Analysis of related factors of optical quality in healthy Chinese adults: a community-based population study

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Abstract

Background: In recent years, visual quality has been extensively investigated in various conditions. In this community-based population study, we analyzed the effects of aging, refraction, and Lens Opacification Classification System III (LOCSIII) score on retinal imaging quality in healthy Chinese adults.

Methods: This cross-sectional study was conducted on sub-group subjects from The Handan Eye Study between October 2012 and January 2013. Healthy subjects over 30-years-old with logarithm of the minimal angle of resolution (logMAR) best-corrected visual acuity (BCVA) less than 0 were included. Retinal image quality was measured by optical quality analysis system (OQAS) and recorded as modulation transfer function cutoff frequency (MTF_{cutoff}), OQAS value (OV) 100%, OV20%, OV9%, Strehl ratio (SR), and objective scatter index (OSI). The correlation between age, spherical equivalent refraction (SE), LOCSIII score, and optical quality parameters were investigated by multivariate analysis.

Results: Among 1108 verified subjects, 690 subjects (1380 eyes) met the inclusion criteria. Their age ranged from 30 to 76 years, SE ranged from −4.75 to 2.75 D. They were divided into five age groups (30–39, 40–49, 50–59, 60–69, and ≥70 years) for further analysis. After multivariate analysis by mixed-effect linear model, SR ($t = -3.03$, $P = 0.002$), OV20% ($t = -2.39$, $P = 0.017$), and OV9% ($t = -3.16$, $P = 0.001$) significantly decreased with the increasing age, whereas logMAR BCVA ($t = 4.42$, $P < 0.001$) and OSI ($t = 4.46$, $P < 0.001$) significantly increased with age. As SE increased, SR ($t = 2.74$, $P = 0.01$), OV20% ($t = 2.31$, $P = 0.02$), and OV9% ($t = 2.79$, $P = 0.005$) significantly elevated, and OSI ($t = -3.38$, $P < 0.001$) significantly decreased. With the increase in cortical opacity score, all optical quality parameters except for SR significantly decreased, including MTF_{cutoff} ($t = -2.78$, $P = 0.01$), OV100% ($t = -2.78$, $P = 0.005$), OV20% ($t = -2.60$, $P = 0.009$), and OV9% ($t = -2.05$, $P = 0.04$). As posterior sub capsular opacity score increased, MTF_{cutoff} ($t = -2.40$, $P = 0.02$) and OV100% ($t = -2.40$, $P = 0.01$) significantly decreased, while OSI ($t = 7.56$, $P < 0.001$) significantly increased.

Conclusions: In healthy Chinese adult population, optical quality-related parameters significantly decrease with the increasing age, and OSI significantly increases with age. In normal BCVA subjects, optical quality is significantly impacted by cortical and posterior sub capsular opacity rather than by nuclear opacity.

Keywords: Cross-sectional study; Prospective study; Vision; Aging; Refractive errors; Cataract

Introduction

Optical quality has been extensively investigated since the commercialization of a new clinical instrument based on the double-pass technique (optical quality analysis system II [OQAS II]; Visiometrics, Terrassa, Spain).[1-3] This objective and quantitative approach has been utilized in various studies to investigate retinal image quality and intraocular scattering. Several simplified indexes have been applied in clinical practice, including modulation transfer function cutoff frequency (MTF_{cutoff}), Strehl ratio (SR), OQAS values (OV) at different contrasts (100%, 20%, and 9%), and objective scatter index (OSI). The principles and usage of these indexes have been stated in previous studies.[2,4]

In previous studies, significant negative correlations between age and optical quality-related parameters in healthy individuals have been reported, as well as a significant positive correlation between age and intraocular scattering.[1,2] However, these studies are not population-based, with a relatively small sample size.

