Anatomy and Pathology/Oncology

Prevalence and Associations of Fundus Tessellation Among Junior Students From Greater Beijing

Yin Guo,[1] Lijuan Liu,[2] Deqiang Zheng,[3,4] Jiali Duan,[5] Youxin Wang,[3,4] Jost B. Jonas,[6] Feifei Tian,[3,4] Shuo Wang,[3,4] Yujian Sang,[3,4] Xiaoyu Zhang,[3,4] Weijie Cao,[3,4] Jinxia Zhang,[3,4] Ming Sun,[3,4] Qiuyue Tian,[3,4] Xiaoni Meng,[3,4] Xiuhua Guo,[3,4] and Lijuan Wu[3,4]

[1]Tongren Eye Care Center, Beijing Tongren Hospital, Capital Medical University, Beijing, China
[2]Beijing Institute of Ophthalmology, Beijing Tongren Hospital, Capital Medical University, Beijing, China
[3]Department of Epidemiology and Biostatistics, School of Public Health, Capital Medical University, Beijing, China
[4]Municipal Key Laboratory of Clinical Epidemiology, Beijing, China
[5]Beijing Center for Disease Prevention and Control, Beijing, China
[6]Department of Ophthalmology, Medical Faculty Mannheim of the Ruprecht-Karls-University Heidelberg, Mannheim, Germany

Correspondence: Lijuan Wu, Department of Epidemiology and Biostatistics, School of Public Health, Capital Medical University, Beijing 100069, China; wujuan811017@163.com.

Submitted: April 21, 2019
Accepted: August 20, 2019

Citation: Guo Y, Liu L, Zheng D, et al. Prevalence and associations of fundus tessellation among junior students from greater Beijing. *Invest Ophthalmol Vis Sci*. 2019;60:4033–4040. https://doi.org/10.1167/iovs.19-27382

Purpose. To determine the prevalence of fundus tessellation and associations with ocular and systemic parameters among junior students from Greater Beijing.

Methods. The school-based study included 1443 individuals with a mean age of 12.4 ± 0.5 years (range: 9–16 years). All participants underwent a comprehensive ophthalmic examination and an interview. Fundus tessellation, defined as variation in the visibility of large choroidal vessels, was differentiated into three grades.

Results. The prevalence and degree of fundus tessellation were 688/1430 (48.1%; 95% confidence intervals [CI]: 45.5%, 50.7%) and 0.54 ± 0.61 (median, 0.00; range, 0–3), respectively. In multivariable regression analysis, a higher degree of fundus tessellation was associated with reduced subfoveal choroidal thickness ($P < 0.001$; beta, −0.02; odds ratio [OR], 0.98; 95% CI: 0.98, 0.99) and longer axial length ($P < 0.001$; beta, 0.23; OR, 1.25; 95% CI: 1.10, 1.43). Subfoveal choroidal thickness decreased from 299 ± 61 μm (95% CI: 293, 304) in eyes without fundus tessellation to 246 ± 57 μm (95% CI: 241, 251), 197 ± 43 μm (95% CI: 187, 207), and 131 ± 30 μm (95% CI: 93, 168) in eyes with grade 1, 2, and 3 fundus tessellation, respectively. A higher degree of peripapillary fundus tessellation was associated with reduced subfoveal choroidal thickness ($P < 0.001$; beta, −0.02; OR, 0.98; 95% CI: 0.98, 0.99) and younger age at myopia onset ($P = 0.008$; beta, 0.41; OR, 1.51; 95% CI: 1.11, 2.04).

Conclusions. The prevalence of fundus tessellation is relatively high in Chinese teenagers. As in adults, the degree of fundus tessellation is a surrogate for choroidal thickness in teenagers. Marked fundus tessellation indicates a leptochoroid and is associated with earlier myopia onset.

Keywords: fundus tessellation, teenagers, epidemiology

The prevalence of myopia has markedly increased during the last decades, and approximately one out of two individuals will be affected by 2050.[1] Due to myopia-related complications including myopic maculopathy and optic nerve damage, myopia may become one of the leading causes of irreversible vision impairment worldwide.[2,3] Fundus tessellation is defined by increased visibility of the large choroidal vessels outside of the parapapillary beta zone.[4] The international classification and grading system of myopic maculopathy, as summarized by Ohno-Matsui and colleagues,[5] described fundus tessellation as category 1 of the myopic appearance of the posterior fundus. Clinical and population-based longitudinal studies with a long-term follow-up of myopic individuals demonstrated that the tessellated fundus can progress into advanced stages of myopic maculopathy, including lacquer cracks and diffuse atrophy.[6–8] For example, in the population-based Beijing Eye Study with a 10-year follow-up, 15 (19%) out of 79 highly myopic eyes with tessellated fundus at baseline developed myopic maculopathy by the end of the follow-up.[8] In addition, a higher prevalence and higher degree of fundus tessellation have been associated with a higher prevalence of primary open-angle glaucoma and age-related macular degeneration.[9–11] Thus, the clinical importance of fundus tessellation may include the role of fundus tessellation as a potential precursor of myopic maculopathy and may extend to the fields of glaucoma and age-related macular degeneration.

