

Peripapillary atrophy area predicts the decrease of macular choroidal thickness in young adults during myopia progression

Menghan Li ,^{1,2,3} Ya Shi,^{1,2} Qiuying Chen,^{1,2} Guangyi Hu,^{1,2,3} Jiamin Xie,^{1,2,3} Luyao Ye,^{1,2} Ying Fan,^{2,3} Jianfeng Zhu,¹ Jiangnan He,¹ Xun Xu ^{2,3}

To cite: Li M, Shi Y, Chen Q, *et al.* Peripapillary atrophy area predicts the decrease of macular choroidal thickness in young adults during myopia progression. *BMJ Open Ophthalmology* 2024;**9**:e001555. doi:10.1136/bmjophth-2023-001555

► Additional supplemental material is published online only. To view, please visit the journal online (<https://doi.org/10.1136/bmjophth-2023-001555>).

ML and YS contributed equally.

ML and YS are joint first authors.

Received 1 November 2023
Accepted 23 March 2024



© Author(s) (or their employer(s)) 2024. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Department of Preventative Ophthalmology, Shanghai Eye Disease Prevention and Treatment Center, Shanghai, China

²Department of Ophthalmology, Shanghai General Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China

³Shanghai Key Laboratory of Fundus Disease, Shanghai, China

Correspondence to

Dr Jiangnan He; hejiangnan85@126.com

ABSTRACT

Objective This study aimed to investigate the influence of peripapillary atrophy (PPA) area and axial elongation on the longitudinal changes in macular choroidal thickness (ChT) in young individuals with myopia.

Methods and analysis In this longitudinal investigation, 431 eyes—342 categorised as non-high myopia (non-HM) and 89 as HM—were examined for 2 years. Participants were examined with swept-source optical coherence tomography. The macular ChT, PPA area and axial length (AL) were measured at baseline and follow-up visits. Multiple regression analysis was performed to identify factors associated with ChT changes. The areas under the receiver operating characteristic curves were analysed to ascertain the predictive capacity of the PPA area and axial elongation for the reduction in macular ChT.

Results Initial measurements revealed that the average macular ChT was $240.35 \pm 56.15 \mu\text{m}$ in the non-HM group and $198.43 \pm 50.27 \mu\text{m}$ in the HM group ($p < 0.001$). It was observed that the HM group experienced a significantly greater reduction in average macular ChT ($-7.35 \pm 11.70 \mu\text{m}$) than the non-HM group ($-1.85 \pm 16.95 \mu\text{m}$, $p = 0.004$). Multivariate regression analysis showed that a greater reduction of ChT was associated with baseline PPA area ($\beta = -26.646$, $p < 0.001$) and the change in AL ($\beta = -35.230$, $p < 0.001$). The combination of the baseline PPA area with the change in AL was found to be effective in predicting the decrease in macular ChT, with an area under the curve of 0.741 (95% CI 0.694 to 0.787).

Conclusion Over 2 years, eyes with HM exhibit a more significant decrease in ChT than those without HM. Combining the baseline PPA area with the change in AL could be used to predict the decrease of macular ChT.

INTRODUCTION

The surge in myopia prevalence has emerged as a significant public health concern in East and Southeast Asia.^{1,2} In these regions, particularly within urban centres, over 80% of young adults suffer from myopia,^{3,4} with high myopia (HM) affecting 19.5% of Shanghai college students.⁵ This demographic is increasingly prone to developing pathological myopia over time, leading to escalating healthcare

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Choroidal thickness was associated with myopia degree, axial length and myopic optic disc characteristics.

WHAT THIS STUDY ADDS

⇒ Combining the peripapillary atrophy area with the change in axial length could be used to predict the longitudinal changes in macular choroidal thickness.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study provides a method for early prediction of choroidal thinning, which may help identify potential adult myopic progressors.

costs. Individuals with HM face an increased risk of myopia-related complications that can result in visual impairment, such as myopia macular degeneration accounting for 32.7% of low vision and 7.7% of blindness cases in the Beijing Eye Study,⁶ as well as contributing to 17.6% of bilateral low vision cases in the Taizhou Eye Study.⁷

The choroid is increasingly recognised for its role in eye growth regulation and myopia development. Numerous studies have indicated that choroidal thinning is associated with increased myopia severity and axial length (AL) in children.^{8,9} In addition, myopic optic disc characteristics are associated with choroidal thinning in young adults.¹⁰ For elderly individuals with HM, thinner macular choroidal thickness (ChT) serves as a risk factor for myopic maculopathy.¹¹ Despite these findings, the interaction between ChT and other ocular parameters in adults, especially those with HM whose myopia degree progresses beyond puberty, is poorly understood.

Given that college students are in their late adolescence or early adulthood and often engage in sustained near-work activities,



they represent potential candidates for studying the emergence of myopia at a young age. Previous studies have found myopic progression in college students and thinner choroids in young HM adults,^{12–14} but there is a lack of longitudinal studies on changes in ChT. Therefore, this study aimed to track the progression of myopia and longitudinal changes in macular ChT, seeking to explore the factors that influence these developments.