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It is known that in cataract patients, different types of lens opacity have different impacts on MTF_{cutoff}, SR, OSI, and contrast sensitivity.[5-9] Therefore, it is helpful to understand the potential effect of cataract on optical quality by analyzing the correlation between different types of lens opacity and various optical quality parameters in a large normal population. In our previous study, we have established the normal range of optical quality in a healthy Chinese adult population aged 30 to 70 years.[10] On that basis, this study aimed to analyze the effects of aging, refraction, and Lens Opacification Classification System III (LOCSIII) score on retinal imaging quality in a healthy Chinese adult population.

Methods

Ethical approval

The study followed the tenets of the *Declaration of Helsinki* and the study protocol was approved by the Beijing Tongren Hospital Ethics Committee (No. TREC2006-22). Written informed consent was obtained from each participant before examinations.

Participants

The Handan Eye Study (HES) is a population-based cross-sectional study involving 6830 participants, aged 30 years or older, representative of rural Chinese populations. The methods employed in the HES have been described in detail elsewhere.[11] This prospective study was conducted based on the sub-group subjects from two administrative villages (ZD and YSL) in the HES between October 2012 and January 2013.

Procedures

All participants underwent comprehensive examinations according to study protocols in the HES,[11] including physical examination, autorefraction, and subjective refraction, visual acuity testing, intraocular pressure measurement (applanation tonométer HA-2; Kowa Company Ltd., Tokyo, Japan), slit-lamp examination, dilated fundus examination, visual field test (Humphrey Visual Field Analyzer 750i; Carl Zeiss, Jena, Germany) and lens opacity grading using the LOCSIII grading system.[12] Physical examination included measurement of height and weight, blood pressure, electrocardiogram, fasting blood glucose, lipid levels, urea nitrogen, and creatinine as well as tests of physical function including walking speed. Visual acuity was tested using a logarithmic visual acuity chart (Precision Vision, La Salle, IL, USA). Best-corrected visual acuity (BCVA) was acquired by a trained optometrist based on readings from Auto refractor-Keratometer (KR8800; Topcon, Tokyo, Japan). The LOCSIII was employed to grade lenticular opacity by slit-lamp microscopy after pupil dilation by reference to the standard photos.[13] Lens opacities were graded using scores ranging from 0.1 (least cataract) to 6.9 for nuclear opacity and nuclear color, and 0.1 to 5.9 for cortical and posterior sub capsular opacity.

The inclusion criteria were as follows, (1) subjects from two administrative villages (ZD and YSL) who participated in the HES 5 years ago, (2) subjects with logMAR BCVA of 0.0 or better, and (3) participants in good physical and mental status. The exclusion criteria were as follows, (1) subjects with any history of eye disease or eye surgery, (2) participants with vitreous or corneal opacity that might potentially impair ocular transparency, (3) those with spherical error >5.0 or <-6.0 D or astigmatism >0.5 D, (4) subjects who had moved from the given home address, had not lived in the village over the past 6 months, were deceased or terminally ill (life expectancy less than 3 months, decided by the village doctors).

The OQASII (Visiometrics) was employed to measure retinal image quality parameters and intraocular scattering of each eye, based on the double-pass technique. Near-infrared light (wavelength 780 nm) was utilized since it was more comfortable for subjects and provided comparable retinal image quality to that acquired with visible light. All measurements were performed by experienced technicians under the mesopic condition with a 4.0-mm artificial pupil. Participants' refractive error was corrected before measurements. Spherical refractive error was automatically corrected by the double-pass system, and astigmatism over 0.50 D was corrected with an external cylindrical lens. The MTF_{cutoff}, SR, OV (at 100%, 20%, and 9% contrasts) and OSI were obtained. Three consecutive measurements were obtained for each parameter for each eye to acquire the mean value. Patients were asked to close their eyes for 30 s before the scan, to maintain an intact tear film during the scan.