The location and morphologic parameters of fundus tessellation have been described in recent studies on healthy adults or on highly myopic patients, but only a few investigations have addressed the prevalence and distribution of fundus tessellation in the eyes of children.[9,12–18] Fundus tessellation may be of significance in children, particularly in China, because the ophthalmoscopic feature of fundus tessellation is associated with axial myopia, and China has witnessed a marked increase in the prevalence and severity of axial myopia in the younger generation.[1–3] In addition, it is of interest to determine whether fundus tessellation is a marker for visual performance as well as the degree and progression of myopia. Therefore, we conducted this school-based study to determine the prevalence of tessellated fundus and its

iovs.arvojournals.org | ISSN: 1552-5783

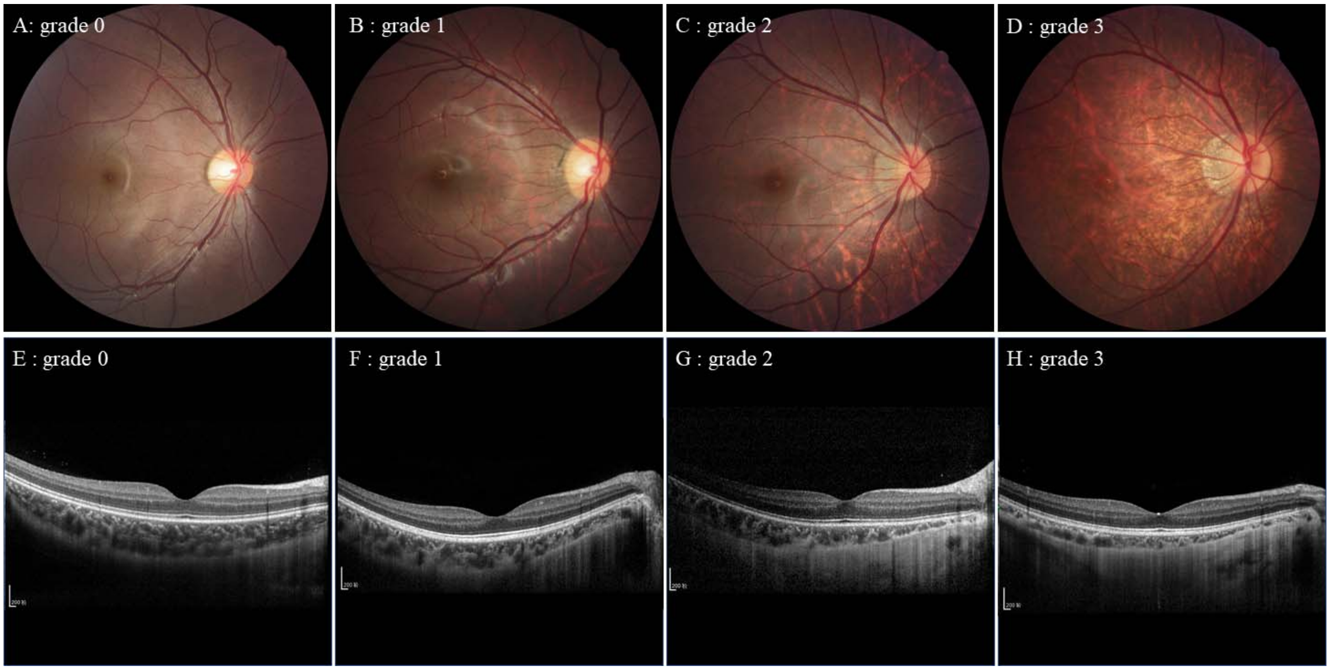

Figure 1. Assessment of fundus tessellation and choroidal thickness in the macular region. (**A–D**) Photographs of macular fundus tessellation as defined by the ophthalmoscopic visibility of the large choroidal vessels. (**E–H**) Optical coherence tomography images showing the choroidal thickness decreasing with the degree of fundus tessellation.

associations with ocular and general parameters among junior students.

Methods

The school-based study was performed in nine schools located in six urban or rural districts (Fengtai District, Changping District, Tongzhou District, Daxing District, Huairou District, and Shijingshan District) of Greater Beijing in 2017. Sampling was performed using a multistage random cluster approach. In the first step, six districts were randomly selected from all 16 districts in the rural and urban regions of Beijing. In the second step, nine schools were selected from the six districts. In a third step, all grade 1 junior students of the selected schools were sampled. The only inclusion criterion was attending the selected schools, and there was no exclusion criterion. The ethics committees of the Capital Medical University, the Beijing Municipal Commission of Education, and the Beijing Center for Disease Prevention and Control approved the study and confirmed that it followed the Declaration of Helsinki. The parents of all participants gave written informed consent. Of 1467 eligible individuals, 1443 individuals (response rate, 98.6%) participated in the survey, with a mean age of 12.4 ± 0.5 years (median, 13 years; range, 9–16 years).

The study participants underwent a comprehensive ophthalmic examination and an interview with a detailed, standardized questionnaire. The ophthalmic examinations included the measurement of uncorrected visual acuity using a retroilluminated Early Treatment Diabetic Retinopathy Study chart with tumbling-E optotypes, autorefractometry (autorefractor KR-8900; Topcon, Tokyo, Japan), slit-lamp examination of the anterior segment, biometry using optical low-coherence reflectometry (Lenstar 900 Optical Biometer; Haag-Streit, Koeniz, Switzerland), and macular and optic disc fundus photography (CR-2; Canon Inc., Tokyo, Japan). The axial length/corneal curvature radius ratio was calculated.[19] Using spectral-domain optical coherence tomography (OCT) (Spectralis; Heidelberg Engineering Co, Heidelberg, Germany) with enhanced depth imaging modality, we measured the thickness of the choroid in the subfoveal region and at a distance of 3000 μm nasally and temporally to the foveola. Choroidal thickness was measured manually from the outer portion of the hyperreflective line corresponding to the retinal pigment epithelium to the inner surface of the sclera by a trained ophthalmologist (Y.G.) using Heidelberg Eye Explorer software (version 5.3.3.0; Heidelberg Engineering Co.). Only right eyes were measured, and the data were included in the study because of the high correlation between the two eyes in refractive error (correlation coefficient *r*, 0.81).

The questionnaire as the basis of the interview was completed by all children and their parents. We assessed basic sociodemographic parameters, such as age; sex; ethnic background; region of habitation (urban/rural); and parental myopia, profession, and level of education. The questionnaire also included information regarding when myopia was first noted, outdoor activities such as how much time the children spent on outdoor activities for leisure (such as playing outdoors and walking) and on sports during the week and during the weekends, and information about the duration of class recesses. We also recorded the time spent with near work, watching television, and the amount of time spent using electronic devices. Body height and weight were measured using the ultrasonic height weight survey meter (NHN-318; Omron, Kyoto, Japan). We also calculated the body mass index as the ratio of body weight (expressed in kg) divided by the square of body height (expressed in meters).