METHODS

Study subjects

Participants eligible for this prospective study were recruited from Shanghai University with baseline and follow-up visits between 2016 and 2018. Patients or the public were not involved in the design, conduct, reporting or dissemination plans of our research.

Ophthalmic examinations

All participants underwent comprehensive ophthalmological examinations at each visit, including refractive error assessment using an autorefractor machine (KR-8900; Topcon, Tokyo, Japan) without cycloplegia, measurement of intraocular pressure (IOP) (TX-F; Topcon, Tokyo, Japan), slit-lamp biomicroscopy, colour fundus examination and measurement of the ChT using swept-source optical coherence tomography (SS-OCT, model DRI OCT-1 Atlantis; Topcon, Japan). Central corneal thickness, lens thickness, anterior chamber depth (ACD) and AL were measured using optical low-coherence reflectometry (Aladdin; Topcon, Japan). Subjective refraction was performed by a trained optometrist for all of the participants. Spherical equivalent (SE) was calculated as the sum of the spherical value and half the cylindrical value. HM was defined as SE \leq -6 dioptre (D) in this study.¹⁵ The best-corrected visual acuity (BCVA) was converted to the logarithm of minimal angle resolution. A detailed medical history was recorded for each student.

Inclusion and exclusion criteria

This prospective study initially enrolled 760 subjects, aged 18–30 years, with SE $<$ 0.5 D, BCVA \geq 20/25, IOP \leq 21 mmHg, normal anterior chamber angles and no evidence of glaucomatous changes or retinal nerve fibre layer abnormalities. Only those who completed both scheduled assessments were included in the analysis. Exclusion criteria encompassed any participant with other ocular diseases (such as congenital cataract, glaucoma or retinopathy), a history of previous intraocular or refractive surgery, or any systemic diseases like hypertension and diabetes. SS-OCT images with poor quality (Signal Strength Index \leq 60) were further excluded.

SS-OCT imaging and assessment

The ChT was measured using SS-OCT (DRI OCT-1 Atlantis; Topcon, Tokyo, Japan), which had a lateral resolution of 10 μ m and an axial resolution of 8 μ m.^{10 16} All measurements corrected for the magnification effects of

refractive error and AL were conducted by a single technician who was experienced in taking SS-OCT images. The follow-up mode of the device guaranteed that the same anatomical locations were scanned at baseline and follow-up visits. To decrease the influence of circadian rhythm changes on ChT, follow-up scans were scheduled within a 2-hour window of the baseline visit time. The segmentation of each layer was initially automated using the device's built-in software, with manual corrections applied in cases where the software inaccurately identified layer boundaries. To determine the reproducibility of manual corrections, 20 images that required manual segmentation were randomly selected by the same technician for duplicate corrections. The consistency of these manual adjustments was confirmed by a Bland-Altman plot, which showed high reproducibility (online supplemental figure S1). The mean difference between the two corrections was -0.4 μ m, and the 95% limits of agreement ranged from -7 to 6 μ m. The intraobserver correlation coefficient was 0.998 ($p <$ 0.001). The ChT was measured as the vertical distance between the Bruch membrane and the choroid-sclera interface (online supplemental figure S2A,B). The Early Treatment Diabetic Retinopathy Study (ETDRS) grid was adopted to calculate the averaged ChT in each grid sector using the built-in software. The diameters of the subfoveal, parafoveal and perifoveal circles were 1 mm, 3 mm and 6 mm, respectively, and they were further divided into superior, inferior, temporal and nasal quadrants (online supplemental figure S2C).

The peripapillary atrophy (PPA) area was quantified using retinal photographs obtained from SS-OCT, through ImageJ V.1.60 software (National Institutes of Health, Maryland, USA; <http://rsb.info.nih.gov/ij/index.html>). This analysis was conducted by two independent, blinded, well-trained examiners (YS and ML with both at least 2 years of ophthalmology-related study or work experience), and averaged data were used in the final analysis. PPA is characterised as an area of chorioretinal atrophy, appearing as an inner crescent where the large choroidal vessels and sclera are distinctly visible.¹⁷ The total pixel count representing the PPA area was determined by Image J software, which was then converted into square millimetres. The magnification was corrected for each participant's AL applying Littmann's formula.¹⁸

Statistical analysis

SPSS V.26.0 software (IBM) was used for all statistical analyses. Statistical significance was set as $p <$ 0.05 (two sided). Due to the strong correlation observed between the SE ($r = 0.788$, $p <$ 0.001) and AL ($r = 0.907$, $p <$ 0.001) of the right and left eyes at baseline, the analysis was limited to the right eye of each participant. Changes in measurements between two visits were determined as the baseline values subtracted from the values at the final visit.