Statistical analysis

Statistical analyses were performed using the SAS software version 9.1.4 (SAS Institute Inc., Cary, NC, USA). Data that did not show normality was presented as median (interquartile range, IQR). The normality of each parameter was evaluated by Shapiro-test, and a P value >0.05 was considered as normally distributed. The comparison of BCVA in each age group was performed by the Kruskal-Wallis test. The correlations of BCVA, optical quality parameters, and OSI with equivalent spherical, age, and lens opacity scores were assessed using Spearman correlation coefficients and shown as scatterplot matrix. For regression analysis, multivariate analysis was performed using a mixed-effect linear model to explore whether BCVA, optical quality parameters, and OSI were affected by equivalent spherical, age, and lens opacity scores. Generally, in statistical analysis, one person's data will be used once. When we encounter binocular data, the data of the same person will be included twice. Because the data of one person's two eyes are related (this is different from the conventional data: the data of two different persons are completely unrelated), this kind of correlation must be processed. The statistical method to deal with this kind of correlation is usually the mixed effect linear model. All P values were two-sided and were considered as statistically significant when <0.05.

Results

One thousand one hundred and eight out of the 1791 subjects from ZD and YSL villages (Yongnian County,

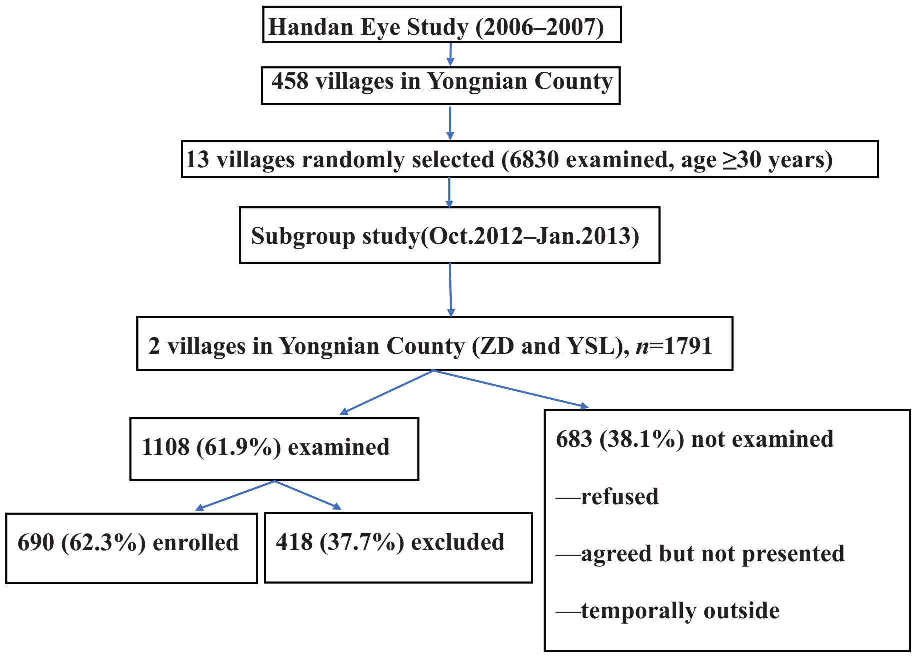

Figure 1: Flowchart of participant enrollment of this research (outlined boxes) and the relationship with Handan Eye Study.

Table 1: Distribution of lens opacity score among all subjects (1380 eyes) according to Lens Opacification Classification System III.

Score	Nuclear opalescence	Nuclear color	Cortical opacities	Posterior sub capsular opacities
0–1.9	0 (0)	0 (0)	1334 (96.66)	1379 (99.91)
2.0–2.9	904 (65.49)	903 (65.42)	28 (2.03)	1 (0.07)
3.0–3.9	456 (33.05)	457 (33.12)	17 (1.23)	0 (0)
4.0–4.9	18 (1.30)	18 (1.30)	1 (0.07)	0 (0)
5.0–5.9	2 (0.14)	2 (0.14)	0 (0)	0 (0)
6.0–6.9	0 (0)	0 (0)	–	–

Data are presented as *n* (%);–: No data.