The degree of fundus tessellation was assessed on the 45° fundus photographs centered on the macula. Referring to the study by Yan and colleagues,[8] fundus tessellation was differentiated between grade 0 for "no visibility of the large choroidal vessels outside the region of the parapapillary beta zone," grade 1 for "slight visibility," grade 2 for "moderate visibility," and grade 3 for "marked visibility" (Fig. 1).[4] The contrast, brightness, background pigmentation, and photographic quality of the images were taken into account.

Standard photographs were used to repeatedly calibrate the subjective assessment of the photographs during the examinations. The measurements were carried out by a trained ophthalmologist (Y.G.) in a masked manner and supervised by a panel of experienced ophthalmologists (L.J.L. and J.B.J.). During tessellation grading, the panel convened several times to discuss and decide upon questionable cases. To determine intraobserver variability, 1 observer (Y.G.) randomly selected the images of 100 eyes of 100 participants and graded them twice in a masked manner with an interval of 2 weeks. The intraobserver variability resulted from the variation in the measurements obtained by this observer. To determine the interobserver variability and reliability, two observers (Y.G. and L.L.J.) assessed the grading of images. The interobserver variability resulted from the fluctuations in measurements among observers. All intra- and interobserver kappa values were greater than 0.84 for the assessment of fundus tessellation in the four peripapillary regions and macular area.

For statistical analysis, we used a commercially available software package (SPSS for windows, version 25.0; IBM-SPSS, Chicago, IL, USA). We presented the continuous parameters as their means ± standard deviations and frequencies as their means and 95% confidence intervals (CI). The spherical equivalent (SE) of refractive error was calculated as spherical error + 1/2 cylindrical error. We defined myopia as SE of ≤–1.0 diopters (D). Low, moderate, and high myopia were defined as SE of ≤–1.0 D, ≤–3.0 D, ≤–6.0 D, respectively. Associations between the degree of fundus tessellation and ocular parameters or systemic variables were first assessed in a univariate analysis. The subsequent multivariable analysis included the degree of fundus tessellation as the dependent variable, and all parameters that were significantly associated with the fundus tessellation in the univariate analysis were included as independent variables. Thus, the model was adjusted for potential confounders. Then, independent variables that showed a high collinearity with other parameters or were no longer significantly associated with fundus tessellation were removed from the list. We presented the regression coefficients beta, odds ratios (ORs), and 95% CI. All P values were two-sided and considered statistically significant when the values were less than 0.05.

Results

Assessable fundus photographs for the examination of fundus tessellation were available for 1430 (99.1%) individuals. Thirteen individuals were excluded due to insufficient quality of the fundus images, such as corneal opacities, large pterygia, and small pupils. The mean age was 12.7 ± 0.71 years (median, 13.0 years; range, 9–16 years), mean SE was –2.39 ± 2.17 D (median, –2.00 D; range, –15.6–4.25 D), mean axial length was 24.48 ± 1.17 mm (median, 24.48 mm; range, 20.70–28.34 mm), and the mean axial length/corneal curvature ratio was 3.13 ± 0.14 (median, 3.12; range, 2.74–3.77).

The presence of fundus tessellation in the macular region was 688/1430 (48.1%; 95% CI: 45.5%, 50.7%). The mean degree of fundus tessellation in the macular region was 0.54 ± 0.61 (median, 0; range, 0–3). The mean degree of peripapillary tessellation was 0.86 ± 0.68 (median, 1; range, 0–3). The peripapillary fundus tessellation stratified by region was 0.68 ± 0.62, 0.70 ± 0.64, 0.75 ± 0.70, and 0.58 ± 0.65 in the superior region, nasal region, inferior region, and temporal region, respectively, with significant differences among the four regions (P < 0.001) (Table 1).

In univariate analysis, a higher degree of macular fundus tessellation was significantly associated with a lower body mass index (P = 0.016), longer known duration of myopia (P < 0.001), worse uncorrected visual acuity (P < 0.001), more myopic refractive error (P < 0.001), longer axial length (P < 0.001), higher corneal curvature radius (P < 0.001), lower lens thickness (P < 0.001), deeper anterior chamber (P < 0.001), thinner subfoveal choroidal thickness (P < 0.001), higher axial length/corneal curvature ratio (P < 0.001), and a higher prevalence of parapapillary beta/gamma zone (P < 0.001) and of parental myopia (P < 0.001) (Table 2). It was not associated with age, sex, foveal retinal thickness, corneal thickness, time spent daily outdoors, time spent daily for studying, time spent daily with electronic gadgets, level of parental education, and parental profession (Table 2).

The multivariable regression analysis included the degree of macular fundus tessellation as the dependent variable. Due to collinearity, we first dropped the parameter of refractive error (variance inflation factor, 2.1) out of the list of independent variables. Due to the lack of statistical significance, we then dropped, step by step, the parameters of paternal myopia (P = 0.977 for either parental myopia; P = 0.793 for both parental myopia), presence of parapapillary beta/gamma zone (P = 0.282), age of myopia onset (P = 0.148), and body mass index (P = 0.103). In the final model, a higher degree of macular fundus tessellation was associated with a thinner subfoveal choroidal thickness (P < 0.001; beta, –0.02; OR, 0.98; 95% CI: 0.98, 0.99) and a longer axial length (P < 0.001; beta, 0.23; OR, 1.25; 95% CI: 1.10, 1.43) (Table 3). If the parameter of axial length was replaced by age of myopia onset, younger age of myopia onset was correlated with a higher degree of macular fundus tessellation (P < 0.001; beta, 0.49; OR, 1.64; 95% CI: 1.16, 2.31) (Table 3).