Demographic and ocular parameters were reported as counts or proportions for categorical data, and as mean (SD) for continuous data. A χ^2 test was applied to assess the group differences in categorical data between groups.

The Student's t-test was performed to detect intergroup differences in continuous data. The differences in ocular parameters between the two visits and those in ChT changes between the two macular sectors were analysed using the paired t-test. Correlation analysis between two ocular parameters was analysed using Pearson correlation coefficients. Multivariate linear regression models were constructed with the ChT change over 2 years as the dependent variable to assess the possible association with other ocular parameters. Logistic regression models were established using ChT decreasing or not as the dependent variable to assess the association with other ocular parameters. ORs and 95% CIs were calculated. The receiver operating characteristic (ROC) curve was plotted, and the area under curve (AUC) to predict ChT thinning was calculated.

RESULTS

General characteristics

Among 760 participants recruited at baseline, 256 were deemed ineligible for the follow-up examination due to school graduation. Of the remaining 504 eligible subjects, 447 attended the 2-year follow-up. However, 16 participants were excluded from further analysis for several reasons: a history of refractive surgery (n=5), absence of SS-OCT images (n=6) and poor-quality SS-OCT images (n=5). Eventually, 431 right eyes of 431 participants were involved in the analysis. This cohort was divided into two groups based on their SE: 342 (79.35%) eyes with SE >-6 D were classified as the non-HM group, and 89 (20.65%) eyes with SE ≤-6 D were classified as the HM group. Participants selected for this study did not exhibit pathological myopia-related changes (myopic maculopathy equal to or more severe than diffuse choroidal atrophy or posterior staphyloma). The mean follow-up time was 20.63±1.38 months (range 20–24 months).

The demographic data and ocular parameters collected across two visits are shown in [table 1](#). The participants' mean age was 19.51±2.20 years (range 18–30 years). There were no significant differences in age, gender, IOP and LT between the two groups at baseline (p=0.244–0.997). The HM group had lower SE (-7.52±1.46 D), worse BCVA (0.03±0.04), deeper ACD (3.77±0.21 mm), larger PPA area (0.87±0.15 mm²) and longer AL (26.40±1.00 mm) (all p<0.05). The mean LT, PPA area and AL increased, while the mean SE and ACD decreased over time (all p<0.05). Compared with non-HM eyes, HM eyes exhibited a more significant axial elongation over time (p=0.001).

Changes in ChT

[Table 1](#) presents the changes in macular ChT over time. At baseline, the HM group had a thinner ChT than the non-HM group (198.43±50.27 μm vs 240.35±56.15 μm, p<0.001). Throughout the 2 years, a decline in ChT was observed in both HM (-7.35±11.70 μm, p<0.001) and non-HM (-1.85±16.95 μm, p=0.045) groups. [Figure 1](#) presents the topographical variations of the ETDRS grid.

The ChT reduction was the most notable in the perifoveal temporal quadrant among the horizontal sectors (all p<0.001).

The relationship between the changes in ChT and other ocular parameters is detailed in [table 2](#). In the non-HM group, a baseline ChT<200 μm and an AL increase≥0.15 mm were associated with notable ChT reduction (both p<0.05). Among HM participants, those with an AL increase of ≥0.15 mm also saw more significant ChT reductions than those with smaller AL changes (p=0.016). The presence of PPA did not affect ChT changes in both groups (both p>0.05).

Factors associated with the changes in ChT

The changes in ChT were negatively associated with age (r=-0.13), baseline AL (r=-0.32), change in AL (r=-0.34) and baseline PPA area (r=-0.32) while showing a positive correlation with the baseline ChT (r=0.17) (all p<0.01). Multivariate linear regression analysis was established to identify independent factors associated with ChT changes in each group ([table 3](#)). Owing to the substantial correlation between the baseline PPA area and baseline AL (p<0.001), only the baseline PPA area was added to the model. After adjusting for age and gender, the ChT changes were correlated with greater elongation of AL and the larger PPA area (both p<0.001) in the whole cohort.

Multiple logistic regression was conducted to explore the associations between ocular parameters and the decrease of ChT (online supplemental table S1). The analysis indicated an increased likelihood of ChT reduction with advancing age (OR 1.127 per annum, p=0.022), larger PPA area (OR 1.063 per 0.01 mm² increment, p<0.001) and greater elongation of AL (OR 1.045 per 0.01 mm increment, p<0.001). The baseline PPA area, the baseline ChT and AL changes were included for single and combined ROC analyses to predict the decrease of ChT ([figure 2](#)). The AUC for individual predictors—AL change, baseline ChT and baseline PPA area—registered at 0.666 (95% CI 0.614 to 0.719), 0.614 (95% CI 0.561 to 0.667) and 0.700 (95% CI 0.651 to 0.748), respectively. After combining the baseline PPA area with the baseline ChT or change in AL, the AUC values were enhanced to 0.701 (95% CI 0.653 to 0.750) and 0.741 (95% CI 0.694 to 0.787).

