size = 16.60 + 26.24 × OSI + 11.34 × minimum pupil size; R^2 value = 17.7%; $F = 14.52$; $P < 0.001$). OSI correlated independently with SR ($P < 0.001$), OV100% ($P < 0.001$), OV20% ($P = 0.002$), and disc halo size ($P = 0.004$). OSI could be predicted by a linear combination of SR, OV100%, OV20%, and disc halo size (OSI = 1.685 − 4.546 × SR − 1.004 × OV100% − 0.983 × OV20% + 0.02 × disc halo size; $R^2 = 63.4\%$; $F = 57.48$; $P < 0.001$).

Discussion

In clinical practice, it is common that some patients with good visual acuity may still experience haloes after an ophthalmic surgery.[15] This indicates the

Table 2. Halo, Visual Quality, and Pupil Parameters (n = 138)

Parameters	Mean	SD	Min	Max	95% CI (Lower Limit)	95% CI (Upper Limit)
Halo radius (arc minutes)	77.17	25.03	60.00	180.00	72.96	81.39
OSI	0.58	0.33	0.20	2.00	0.52	0.63
SR	0.21	0.05	0.11	0.33	0.20	0.22
MTF cutoff (cpd)	36.27	7.98	18.93	53.97	34.93	37.61
OV 100%	1.21	0.27	0.60	1.80	1.16	1.26
OV 20%	0.91	0.23	0.50	1.50	0.87	0.95
OV 9%	0.59	0.16	0.30	0.90	0.56	0.62
Initial size (mm)	6.26	0.54	5.00	7.40	6.16	6.35
Amplitude of contraction (mm)	241.06	52.44	64.00	298.00	232.23	249.89
Latency of contraction (ms)	6.67	0.77	5.22	9.70	6.54	6.80
Duration of contraction (ms)	653.96	77.69	460.00	932.00	640.88	667.03
Velocity of contraction (mm/s)	2.13	0.18	1.60	2.70	2.10	2.16
Latency of dilation (ms)	892.33	67.78	524.00	1100.00	880.92	903.74
Duration of dilation (ms)	2.44	0.49	1.58	4.39	2.36	2.52
Velocity of dilation (mm/s)	1578.29	86.79	1098.00	1738.00	1563.68	1592.90
Maximum pupil (mm)	6.75	0.55	5.20	8.00	6.66	6.84
Minimum pupil (mm)	3.98	0.52	2.90	5.10	3.89	4.07
Average pupil (mm)	5.50	0.55	4.30	7.16	5.41	5.59

D, diopters; SE, spherical equivalent.

Table 3. Correlation Analysis Between Age, Spherical Equivalent Refraction, Pupil Parameters, and Visual Quality Parameters

	Halo Radius (arc minutes)		OSI		SR		MTF Cut Off (cpd)	
Variables	R	*P*	R	*P*	R	*P*	R	*P*
Halo radius (arc minutes)	/	/	0.346**	<0.001	−0.314**	<0.001	−0.313**	<0.001
OSI	0.346**	<0.001	/	/	−0.812**	<0.001	−0.753**	<0.001
SR	−0.314**	<0.001	-0.812**	<0.001	/	/	0.820**	<0.001
MTF cut off (cpd)	−0.313**	<0.001	-0.753**	<0.001	0.812**	<0.001	/	/
Age (years)	−0.042	0.625	0.113	0.187	−0.176	0.039	−0.237*	0.005
SE (retinoscopy) (D)	−0.165	0.053	−0.128	0.133	0.122	0.153	0.105	0.221
SE (OQAS) (D)	−0.195	0.022	−0.206	0.016	0.179	0.036	0.283*	0.001
OV 100%	−0.313**	<0.001	−0.739**	<0.001	0.809**	<0.001	0.991**	<0.001
OV 20%	−0.342**	<0.001	−0.792**	<0.001	0.900**	<0.001	0.949**	<0.001
OV 9%	−0.332**	<0.001	−0.792**	<0.001	0.947**	<0.001	0.875**	<0.001
Initial diameter (mm)	0.218	0.010	−0.097	0.256	0.080	0.352	0.120	0.162
Amplitude of contraction (mm)	−0.036	0.676	0.014	0.875	0.021	0.806	0.093	0.279
Latency of contraction (ms)	−0.041	0.632	−0.109	0.205	0.090	0.292	0.099	0.250
Duration of contraction (ms)	−0.091	0.289	0.017	0.841	0.039	0.653	0.039	0.648
Velocity of contraction (mm/s)	0.136	0.110	0.036	0.674	−0.038	0.661	0.039	0.650
Latency of dilation (ms)	−0.175	0.041	−0.084	0.331	0.131	0.128	0.137	0.111
Duration of dilation (ms)	0.178	0.037	0.070	0.417	−0.083	0.333	−0.101	0.236
Velocity of dilation (mm/s)	−0.001	0.987	0.010	0.904	−0.012	0.892	0.007	0.931
Maximum pupil (mm)	0.137	0.110	−0.080	0.353	0.057	0.510	0.121	0.156
Minimum pupil (mm)	0.257*	0.002	−0.073	0.392	0.028	0.742	0.082	0.342
Average pupil (mm)	0.210	0.013	−0.116	0.177	0.057	0.508	0.118	0.167