Subfoveal choroidal thickness decreased from 299 ± 61 µm (95%CI: 293, 304) in eyes without fundus tessellation to 246 ± 57 µm (95% CI: 241, 251) in eyes with grade 1 of fundus tessellation, to 197 ± 43 µm (95% CI: 187, 207) in eyes with grade 2 of fundus tessellation, and to 131 ± 30 µm (95% CI: 93, 168) in eyes with grade 3 of fundus tessellation (Fig. 2). In a similar manner, the choroidal thickness at a distance of 3000 µm nasally and temporally to the foveola decreased significantly (P < 0.001) with the degree of fundus tessellation (Fig. 3).

If the degree of peripapillary fundus tessellation was assessed, the multivariable analysis revealed similar results, with a higher degree of peripapillary fundus tessellation being significantly associated with a thinner choroidal thickness in the peripapillary region (P < 0.001; beta, –0.02; OR, 0.98; 95% CI: 0.98, 0.99) and younger age of myopia onset (P = 0.008; beta, 0.41; OR, 1.13; 95% CI: 1.01, 1.26) (Table 4).

Discussion

In our school-based study on junior students, the mean prevalence of fundus tessellation was 48.1%, and a higher degree of fundus tessellation was mostly associated with reduced subfoveal choroidal thickness and younger age of myopia onset. A high degree of fundus tessellation may be considered a surrogate for a leptochoroid (i.e., a thin choroid).

The prevalence of macular fundus tessellation found in our study population with a mean age of 12.7 ± 0.71 years was consistent with a mean prevalence of 54.6% reported in a recent study by Wong and colleagues[14] on highly myopic Chinese adolescents with a mean age of 14.0 ± 1.0 years. The prevalence of fundus tessellation in our study was lower than the value of 65.1% found in an investigation performed by Terasaki and coworkers[17] on 126 healthy volunteers with an age of 26.0 ± 4.1 years, which was older than the mean age of our study population. Correspondingly, the mean degree of

Table 1. Baseline Characteristics of the Participants in the Beijing Teenage Myopia Study, Presented as the Median and Interquartile Range for Continuous Variables

Characteristics	Total, *N* = 1430	Myopic Subgroup, *n* = 1020	Nonmyopic Subgroup, *n* = 410	*P* Value
Systemic parameters				
Age, y	13.00 (1.00)	13.00 (1.00)	13.00 (1.00)	0.376
Boys, number (%)	795 (55.59)	555 (54.41)	240 (58.54)	0.156
Height, cm	160.00 (10.80)	160.40 (10.00)	160.00 (9.90)	0.017
Weight, kg	52.40 (18.60)	52.50 (18.80)	52.35 (17.25)	0.564
Body mass index, kg/m^2	20.34 (6.16)	20.37 (6.12)	20.26 (6.39)	0.684
Ophthalmologic parameters				
Uncorrected visual acuity, logMAR	0.30 (0.60)	0.52 (0.40)	0.00 (0.08)	<0.001
Refractive error, D	−2.00 (3.00)	−2.88 (2.63)	−0.25 (0.63)	<0.001
Axial length, mm	24.42 (1.57)	24.83 (1.38)	23.50 (0.98)	<0.001
Corneal thickness, μm	546.00 (43.00)	546.00 (43.00)	546.00 (44.00)	0.713
Corneal radius of curvature, mm	7.81 (0.34)	7.80 (0.35)	7.82 (0.34)	0.239
Lens thickness, mm	3.40 (0.24)	3.37 (0.22)	3.49 (0.25)	<0.001
Anterior chamber depth, mm	3.18 (0.33)	3.23 (0.31)	3.05 (0.35)	<0.001
Axial length/corneal curvature radius ratio	3.12 (0.20)	3.18 (0.16)	3.00 (0.09)	<0.001
Foveal retinal thickness, μm	213.00 (22.00)	213.00 (21.00)	211.00 (22.00)	<0.001
Subfoveal choroidal thickness, μm	262.00 (95.00)	250.00 (82.00)	310.50 (84.50)	<0.001
Choroidal thickness at 3 mm nasal to fovea, μm	155.00 (68.00)	148.00 (62.00)	179.00 (77.00)	<0.001
Choroidal thickness at 3 mm temporal to fovea, μm	276.00 (80.00)	266.00 (73.00)	309.00 (73.50)	<0.001
Fundus tessellation in the macular region, number (%)				
Grade 0	742 (51.89)	453 (44.41)	289 (70.49)	<0.001
Grade 1	610 (42.66)	495 (48.53)	115 (28.05)	
Grade 2 and 3	78 (5.45)	72 (7.06)	6 (1.46)	
Degree of fundus tessellation in the parapapillary region	0.75 (1.00)	1.00 (1.00)	0.25 (1.00)	<0.001
Parapapillary atrophy, number (%)	1117 (78.11)	903 (88.53)	214 (52.20)	<0.001
Interview questions				
Outdoor time per day, hours	0.85 (0.82)	0.81 (0.81)	0.95 (0.82)	<0.001
Study time per day, hours	2.14 (1.26)	2.14 (1.31)	2.10 (1.16)	0.059
Time spent with electronic gadgets per day, hours	0.57 (0.64)	0.57 (0.64)	0.54 (0.64)	0.371
Parental myopia, number (%)				
Neither	683 (47.93)	433 (42.53)	250 (61.43)	<0.001
Either	532 (37.33)	408 (40.08)	124 (30.47)	
Both	210 (14.74)	177 (17.39)	33 (8.11)	
Paternal education, number (%)				
Junior middle school or less	208 (14.58)	133 (13.08)	75 (18.29)	0.009
Senior middle school	526 (36.86)	368 (36.18)	158 (38.54)	
College/Bachelor/Postgraduate	693 (48.56)	516 (50.74)	177 (43.17)	
Maternal education, number (%)				
Junior middle school or less	250 (17.56)	170 (16.72)	80 (19.66)	0.128
Senior middle school	514 (36.10)	359 (35.30)	155 (38.08)	
College/Bachelor/Postgraduate	660 (46.35)	488 (47.98)	172 (42.26)	
Paternal profession, number (%)				
Physical profession (worker, farmer, household duties)	352 (24.62)	253 (24.80)	99 (24.15)	0.794
Mental profession (working in government, teacher, etc.)	1078 (75.38)	767 (75.20)	311 (75.85)	
Maternal profession, number (%)				
Physical profession (worker, farmer, household duties)	350 (24.48)	258 (25.29)	92 (22.44)	0.256
Mental profession (working in government, teacher, etc.)	1080 (75.52)	762 (74.71)	318 (77.56)	