DISCUSSION

In the current study, we explored the longitudinal changes in ChT over 2 years and identified associated factors. Our findings revealed a significantly greater reduction in average macular ChT in the HM group compared with the non-HM group. Older age, larger PPA area and greater axial elongation were identified as risk factors for greater ChT reduction. Moreover, the combination of the PPA area and the change in AL could predict the decrease in ChT.

Axial elongation is a recognised phenomenon predominantly occurring during childhood and adolescence,

Table 1 Demographics and ocular parameters of the participants at two visits

Variables	Whole cohort (N=431)		Non-high myopia (N=342)		High myopia (N=89)		P value†	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Change
Age, years	19.51 (2.20)	21.51 (2.20)*	19.45 (2.14)	21.49 (2.22)*	19.75 (2.42)	21.57 (2.14)*	0.244	–
Female, n (%)	213 (49.4)	213 (49.4)	169 (49.4)	169 (49.4)	44 (49.4)	44 (49.4)	0.997	–
SE, D	–3.95 (2.57)	–4.34 (2.56)*	–3.02 (1.89)	–3.44 (1.93)*	–7.52 (1.46)	–7.77 (1.62)*	<0.001	0.232
BCVA, logMAR	0.01 (0.03)	0.01 (0.03)	0.00 (0.02)	0.00 (0.02)	0.03 (0.04)	0.03 (0.05)	<0.001	0.063
IOP, mmHg	16.32 (2.53)	16.13 (2.52)	16.29 (2.38)	16.07 (2.27)	16.40 (3.04)	16.30 (3.27)	0.438	0.798
ACD, mm	3.72 (0.23)	3.60 (0.33)*	3.71 (0.26)	3.59 (0.33)*	3.77 (0.21)	3.66 (0.31)*	0.035	0.983
CCT, μ m	540.44 (37.00)	539.78 (38.34)	542.39 (36.55)	540.94 (39.11)	532.98 (37.96)	535.34 (35.08)	0.034	0.070
LT, mm	3.51 (0.23)	3.56 (0.20)*	3.51 (0.24)	3.56 (0.20)*	3.52 (0.20)	3.56 (0.19)*	0.550	0.286
PPA area, mm ²	0.72 (0.14)	0.75 (0.25)*	0.68 (0.11)	0.71 (0.19)*	0.87 (0.15)	0.93 (0.35)	<0.001	0.277
AL, mm	25.25 (1.15)	25.32 (1.18)*	24.95 (0.99)	25.01 (1.01)*	26.40 (1.00)	26.51 (1.02)*	<0.001	0.001
ChT, μ m								
Average thickness	231.69 (57.50)	228.71 (60.95)*	240.35 (56.15)	238.50 (58.88)*	198.43 (50.27)	191.08 (53.96)*	<0.001	0.004
Subfoveal	237.55 (67.75)	237.26 (71.22)	249.16 (65.40)	249.39 (68.76)	192.95 (57.60)	190.65 (60.74)	<0.001	0.251
Inner temporal	253.60 (64.84)	249.07 (69.06)*	264.48 (62.45)	260.89 (66.76)*	211.79 (56.59)	203.63 (58.29)*	<0.001	0.043
Inner superior	245.64 (63.42)	243.99 (67.19)	255.68 (61.97)	255.19 (64.94)	207.05 (53.63)	200.94 (57.90)*	<0.001	0.011
Inner nasal	214.26 (65.38)	211.74 (69.24)*	224.47 (63.62)	222.86 (66.58)	175.02 (56.94)	169.00 (62.60)*	<0.001	0.028
Inner inferior	242.64 (66.67)	239.52 (71.82)*	253.31 (64.77)	251.01 (69.81)	201.64 (57.63)	195.36 (61.95)*	<0.001	0.061
Outer temporal	258.85 (59.61)	253.13 (63.24)*	267.87 (58.25)	263.44 (61.51)*	225.18 (52.39)	214.63 (54.38)*	<0.001	0.043
Outer superior	251.37 (60.30)	248.10 (61.74)*	258.84 (59.82)	256.79 (59.87)	222.68 (53.41)	214.70 (57.58)*	<0.001	0.003
Outer nasal	170.72 (57.87)	169.97 (62.21)	178.13 (57.37)	178.67 (60.71)	142.25 (50.79)	136.55 (56.65)*	<0.001	0.001
Outer inferior	235.23 (62.00)	233.18 (66.00)*	243.19 (61.43)	242.57 (64.88)	204.63 (54.47)	197.11 (57.56)*	<0.001	0.004

Data are presented as mean (SD) unless otherwise indicated.

*p<0.05 for comparisons between the baseline and the follow-up using the paired t-test.

†Comparison between two groups using the Student's t-test for continuous data or χ^2 test for categorical data.