Handan City, Hebei Province, China) participated in the study. According to the inclusion criteria, 690 subjects (1380 eyes) were enrolled in the present study [Figure 1]. Three hundred and thirty-six subjects (48.7%) were male and 354 subjects (51.3%) were female. The age of these participants ranged from 30 to 76 years. The equivalent spherical ranged from −4.75 to 2.75 D. They were divided into five age groups (including 30–39, 40–49, 50–59, 60–69, and ≥70 years) for further age-stratified sub-group analysis. The same approach has been used by other authors to examine visual function changes with ageing.[3,14,15] Distribution of lens opacity score of all subjects according to LOCSIII is shown in Table 1. The median and interquartile range (Q1–Q3) of equivalent spherical, BCVA, optical quality parameters, and OSI in each age group are shown in Table 2. By the Kruskal-Wallis test, BCVA was significantly different among age groups ($H = 60.535$, $P < 0.001$). After pairwise comparisons, BCVA in 30 to 39 years age group was significantly better than 40 to 49, 50 to 59, and 60 to 69 years groups ($P < 0.001$), and was also better than >70 years age group ($P = 0.010$). BCVA in 40 to 49 years age group was significantly better than 60 to 69 years age group ($P = 0.004$). The difference between other age groups was not significant ($P > 0.05$).

As shown in Table 1, most subjects had low lens opacity scores representing none to mild cataract. A scatterplot matrix was drawn to show the correlation between the analyzed variables [Figure 2]. Although the correlation of each variable is directly shown in the scatterplot matrix, regression analysis was necessary to explore the exact correlation between each variable. In order to avoid the effect of binocular data, the mixed-effect linear model was applied in multivariate analysis afterwards, the results of the mixed-effect linear model are shown in Table 3. Several factors, including age, equivalent spherical, cortical opacity, and posterior sub capsular opacity, significantly affected BCVA, optical quality parameters, and intraocular scattering index. SR ($t = -3.03$, $P = 0.002$), OV20% ($t = -2.39$; $P = 0.017$), and OV9% ($t = -3.16$, $P = 0.001$) significantly decreased with the increasing age, whereas logMAR BCVA ($t = 4.42$, $P < 0.001$) and OSI ($t = 4.46$, $P < 0.001$)

Table 2: Equivalent spherical, best-corrected visual acuity, optical quality parameters, and objective scatter index in each age group.

Age (years)	Eyes	SE (D)	logMAR BCVA	MTF_{cutoff} (cpd)	Strehl ratio	OV100%	OV20%	OV9%	OSI
30–39	146	0 (−0.28 to 0)	0 (0–0)	37.53 (28.24–44.37)	0.20 (0.16–0.24)	1.25 (0.94–1.47)	1.22 (0.92–1.49)	1.19 (0.91–1.41)	0.60 (0.40–0.80)
40–49	586	0 (−0.25 to 0)	0 (0–0)	37.06 (29.75–43.82)	0.19 (0.16–0.22)	1.23 (0.98–1.45)	1.19 (0.95–1.42)	1.13 (0.91–1.38)	0.60 (0.40–0.80)
50–59	440	0 (−0.25 to 0.12)	0 (0–0)	36.67 (31.06–43.34)	0.18 (0.15–0.22)	1.21 (1.01–1.44)	1.18 (0.94–1.42)	1.08 (0.86–1.35)	0.60 (0.50–0.90)
60–69	190	0 (−0.12 to 0.75)	0 (0–0)	32.36 (25.23–39.50)	0.16 (0.13–0.21)	1.07 (0.82–1.30)	1.00 (0.79–1.27)	0.96 (0.75–1.23)	0.85 (0.60–1.20)
≥70	18	0.12 (−0.12 to 1.31)	0 (0–0)	27.82 (22.00–36.25)	0.15 (0.12–0.17)	0.92 (0.73–1.20)	0.86 (0.70–1.04)	0.82 (0.64–1.01)	1.05 (0.87–1.40)

Data are shown as *n* or median (interquartile range, IQR). SE: Spherical equivalent refraction; logMAR: Logarithm of the minimal angle of resolution; BCVA: Best-corrected visual acuity; MTF_{cutoff}: Modulation transfer function cutoff frequency; cpd: Cycles per degree; OV: Optical quality analysis system values; OSI: Objective scatter index.