macular fundus tessellation in our young study population was lower than the degree of fundus tessellation in the elderly population of the Beijing Eye Study, with a mean degree of 0.84 ± 0.79.[9] Both comparisons reflected the association between a higher prevalence and degree of fundus tessellation and older age in adults.[9] In contrast, the prevalence of fundus tessellation in our young study population was considerably higher than the prevalence of 34.2% reported for an elderly Japanese population with a mean age of 41.4 ± 16.7 years.[6] Despite a marked difference in age, the prevalence of fundus tessellation in our study population was similar to the prevalence of 45.5% observed in 1670 participants in the population-based Kumejima Study, with a mean age of 53.6 ± 10.3 years.[18] In agreement with the association of a higher fundus tessellation prevalence and longer axial length (and older age), Zhou and colleagues[12] found a fundus tessellation prevalence of 67% in highly myopic eyes of Chinese individuals with a mean age of 37.2 ± 9.9 years. This percentage was higher than that in our study on a younger and less myopic study population. In general, the differences in the prevalence and degree of fundus tessellation between the study populations may be due to differences between the study populations in age and axial length and may also reflect the increase in the prevalence of axial myopia in the young generation in China.

Table 2. Associations Between the Degree of Macular Fundus Tessellation and Ocular and Systemic Parameters in the Beijing Teenage Myopia Study (Univariate Analysis), Presented as the Median and Interquartile Range for Continuous Variables

Variable	Grade 0	Grade 1	Grade 2 and 3	OR (95% CI)	*P* Value
Systemic parameters					
Age, year	13.00 (1.00)	13.00 (1.00)	12.00 (1.00)	1.01 (0.88, 1.17)	0.857
Boys, number (%)	413 (55.66)	341 (55.90)	41 (52.56)	0.98 (0.80, 1.21)	0.867
Age from myopia onset (<10 years), number (%)	69 (9.39)	106 (17.43)	26 (33.33)	2.49 (1.85, 3.34)	<0.001
Body mass index, kg/m^2	20.69 (6.20)	20.00 (6.16)	19.22 (7.28)	0.97 (0.95, 0.99)	0.014
Ophthalmologic parameters					
Refractive error, D	−1.38 (2.53)	−2.50 (3.13)	−4.00 (3.03)	0.75 (0.72, 0.79)	<0.001
Degree of myopia, number (%)					
Nonmyopia	289 (38.95)	115 (18.85)	6 (7.69)	1	
Low myopia	268 (36.12)	231 (37.87)	23 (29.49)	2.27 (1.73, 2.97)	<0.001
Moderate myopia	158 (21.29)	214 (35.08)	36 (46.15)	3.90 (2.93, 5.19)	<0.001
High myopia	27 (3.64)	50 (8.20)	13 (16.67)	6.16 (3.87, 9.81)	<0.001
Axial length, mm	24.11 (1.46)	24.76 (1.58)	25.61 (1.82)	1.87 (1.69, 2.08)	<0.001
Foveal retinal thickness, μm	213.00 (21.00)	213.00 (23.00)	208.00 (28.00)	1.00 (1.00, 1.01)	0.125
Subfoveal choroidal thickness, μm	296.00 (82.00)	237.00 (74.00)	188.00 (65.50)	0.98 (0.97, 0.98)	<0.001
Choroidal thickness at 3 mm nasal to fovea, μm	178.50 (63.00)	136.00 (55.00)	96.00 (42.00)	0.98 (0.97, 0.98)	<0.001
Choroidal thickness at 3 mm temporal to fovea, μm	293.00 (69.00)	258.00 (72.00)	231.00 (66.00)	0.99 (0.99, 0.99)	< 0.001
Parapapillary atrophy, number (%)	511 (68.86)	531 (87.05)	75 (96.15)	3.41 (2.58, 4.50)	<0.001
Interview questions					
Outdoor time per day, hours	0.88 (0.81)	0.83 (0.79)	0.75 (1.04)	0.93 (0.79, 1.10)	0.398
Study time out school per day, hours	2.13 (1.24)	2.13 (1.23)	2.18 (1.64)	1.05 (0.94, 1.16)	0.389
Time spent with electronic gadgets per day, hours	0.57 (0.64)	0.57 (0.69)	0.61 (0.79)	0.98 (0.83, 1.15)	0.769
Parental myopia, number (%)					
Neither	370 (50.07)	283 (46.55)	30 (38.47)	1.00	
Either	267 (36.13)	237 (38.98)	28 (35.90)	1.17 (0.94, 1.47)	0.158
Both	102 (13.80)	88 (14.47)	20 (25.64)	1.35 (1.01, 1.83)	0.049
Paternal education, number (%)					
Junior middle school or less	104 (14.05)	90 (14.78)	14 (17.95)		
Senior middle school	289 (39.05)	217 (35.63)	20 (25.64)	0.79 (0.58, 1.08)	0.145
College/Bachelor/Postgraduate	347 (46.89)	302 (49.60)	44 (56.41)	0.90 (0.73, 1.34)	0.949
Maternal education, number (%)					
Junior middle school or less	130 (17.62)	105 (17.30)	15 (19.23)		
Senior middle school	271 (36.72)	222 (36.51)	21 (26.92)	0.94 (0.70, 1.26)	0.686
College/Bachelor/Postgraduate	337 (45.67)	281 (46.22)	42 (53.85)	1.04 (0.78, 1.39)	0.778