ACD, anterior chamber depth; AL, axial length; BCVA, best-corrected visual acuity; CCT, central corneal thickness; ChT, choroidal thickness; D, dioptre; IOP, intraocular pressure; logMAR, logarithm of minimum angle resolution; LT, lens thickness; PPA, parapapillary atrophy; SE, spherical equivalent.

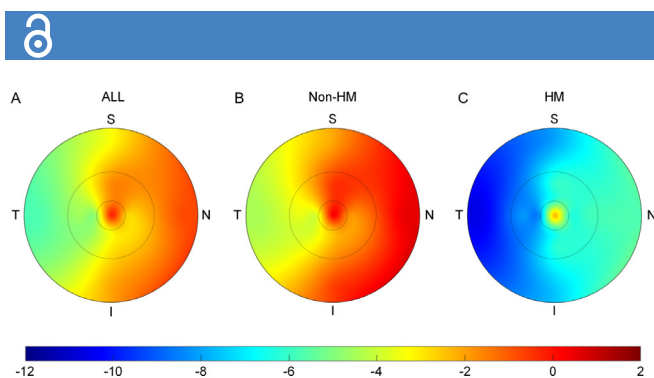


Figure 1 Topographic variation of the changes in choroidal thickness in all participants, non-high myopia (non-HM) group and HM group (A, B and C, respectively).

potentially leading to myopia if elongation exceeds the eyes' focal point.¹⁹ The prevalence of myopia reaches its peak, while that of hyperopia reaches its minimum at the age of 25, suggesting a possible age at which axial elongation ceases.^{20 21} In the current study, the mean AL elongation was 0.06 mm for non-HM eyes and 0.10 mm for HM eyes over 2 years, corroborating findings from previous studies on adult populations with HM in Japanese and Chinese demographics.^{22–24} For example, Saka *et al*²² observed significant AL increases of 0.13 mm over a 2-year period in adults aged 22–84 years, while Ohsugi *et al*²³ reported an annual AL increase of 0.04 mm in HM eyes without macular complications among individuals aged 34–82 years. Recently, Lee *et al*²⁴ reported an annual axial elongation rate of 0.05–0.07 mm in HM patients over 20 years old. Given that our study's participants were in their early adulthood (aged 18–30 years) and exhibited no obvious myopia-related complications, there exists a potential oversight in healthcare engagement and a tendency to overuse their eyes in this demographic. The continuous myopia progression in young adults

underscores a critical need for heightened surveillance and the implementation of preventative measures to curb the advancement of myopia and mitigate the risk of myopic maculopathy.²⁵

Choroidal thinning has been established as an important structural change in myopia in numerous animal studies and cross-sectional research of adults.^{26–29} Furthermore, longitudinal investigations in children have also reported marked choroidal thinning concurrent with myopia development.^{30–32} In this study, the mean change in ChT over 2 years was $-2.98 \mu\text{m}$ (range -83.53 to $43.90 \mu\text{m}$). This change parallels findings from a 1-year longitudinal study in adolescents aged 14–18 years,³² highlighting the choroid's pivotal role in the pathogenesis of HM and its association with myopic atrophy maculopathy, such as lacquer cracks and choroidal neovascularisation.³³ Compared with those without HM, young adults with HM experienced ChT decreasing over 2 years, indicating early structural changes during HM development, although pathological maculopathy typically manifests in later stages, predominantly among middle-aged and elderly people. In addition, a greater decrease was observed in ChT in the perifoveal temporal region compared with the perifoveal nasal and subfoveal regions. This difference may be attributed to the fact that the choroid is thickest in the temporal sector and thinnest in the nasal sector of all nine ETDRS sectors for eyes with HM, limiting the degree of change.^{29 34} The minimal change observed subfoveally may be protected for individuals with HM since central fovea plays a crucial role in determining visual acuity.

Various factors correlated with ChT changes in myopia have been widely discussed. Age is an important factor influencing choroidal changes; both children and adults with myopia have shown decreased ChT with age.³⁵ In

Table 2 Changes in choroidal thickness stratified by ocular parameters

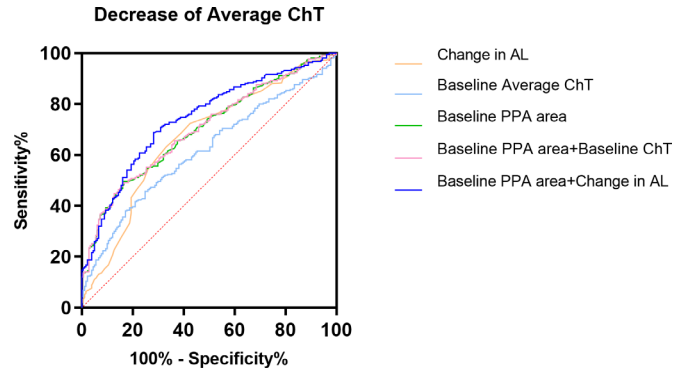
Variables	Non-high myopia (N=342)		High myopia (N=89)	
	N	Average ChT, μm	N	Average ChT, μm
Baseline average ChT				
<200 μm	80	-6.08 (13.03)	49	-9.15 (11.06)
$\geq 200 \mu\text{m}$	262	-0.55 (17.80)	40	-5.15 (12.21)
P value	0.003		0.109	
Change in AL				
<0.15 mm	270	-0.63 (17.25)	59	-5.24 (12.31)
$\geq 0.15 \text{ mm}$	72	-6.42 (15.06)	30	-11.51 (9.23)
P value	0.010		0.016	
Presence of PPA				
Without	105	0.10 (16.88)	15	-3.40 (10.81)
With	237	-2.71 (16.95)	74	-8.15 (11.78)
P value	0.157		0.152	