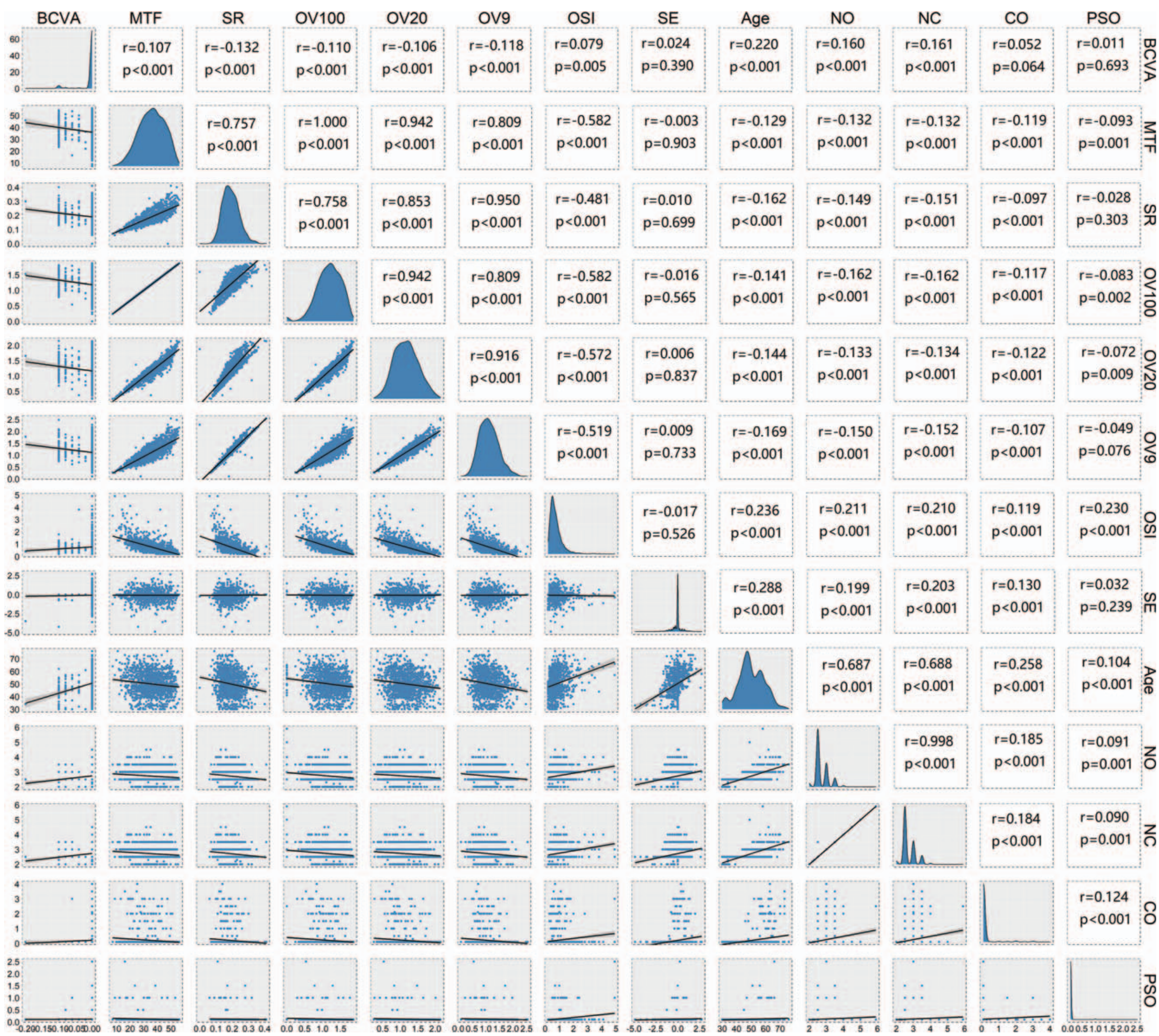

Figure 2: Scatterplot matrix showing the associations between logMAR BCVA, MTF_{cutoff}, SR, OV100%, OV20%, OV9%, OSI, SE, age, NO, NC, CO, and PSO. BCVA: Best-corrected visual acuity; CO: Cortical opacities score; logMAR: Logarithm of the minimal angle of resolution; MTF_{cutoff}: Modulation transfer function cutoff frequency; NC: Nuclear color score; NO: Nuclear opalescence score; OSI: Objective scatter index; OV: Optical quality analysis system values; PSO: Posterior sub capsular opacities; SE: Spherical equivalent refraction; SR: Strehl ratio.

Table 3: Effects of aging, equivalent spherical, and LOCSIII score on BCVA, optical quality parameters, and OSI.

Dependent variable	Independent variable	β	Standard error	t	P
logMAR BCVA	SE	−0.002	0	−1.41	0.16
	NO	−0.001	0.02	−0.06	0.95
	NC	0.002	0.02	0.11	0.91
	CO	−0.001	0	−0.73	0.46
	PSO	−0.003	0	−0.74	0.46
	Age	0.001	0	4.42	<0.001
MTF_{cutoff}	SE	0.837	0.46	1.83	0.07