Our study is in agreement with previous investigations in that thinner choroidal thickness was strongly associated with a higher degree of fundus tessellation.[9,12–18] In the Beijing Eye Study, a higher degree of fundus tessellation was mostly associated with longer axial length and older age, in addition to male sex, lower body mass index, worse best corrected visual acuity, thinner subfoveal choroidal thickness, larger parapapillary beta zone, lower prevalence of intermediate age-related macular degeneration, and lower prevalence of late age-related macular degeneration.[9] In our young study population, the prevalence and degree of fundus tessellation were mostly correlated with a thinner subfoveal choroid, whereas the associations with age, sex, body mass index, and uncorrected visual acuity were nonsignificant in the multivariable model. The lack of an association between the prevalence of fundus tessellation and age in our study may have been due to the small age range of our study population. The association between fundus tessellation and choroidal thickness was also reported in a hospital-based study performed by Chen and colleagues[11] from South China and in a study conducted by Koh and associates[20] in Singapore. In contrast to our study and the Beijing Eye Study, the investigation performed by Yoshihara et al.[15] did not find a relationship between fundus tessellation and axial length.

The morphology and change in the degree of fundus tessellation have been assessed in previous studies from Japan and China.[5,6,13,15,17,18,21] In a natural history study of high

Table 3. Associations (Multivariable Analysis) Between the Degree of Macular Fundus Tessellation and Ocular and Systemic Parameters in the Beijing Teenage Myopia Study With Axial Length Included (Model 1) and Excluded (Model 2)

Parameter	Beta (95% CI)	OR (95% CI)	*P* Value
Model 1			
Subfoveal choroidal thickness, μm	−0.02 (−0.02, −0.01)	0.98 (0.98, 0.99)	<0.001
Axial length, mm	0.23 (0.10, 0.36)	1.25 (1.10, 1.43)	<0.001
Model 2			
Subfoveal choroidal thickness, μm	−0.02 (−0.02, −0.02)	0.98 (0.98, 0.99)	<0.001
Age of myopia onset			
≥10 years or no myopia		1	
<10 years	0.49 (0.15, 0.84)	1.64 (1.16, 2.31)	<0.001

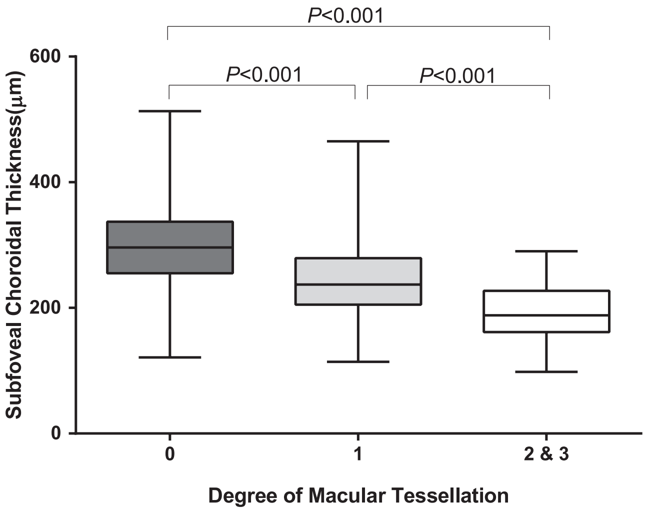

FIGURE 2. Graph showing the distribution of subfoveal choroidal thickness stratified by the degree macular fundus tessellation.

myopia, fundus tessellation was considered the first fundus lesion observed in eyes with eventual pathologic myopia. In some eyes, fundus tessellation progressed to the development of lacquer cracks and patchy atrophies, ultimately leading to the development of myopic choroidal neovascularization at the edge of patchy atrophy.[6] Wong and colleagues[14] reported that compared to eyes with a late onset, eyes with an early onset of fundus tessellation had a thinner choroid. However, whether fundus tessellation is a marked risk factor for the eventual development of myopic maculopathy in later life remains unknown.

The clinical importance of the increased prevalence of fundus tessellation in our study population has remained unclear so far. In previous hospital-based studies and the population-based Beijing Eye Study, individuals with a higher degree of fundus tessellation had a higher prevalence of glaucomatous optic neuropathy and a larger parapapillary beta zone.[4,9] In contrast, an association between a higher prevalence of fundus tessellation and a higher prevalence of parapapillary atrophy was not found in the final multivariable model of our study population. This discrepancy between the studies may have been observed because the parapapillary atrophy in our study population mostly represented the parapapillary gamma zone, which is correlated with myopic axial elongation, while in the analysis of the Beijing Eye Study, parapapillary atrophy mostly consisted of the parapapillary beta zone, which is correlated with glaucomatous optic nerve damage.[22] Another reason for the discrepancy between these studies was that our study population did not include patients with glaucoma. An additional potential implication of fundus tessellation may be the yet unconfirmed finding of an association between greater progression of macular fundus tessellation and lower cognitive function after adjusting for age, level of education, subfoveal choroidal thickness, and myopic change in refractive error.[21]

The association between a higher degree of fundus tessellation and longer axial length may be associated with changes in the vascular and nonvascular architecture of the choroid due to axial elongation. According to previous studies, the choroidal thinning in axially elongating eyes led to a decrease in the thickness predominantly of the large-sized vessels (Haller's layer) and medium-sized vessels (Sattler's layer) so that the ratio of the small-sized vessel layer to the total choroidal thickness increased with longer axial length.[23] In addition, axial elongation leads to thinning or compression of the intervascular tissue of the choroid. Thus, which of these axial elongation-related changes in the choroid leads to better visibility of the large choroidal vessels upon ophthalmoscopy, that is an increased degree of fundus tessellation, has remained unclear.