The data are the changes from baseline for each group, presented as mean (SD).
P value for comparisons between stratifications using the Student's t-test.
AL, axial length; ChT, choroidal thickness; PPA, parapapillary atrophy.

Table 3 Multivariate linear regression analysis of associated factors with the changes in average ChT

Variables	Whole cohort (N=431)		Non-high myopia (N=342)		High myopia (N=89)	
	β (95%CI)	P value	β (95%CI)	P value	β (95%CI)	P value
Gender	-2.156 (-5.098 to 0.785)	0.15	-2.882 (-6.426 to 0.662)	0.111	0.044 (-4.743 to 4.832)	0.985
Age, years	-1.025 (-1.675 to -0.375)	0.002	-1.097 (-1.898 to -0.297)	0.007	-0.717 (-1.673 to 0.238)	0.139
Baseline average ChT, μm	-0.024 (-0.052 to 0.004)	0.091	-0.034 (-0.067 to -0.001)	0.046	0.019 (-0.030 to 0.068)	0.440
Baseline PPA area, mm^2	-26.646 (-38.059 to -15.232)	<0.001	-32.100 (-48.697 to -15.503)	<0.001	-15.917 (-33.057 to 1.223)	0.068
Change in AL, mm	-35.230 (-47.217 to -23.243)	<0.001	-36.216 (-50.804 to -21.627)	<0.001	-30.044 (-48.204 to -11.884)	0.001

AL, axial length; ChT, choroidal thickness; PPA, parapapillary atrophy.

**Figure 2** Receiver operating characteristic curves of the decrease of average ChT. AL, axial length; ChT, choroidal thickness; PPA, parapapillary atrophy.

this study, older age, greater baseline ChT, larger PPA area and greater AL elongation were correlated with larger choroidal thinning in the non-HM group, while the change in AL was the solitary factor influencing ChT dynamics in the HM group. Moreover, every 1 mm increase of the change in AL was associated with a more significant decrease in macular ChT ($\beta=-36.216$, $p<0.001$) in the non-HM group compared with that in the HM group ($\beta=-30.044$, $p=0.016$). Duan *et al*¹⁴ found greater AL was the exclusive contributor to choroidal thinning in college students with HM. However, previous studies have shown discrepancies regarding the relationship between AL and ChT. In myopic children, the degree of choroidal thinning was found to be associated with AL.^{9 35 36} Furthermore, the ChT could predict the rates of ocular growth in chick eyes.³⁷ Troilo *et al*²⁷ and Xiong *et al*^{32 36} suggested a potential compensatory mechanism underlying choroid modulation during early-stage myopia progression. The association between the rate of AL elongation and the rate of choroidal thinning in this study also hinted at a potential mechanism affecting both ChT and AL in HM. Conversely, a faction of research demonstrates that the increase of AL is not significantly related to the decrease of ChT, attributing the observed differences to variances across study demographics, the effect of circadian rhythm, and the presence of unknown mechanisms governing choroidal changes.^{31 32 38 39}

The PPA area and changes in AL could predict whether the ChT decreased or not in the whole cohort. PPA is the temporal parapapillary region with uncovered Bruch's membrane, associated with axial elongation-induced optic disc rotation in myopic eyes.⁴⁰ The presence and enlargement of PPA are risk factors for pathological myopia.^{11 41} Our previous cross-sectional study¹⁰ discovered the PPA area was negatively correlated with the ChT. These observations are further validated by longitudinal analysis of the same cohort,⁴² indicating the potential of using artificial intelligence for PPA area quantification from fundus photographs, alongside routine AL measurement, to predict decreases in ChT, facilitating clinical application.

The study's main strength is its comprehensive follow-up of young adults. Nevertheless, several limitations warrant attention. The relatively short follow-up period and limited number of visits may have insufficient power to fully elucidate the changing process of biometrics and subtle relationships between the changes in ChT and other biometrics. Additionally, while the predictive ability (AUC=0.741) for choroidal thinning using baseline PPA area combined with change in AL is considered acceptable, it falls short of excellence. Furthermore, it should be noted that the participants of the study solely consisted of college students, limiting generalisability to a wider demographic. Finally, the omission of peripapillary ChT change analysis, which might be related to the structural changes of the optic disc in myopic eyes, represents a further limitation. Future studies should consider extending the duration of follow-up and increasing the frequency of evaluations to more accurately delineate the progression of ChT changes and their correlation with other ocular metrics so as to address these limitations.