	NO	2.163	9.03	0.24	0.81
	NC	−3.794	9.04	−0.42	0.67
	CO	−1.662	0.60	−2.78	0.01
	PSO	−4.889	2.04	−2.40	0.02
	Age	−0.081	0.05	−1.75	0.08
SR	SE	0.007	0	2.74	0.01
	NO	0.058	0.05	1.20	0.23
	NC	−0.066	0.05	−1.35	0.18
	CO	−0.007	0	−2.00	0.05
	PSO	−0.004	0.01	−0.37	0.71
	Age	−0.001	0	−3.03	0.002
OV100%	SE	0.027	0.2	1.83	0.06
	NO	0.072	0.30	0.24	0.81
	NC	−0.126	0.30	−0.42	0.67
	CO	−0.055	0.02	−2.78	0.005
	PSO	−0.163	0.07	−2.40	0.01
	Age	−0.002	0	−1.75	0.08
OV20%	SE	0.038	0.2	2.31	0.02
	NO	0.207	0.32	0.64	0.52
	NC	−0.254	0.32	−0.79	0.43
	CO	−0.056	0.02	−2.60	0.009
	PSO	−0.133	0.07	−1.82	0.06
	Age	−0.004	0	−2.39	0.017
OV9%	SE	0.025	0	2.79	0.005
	NO	0.204	0.17	1.17	0.24
	NC	−0.226	0.17	−1.29	0.19
	CO	−0.024	0.01	−2.05	0.04
	PSO	−0.051	0.04	−1.31	0.19
	Age	−0.002	0	−3.16	0.001
OSI	SE	−0.081	0.02	−3.38	0.001
	NO	0.266	0.45	0.59	0.56
	NC	−0.183	0.45	−0.41	0.68
	CO	0.055	0.03	1.75	0.08
	PSO	0.788	0.10	7.56	<0.001
	Age	0.011	0	4.46	<0.001