When the study population was divided into a myopic subgroup and a nonmyopic subgroup, the foveal retinal thickness was thinner in the myopic subgroup, with the difference between both subgroups being small. Previous studies have yielded conflicting data on the retinal thickness in myopic individuals.[24–26] In some recent studies, the retina in the parafoveal regions was significantly thinner in myopic subjects than in nonmyopic individuals, indicating that during

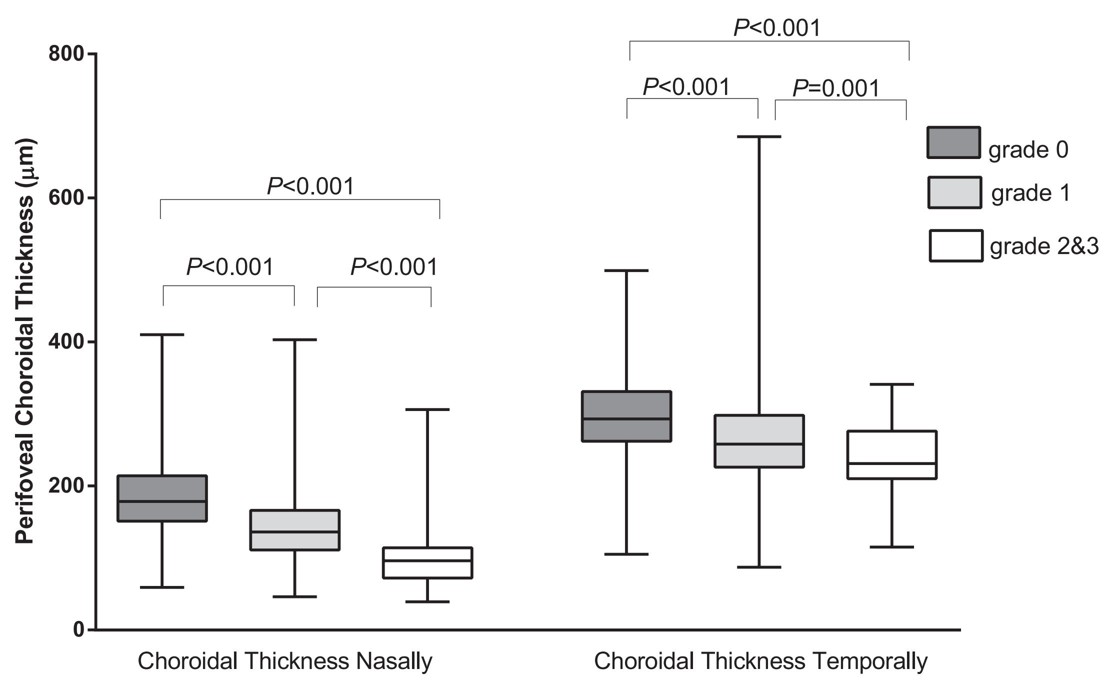

FIGURE 3. Graph showing the distribution of perifoveal choroidal thickness stratified by the degree macular fundus tessellation.

TABLE 4. Associations Between the Degree of Parapapillary Fundus Tessellation With Ocular and Systemic Parameters in the Beijing Teenage Myopia Study (Multivariate Analysis) With Axial Length Included (Model 1) and Excluded (Model 2)

Parameter	Beta (95% CI)	OR (95% CI)	*P* Value
Model 1			
Subfoveal choroidal thickness, μm	−0.02 (−0.02, −0.02)	0.98 (0.98, 0.99)	<0.001
Axial length, mm	0.12 (0.01, 0.23)	1.13 (1.01, 1.26)	0.034
Model 2			
Subfoveal choroidal thickness, μm	−0.02 (−0.02, −0.02)	0.98 (0.98, 0.98)	<0.001
Age of myopia onset			
≥10 years or no myopia		1	
<10 years	0.41 (0.11, 0.71)	1.51 (1.11, 2.04)	0.008

the early stage of myopia progression, choroidal thinning occurs first and is followed by a retinal thinning in the perifoveal area, which then may progress centripetally.[27,28] Six participants of our nonmyopic subgroup had a grade 2 fundus tessellation (Table 1). Their mean refractive error was –0.06 ± 0.36 D as compared to –0.10 ± 0.71 D in the other nonmyopic individuals. However, the six subjects with grade 2 fundus tessellation had longer axial lengths (24.00 ± 0.31 mm vs. 23.46 ± 0.79 mm) and a thinner subfoveal choroid (226 ± 28 μm vs. 309 ± 63 μm). Because choroidal thinning is the anatomic correlate of fundus tessellation and strongly depends on axial elongation, the longer axial length in the group of six nonmyopic individuals with grade 2 fundus tessellation may have been the reason for the refractive error-related unusually high degree of fundus tessellation.

Limitations of our study should be discussed. First, the assessment of the degree of fundus tessellation was subjective and depended on the skills of the examiner. However, the examiner was well trained and regularly supervised by ophthalmologists experienced in the field. Second, the study was school-based, not population-based, so the possibility of a selection bias existed. However, the schools were chosen based on the representativeness of the region in which they were located. Third, refractometry was not performed under cycloplegic conditions. However, axial length was measured, which was independent of the accommodative status of the lens. Axial length and the calculated parameter of axial length/corneal curvature radius ratio could be taken as a surrogate for refractive error. Fourth, photographs centered on the optic disc were not acquired, which may have an influence on the assessment of peripapillary fundus tessellation.

In conclusion, the prevalence of fundus tessellation was relatively high in Chinese teenagers. As in adults, the degree of fundus tessellation is a surrogate for choroidal thickness in teenagers. Marked fundus tessellation indicated a leptochoroid, which was associated with earlier onset myopia.

Acknowledgments

Supported by the National Natural Science Foundation of China (81602909) and the Project from Beijing Municipal Commission (PXM2018_014226_000026 and PXM2019_014226_000006).