CONCLUSION

HM eyes exhibited a significantly larger decrease in ChT than their non-HM counterparts. The elongation of AL and large PPA area indicated ChT thinning in young adults, pointing out the early change in HM and the underlying mechanism of pathological myopia.

Contributors ML and YS interpreted the data and drafted the article; JH interpreted the data and substantially revised the article; QC and JX analysed the data; GH and LY conducted the fieldwork for data acquisition; YF and JZ designed the study. XX made substantial contributions to the conception. JH is responsible for the overall content as the guarantor. All authors read and approved the final manuscript.

Funding This study was supported by the Three-year Action Program of Shanghai Municipality for Strengthening the Construction of Public Health System (GW11-1-22), National Key Research and Development Programme of China (Project No. 2019YFC0840607, 2022YF2502800), the National Natural Science Foundation of China (Project No. 82171100), the Clinical Science and Technology Innovation Project of Shanghai Shenkang Hospital (Project No. SHDC12020127).

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study was approved by the Ethics Committee of Shanghai General Hospital, Shanghai, China (approval number: 2015KY156) and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. The data analysed during the current study are available from the corresponding author on reasonable request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Menghan Li <http://orcid.org/0000-0002-5495-6150>

Xun Xu <http://orcid.org/0000-0002-4246-4343>

REFERENCES

- Baird PN, Saw S-M, Lanca C, *et al*. Myopia. *Nat Rev Dis Primers* 2020;6:99.
- Morgan IG, Ohno-Matsui K, Saw SM. Myopia. *Lancet* 2012;379:1739–48.
- Lee Y-Y, Lo C-T, Sheu S-J, *et al*. What factors are associated with myopia in young adults? A survey study in Taiwan military conscripts. *Invest Ophthalmol Vis Sci* 2013;54:1026–33.
- Yam JC, Tang SM, Kam KW, *et al*. High prevalence of myopia in children and their parents in Hong Kong Chinese population: the Hong Kong children eye study. *Acta Ophthalmol* 2020;98:e639–48.
- 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;53:7504–9.
- Xu L, Wang Y, Li Y, *et al*. Causes of blindness and visual impairment in urban and rural areas in Beijing: the Beijing eye study. *Ophthalmology* 2006;113:1134.
- Tang Y, Wang X, Wang J, *et al*. Prevalence and causes of visual impairment in a Chinese adult population: the Taizhou eye study. *Ophthalmology* 2015;122:1480–8.
- Tian F, Zheng D, Zhang J, *et al*. Choroidal and retinal thickness and axial eye elongation in Chinese Junior students. *Invest Ophthalmol Vis Sci* 2021;62:26.
- 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;168:164–76.
- Chen Q, He J, Yin Y, *et al*. Impact of the morphologic characteristics of optic disc on Choroidal thickness in young myopic patients. *Invest Ophthalmol Vis Sci* 2019;60:2958–67.
- Chen Q, He J, Hu G, *et al*. Morphological characteristics and risk factors of myopic maculopathy in an older high myopia population-based on the new classification system (ATN). *Am J Ophthalmol* 2019;208:356–66.
- Lv L, Zhang Z. Pattern of myopia progression in Chinese medical students: a two-year follow-up study. *Graefes Arch Clin Exp Ophthalmol* 2013;251:163–8.
- Harb E, Hyman L, Gwiazda J, *et al*. Choroidal thickness profiles in myopic eyes of young adults in the correction of myopia evaluation trial cohort. *Am J Ophthalmol* 2015;160:62–71.
- Duan F, Yuan Z, Deng J, *et al*. Choroidal thickness and associated factors among adult myopia: a baseline report from a medical University student cohort. *Ophthalmic Epidemiol* 2019;26:244–50.
- Flitcroft DL, He M, Jonas JB, *et al*. IML - defining and classifying myopia: a proposed set of standards for clinical and epidemiologic studies. *Invest Ophthalmol Vis Sci* 2019;60:M20–30.
- Hu G, Chen Q, Xu X, *et al*. Morphological characteristics of the optic nerve head and choroidal thickness in high myopia. *Invest Ophthalmol Vis Sci* 2020;61:46.
- Park H-YL, Lee K, Park CK. Optic disc torsion direction predicts the location of glaucomatous damage in normal-tension glaucoma patients with myopia. *Ophthalmology* 2012;119:1844–51.
- Bennett AG, Rudnicka AR, Edgar DF. Improvements on Littmann's method of determining the size of retinal features by fundus photography. *Graefes Arch Clin Exp Ophthalmol* 1994;32:361–7.
- Zadnik K, Manny RE, Yu JA, *et al*. Ocular component data in schoolchildren as a function of age and gender. *Optom Vis Sci* 2003;80:226–36.
- Hashemi H, Fotouhi A, Mohammad K. The age- and gender-specific prevalences of refractive errors in Tehran: the Tehran eye study. *Ophthalmic Epidemiol* 2004;11:213–25.
- Hashemi H, Iribarren R, Morgan IG, *et al*. Increased Hyperopia with ageing based on cycloplegic refractions in adults: the Tehran eye study. *Br J Ophthalmol* 2010;94:20–3.
- Saka N, Moriyama M, Shimada N, *et al*. Changes of axial length measured by IOL master during 2 years in eyes of adults with pathologic myopia. *Graefes Arch Clin Exp Ophthalmol* 2013;251:495–9.