This multivariate analysis was performed using a mixed-effect linear model. LOCS: Lens Opacification Classification System; BCVA: Best-corrected visual acuity; OSI: Objective scatter index; logMAR: Logarithm of the minimal angle of resolution; SE: Spherical equivalent refraction; NO: Nuclear opalescence score; NC: Nuclear color score; CO: Cortical opacities score; PSO: Posterior sub capsular opacities; MTF_{cutoff}: Modulation transfer function cutoff frequency; SR: Strehl ratio; OV: Optical quality analysis system values.

significantly increased with age. As SE increased, SR ($t = 2.74$, $P = 0.01$), OV20% ($t = 2.31$, $P = 0.02$), and OV9% ($t = 2.79$, $P = 0.005$) significantly elevated, and OSI ($t = -3.38$, $P = 0.001$) significantly decreased. With the increase in cortical opacity score, all optical quality parameters except for SR significantly decreased, including MTF_{cutoff} ($t = -2.78$, $P = 0.01$), OV100% ($t = -2.78$, $P = 0.005$), OV20% ($t = -2.60$, $P = 0.009$), and OV9% ($t = -2.05$, $P = 0.040$). As posterior sub capsular opacity score increased, MTF_{cutoff} ($t = -2.40$, $P = 0.02$) and OV100% ($t = -2.40$, $P = 0.01$) significantly decreased, while OSI ($t = 7.65$, $P < 0.001$) significantly increased.

Discussion

Optical quality has gained more and more concern as people's demand to see clearly is gradually increasing. As suggested by findings in the present study, in healthy Chinese adult population in rural areas of northern China, optical quality parameters (including SR, OV20%, and OV9%) significantly decreased with the increase in age, while OSI significantly elevated with age. In normal BCVA subjects, optical quality is significantly impacted by cortical and posterior sub capsular opacity rather than by nuclear opacity. Although our conclusion was not distinctive, the result of our study can help the ophthalmic practitioner understand the importance of optical quality in the early-cataract patient, especially when their visual acuity was normal but still having visual complaints.

Previous researches have reported the phenomenon of decreased optical quality with age.[1-3] In agreement with previous studies, our research showed that optical quality parameters (including SR, OV20%, and OV9%) significantly decreased with age, while OSI significantly elevated with age. Martínez-Roda and colleagues reported the reference values for optical quality and OSI among 198 volunteers aged 31 to 70 years in Spain.[1] The overall optical quality of our subjects in each same age group was better than their subjects'. Such discrepancy might be caused by the different inclusion criteria concerning BCVA used in this study. In their study, subjects with BCVA better than 16/20 were enrolled, on the contrary, subjects with logMAR BCVA ≤ 0 were included in this study. Another possible reason may be that the dark-eyed individuals have less intraocular scattering compared with the blue-eyed individuals due to the darker pigmentation of the iris and choroid and subsequently more light absorption.[16]

Different types of cataracts may make different contributions to ocular scattering.[6-8] Similar to the study by Cabot and his colleagues, OSI and MTF_{cutoff} were significantly correlated with the severity of all types of cataracts (including nuclear, cortical, and posterior sub capsular cataract), as revealed by Spearman correlation coefficients calculation.[6] However, in our study, MTF_{cutoff} and OSI were not significantly correlated with nuclear opalescence or nuclear color after a mixed-effect linear model test. On the contrary, cortical opacity scores were correlated with the degradation of optical quality parameters including MTF_{cutoff}, OV100%, OV20%, and OV9%. Meanwhile, posterior sub capsular opacity scores were correlated with the degradation of MTF_{cutoff} and OV100%, as well as the elevation of OSI. By contrast, nuclear opalescence and nuclear color did not significantly affect optical quality.