Disclosure: **Y. Guo**, None; **L. Liu**, None; **D. Zheng**, None; **J. Duan**, None; **Y. Wang**, None; **J.B. Jonas**, P; **F. Tian**, None; **S. Wang**, None; **Y. Sang**, None; **X. Zhang**, None; **W. Cao**, None; **J. Zhang**, None; **M. Sun**, None; **Q. Tian**, None; **X. Meng**, None; **X. Guo**, None; **L. Wu**, None

References

1. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology.* 2016;123:1036–1042.
2. Sun J, Zhou J, Zhao P, et al. High prevalence of myopia and high myopia in 5060 Chinese university students in Shanghai. *Invest Ophthalmol Vis Sci*. 2012;53:7504–7509.
3. Guo Y, Duan JL, Liu LJ, et al. High myopia in Greater Beijing School Children in 2016. *PLoS One*. 2017;12:e0187396.
4. Jonas JB, Gurndler A. Optic disc morphology in 'age-related atrophic glaucoma'. *Graefes Arch Clin Exp Ophthalmol*. 1996;234:744–749.
5. Ohno-Matsui K, Kawasaki R, Jonas JB, et al. International photographic classification and grading system for myopic maculopathy. *Am J Ophthalmol*. 2015;159:877–883.
6. Hayashi K, Ohno-Matsui K, Shimada N, et al. Long term pattern of progression of myopic maculopathy: a natural history study. *Ophthalmology.* 2010;117:1595–1611.
7. Fang Y, Yokoi T, Nagaoka N, et al. Progression of myopic maculopathy during 18-year follow-up. *Ophthalmology.* 2018;125:863–877.
8. Yan YN, Wang YX, Yang Y, et al. Ten-year progression of myopic maculopathy: The Beijing Eye Study 2001-2011. *Ophthalmology.* 2018;125:1253–1263.
9. Yan YN, Wang YX, Xu L, Xu J, Wei WB, Jonas JB. Fundus tessellation: prevalence and associated factors: The Beijing Eye Study 2011. *Ophthalmology.* 2015;122:1873–1880.
10. Spaide RF. Age-related choroidal atrophy. *Am J Ophthalmol*. 2009;147:801–810.
11. Chen H, Wen F, Li H, et al. The types and severity of high myopic maculopathy in Chinese patients. *Ophthalmic Physiol Opt*. 2012;32:60–67.
12. Zhou Y, Song M, Zhou M, Liu Y, Wang F, Sun X. Choroidal and retinal thickness of highly myopic eyes with early stage of myopic chorioretinopathy: tessellation. *J Ophthalmol*. 2018;2018:2181602.
13. Takahashi A, Ito Y, Iguchi TR, Yasuma TR, Ishikawa K, Terasaki H. Axial length increases and related changes in highly myopic normal eyes with myopic complications in fellow eyes. *Retina*. 2012;32:127–133.
14. Wong YL, Ding Y, Sabanayagam C, et al. Longitudinal changes in disc and retinal lesions among highly myopic adolescents in Singapore over a 10-year period. *Eye Contact Lens*. 2018;44:286–291.
15. Yoshihara N, Yamashita T, Ohno-Matsui K, Sakamoto T. Objective analyses of tessellated fundi and significant correlation between degree of tessellation and choroidal thickness in healthy eyes. *PLoS One*. 2014;9:e103586.
16. Jaqadeesh D, Philip K, Naduvilath TJ, et al. Tessellated fundus appearance and its association with myopic refractive error. *Clin Exp Optom.* 2019;102:378–384.
17. Terasaki H, Yamashita T, Yoshihara N, et al. Location of tessellations in ocular fundus and their associations with optic disc tilt, optic disc area, and axial length in young healthy eyes. *PLoS One*. 2016;11:e0156842.

18. Yamashita T, Iwase A, Kii Y, et al. Location of ocular tessellation in Japanese: population-based Kumejima Study. *Invest Ophthalmol Vis Sci*. 2018;59:4963–4967.
19. Guo Y, Liu LJ, Xu L, et al. Outdoor activity and myopia among primary students in rural and urban of Beijing. *Ophthalmology.* 2013;120:277–283.
20. Koh V, Tan C, Tan PT, et al. Myopic maculopathy and optic disc changes in highly myopic young Asian eyes and impact on visual acuity. *Am J Ophthalmol*. 2016;164:69–79.
21. Yan YN, Wang YX, Yang Y, et al. Long-term progression and risk factors of fundus tessellation in the Beijing Eye Study. *Sci Rep*. 2018;8:10625.
22. Dai Y, Jonas JB, Huang H, Wang M, Sun X. Microstructure of parapapillary atrophy: beta zone and gamma zone. *Invest Ophthalmol Vis Sci*. 2013;54:2013–2018.
23. Zhao J, Wang YX, Zhang Q, Wei WB, Xu L, Jonas JB. Macular choroidal small-vessel layer, Sattler's layer and Haller's layer thicknesses: The Beijing Eye Study. *Sci Rep*. 2018;8:4411.
24. Ooto S, Hangai M, Tomidokoro A, et al. Effects of age, sex, and axial length on the three-dimensional profile of normal macular layer structures. *Invest Ophthalmol Vis Sci*. 2011; 52:8769–8779.
25. Liu X, Shen M, Yuan Y, et al. Macular thickness profiles of intraretinal layers in myopia evaluated by ultrahigh resolution optical coherence tomography. *Am J Ophthalmol*. 2015;160: 53–61.
26. Chen S, Wang B, Dong N, Ren X, Zhang T, Xiao L. Macular measurements using spectral-domain optical coherence tomography in Chinese myopic children. *Invest Ophthalmol Vis Sci*. 2014;55:7410–7416.
27. Jin P, Zou H, Zhu J, et al. Choroidal and retinal thickness in children with different refractive status measured by swept-source optical coherence tomography. *Am J Ophthalmol*. 2016;168:164–167.
28. Read SA, Alonso-Caneiro D, Vencent SJ. Longitudinal changes in macular retinal layer thickness in pediatric populations: myopic vs non-myopic eyes. *PLoS One*. 2017;12:e0180462.