CI=confidence interval.
*$P < 0.01$.
**$P < 0.001$.

importance of haloes measurements after surgery and even before surgery. Haloes can be measured with MonCv3 directly, and reflected by OSI with OQAS. The relationship of both measurements needs further investigation. To our knowledge, this study is the first study to assess the relationships between OQAS and haloes measurements. The reference values for disc halo size and objective optical quality were also established in healthy young subjects.

In the current study, the mean disc halo size was 77.17 ± 25.03 arcmin, and in 60.9% (84/138) of the eyes, it was > 60 arcmin. These results are similar to those reported in previously by Puell et al.[10] In the study by Puell et al.,[10] the mean disc halo size in 28 eyes of 28 patients aged 20 to 29 years was 88.4 ± 22.1 arcmin.

The mean OSI was 0.58 ± 0.33 in the present study, which is concordant with that reported previously.[11,16,17] Martinez-Roda et al.[17] investigated OSI in 178 patients with a sphere range of −6.00 to +3.00 D and astigmatism < 2 D and reported a mean OSI of 0.38 ± 0.19. Miao et al.[11] reported a mean OSI of 0.50 ± 0.39 in 28 eyes with mild myopia. The mean OSI in 20 healthy subjects with myopia no worse than −6.50 D was 0.899 ± 0.369 in a study reported by Iijima et al.[16]

In the current study, disc halo size correlated independently with OSI and minimum pupil size (disc halo size = 16.60 + 26.24 × OSI + 11.34 × minimum pupil size; R^2 value = 17.7%, F = 14.52, $P < 0.001$). Previous studies also found the relationship between optical quality parameters and haloes.[3,18] Disc halo size was measured above 60 arcmin of PSF. PSF, which represents the spatial equivalent of an impulse of a focused optical system, was used to describe objective visual quality. OSI is the ratio of the annular area of 12 to 20 arcmin to the central peak of 1 arcmin in the PSF, which was calculated though double-pass retinal image that affected by both ocular aberrations and intraocular scattering.[19]

Disc halo size was also correlated with minimum pupil size in response to light in the current study, which is consistent with Zhao et al.[9] They also found that individuals with large minimum pupil size (≥4 mm) experience more haloes than those with small minimum pupil size in 197 myopic eyes. Eyes with a larger minimum pupil receive more light and experience a higher disc halo size. Another potential impact is aberrations dependent on pupil size. Villa et al.[20] observed that corneal higher-order aberrations dependent on pupil size correlated significantly with haloes.

It has been known that aberrations have an influence on haloes. Presently, wavefront-guided, topography-based, or Q-value–guided customized ablations have been reported to reduce the occurrence of haloes compared to conventional surgeries.[17] This relationship between aberrations and haloes[20] also helps to explain our outcomes on the relationships of haloes, OSI, and minimum pupil size, since aberrations are taken into consideration together with intraocular scattering in double-pass OQAS images,[19] and aberrations change with pupil size.

Objective visual quality parameters were not significantly associated with pupillary response to light, whereas haloes demonstrated significant association. The primary reason was that OQAS was measured with an artificial pupil of 4.0 mm diameter. These observations suggest that OQAS and halo measurements evaluate vision quality independently. OQAS facilitates a more objective assessment than halo measurements, and incorporates merely optical technology,[11,12] whereas halo measurements are at least partially influenced by patient cooperation and incorporates psychophysics together with optical technology.[10] Thus the two measurements cannot replace each other. It is not surprising that OSI together with minimum pupil size could only explain 17.7% of the variation in disc halo size.

This study has a few limitations. The age range of the subjects in the present study was extremely narrow. Notably, however, vision quality can be considered to be at its peak during the ages of 17 to 20 years; thus the measurements reported herein constitute robust reference values derived from a well-defined and highly relevant age group of healthy young subjects. Another limitation of the study is that contrast sensitivity—which could have yielded additional information pertaining to visual quality—was not used.

In conclusion, although OQAS and halo measurements cannot replace each other, there is still evidence that eyes with worse objective vision quality exhibit larger haloes. Both measurements are useful in clinical practice to help quantify the vision quality and complement each other. This study also yield reference values of disc halo size and objective optical quality from a well-defined group of healthy young subjects.

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