The scattering of the eye can be divided into light scattered toward the retina (forward scatter) and light scattered backward (backscatter). It is known that nuclear opacity is optically more regular than cortical and posterior sub capsular opacity, and is associated with higher backscatter rather than forward scatter. On the contrary, posterior sub capsular opacity produces more forward scatter compared with nuclear and cortical cataracts.[17] The forward scatter has been well recognized to have functional importance,[8] and the double-pass technique is proposed to estimate the contribution of forward scattering that affects vision. In addition, it has been pointed out that in patients with visual acuity worse than 20/40, visual acuity and OSI are correlated with the severity of sub capsular posterior cataract, but not with the severity of nuclear opalescence or nuclear color.[6] In cataractous eyes, compared with nuclear cataracts, cortical cataracts are likely to rapidly and strongly affect optical quality.[5] Our result implied that in healthy Chinese adult population with normal BCVA, the optical quality was potentially impacted by cortical and posterior sub capsular lens opacity, but not by nuclear opacity. As a sensitive index, OSI was also significantly affected by posterior sub capsular opacity. In conclusion, more attention should be paid to cortical and posterior sub capsular lens opacity, even in normal BCVA subjects, as they may potentially cause optical quality degradation.

In our study, with the increase in equivalent spherical (range, −4.75 to 2.75 D), SR, OV20%, and OV9% significantly increased, while OSI significantly decreased. As reported by previous studies, people aged around 40 to 65 years have a hyperopic shift, while those aged over 70 years have a myopic shift over time.[18,19] Myopic shift is associated with nuclear opalescence and change in lens power.[15] Participants with moderate cortical opacity (like our subjects) are more likely to have a hyperopic shift than those with severe cortical opacity who are more likely to have a myopic shift. In this study, we acquired double-pass images of every eye at best focus, and spherical refractive error was automatically corrected by the double-pass system internally (from −8.00 to +6.00 D).[5,6] However, mild and moderate myopia (range, −4.75 to 0 D) tends to show better optical quality and less intraocular scattering than those of mild hyperopia (range, 0 to 2.75 D). It is known that with the increase in refractive power, the high-order aberrations (such as coma, trefoil, and spherical aberration) also increase. Besides, although low-order aberrations are corrected in advance by the OQAS system, the acquired retinal image contains information about both high-order aberrations and intraocular scattering.[20] There is no consensus on the correlation of refractive error with high-order aberrations among different studies. Several studies find that spherical aberrations are higher in hyperopic eyes than in emmetropic and myopic eyes, but others report no significant difference in high-order aberrations among emmetropic, hyperopic, and myopic eyes after adjusting for age.[21-23] The discrepancy among these studies may be related to the different subject groups, measurement techniques, and data analyses.

The strengths of the present study included a population-based survey among normal BCVA Chinese adults. However, several limitations should be noted. First, only few subjects with LOCS III nuclear score over 4 were enrolled. In previous studies concerning age-related optical quality changes, the age-related lens changes are acceptable, especially for nuclear sclerotic changes.[1] All of our enrolled subjects had logMAR BCVA ≤ 0; thus, it was reasonable to believe that our results might reflect the normal Chinese population with a wide range of age. Another notable limitation was the use of data from bilateral eyes. Data from paired eyes are likely to be correlated, except in asymmetric disease.[24] Some authors attempt to avoid this problem by measuring one eye only, but this procedure can result in the loss of statistical power.[25-26] In this study, to avoid the effect of binocular data, a mixed-effect linear model was adopted in multivariate analysis conducted by an experienced statistician. Finally, tear film integrity also affects optical quality. However, in this study, we did not perform a tear film stability test. Instead, the participants were asked to close their eyes for 30 s before the scan, to maintain an intact tear film. Furthermore, chromatic discrimination may also affect visual performance, and its influence on optical quality should be addressed in further study.

In conclusion, present results indicate that, in healthy Chinese adult population, optical quality parameters (including SR, OV20%, and OV9%) significantly decreased with the increase in age, and OSI significantly increases with age. In normal BCVA subjects, optical quality is significantly impacted by cortical and posterior sub capsular opacity rather than by nuclear opacity.

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Conflicts of interest

None.

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