- 23 Ohsugi H, Ikuno Y, Shoujou T, *et al.* Axial length changes in highly myopic eyes and influence of myopic macular complications in Japanese adults. *PLoS One* 2017;12:e0180851.
- 24 Lee JTL, Guo X, Li Z, *et al.* Progression and longitudinal biometric changes in highly myopic eyes. *Invest Ophthalmol Vis Sci* 2020;61:34.
- 25 Flores-Moreno I, Puertas M, Almazán-Alonso E, *et al.* Pathologic myopia and severe pathologic myopia: correlation with axial length. *Graefes Arch Clin Exp Ophthalmol* 2022;260:133–40.
- 26 Fitzgerald MEC, Wildsoet CF, Reiner A. Temporal relationship of choroidal blood flow and thickness changes during recovery from form deprivation myopia in chicks. *Exp Eye Res* 2002;74:561–70.
- 27 Troilo D, Nickla DL, Wildsoet CF. Choroidal thickness changes during altered eye growth and refractive state in a primate. *Invest Ophthalmol Vis Sci* 2000;41:1249–58.
- 28 Flores-Moreno I, Lugo F, Duker JS, *et al.* The relationship between axial length and choroidal thickness in eyes with high myopia. *Am J Ophthalmol* 2013;155:314–9.
- 29 Tan CSH, Cheong KX, Lim LW, *et al.* Topographic variation of choroidal and retinal thicknesses at the macula in healthy adults. *Br J Ophthalmol* 2014;98:339–44.
- 30 Fontaine M, Gaucher D, Sauer A, *et al.* Choroidal thickness and ametropia in children: a longitudinal study. *Eur J Ophthalmol* 2017;27:730–4.
- 31 Jin P, Zou H, Xu X, *et al.* Longitudinal changes in choroidal and retinal thicknesses in children with myopic shift. *Retina* 2019;39:1091–9.
- 32 Xiong S, He X, Zhang B, *et al.* Changes in choroidal thickness varied by age and refraction in children and adolescents: a 1-year longitudinal study. *Am J Ophthalmol* 2020;213:46–56.
- 33 Wang S, Wang Y, Gao X, *et al.* Choroidal thickness and high myopia: a cross-sectional study and meta-analysis. *BMC Ophthalmol* 2015;15:70.
- 34 Lee K, Lee J, Lee CS, *et al.* Topographical variation of macular choroidal thickness with myopia. *Acta Ophthalmol* 2015;93:e469–74.
- 35 Read SA, Fuss JA, Vincent SJ, *et al.* Choroidal changes in human myopia: insights from optical coherence tomography imaging. *Clin Exp Optom* 2019;102:270–85.
- 36 Xiong S, He X, Deng J, *et al.* Choroidal thickness in 3001 Chinese children aged 6 to 19 years using swept-source OCT. *Sci Rep* 2017;7:45059.
- 37 Nickla DL, Totonelly K. Choroidal thickness predicts ocular growth in normal chicks but not in eyes with experimentally altered growth. *Clin Exp Optom* 2015;98:564–70.
- 38 Wei WB, Xu L, Jonas JB, *et al.* Subfoveal choroidal thickness: the Beijing eye study. *Ophthalmology* 2013;120:175–80.
- 39 Duan F, Chen Z, Wang Z, *et al.* Longitudinal choroidal thickness changes among Chinese young adults with various refractive errors. *Front Med (Lausanne)* 2023;10:1036087.
- 40 Jonas JB, Wang YX, Zhang Q, *et al.* Parapapillary gamma zone and axial elongation-associated optic disc rotation: the Beijing eye study. *Invest Ophthalmol Vis Sci* 2016;57:396.
- 41 Fang Y, Yokoi T, Nagaoka N, *et al.* Progression of myopic maculopathy during 18-year follow-up. *Ophthalmology* 2018;125:863–77.
- 42 Hu G, Xie J, Shi Y, *et al.* Morphological characteristics of the optic nerve head and impacts on longitudinal change in macular choroidal thickness during myopia progression. *Acta Ophthalmol* 2022;100:e1708–18.