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

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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±56.15 µm in the non-HM group and 198.43±50.27 µm 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±11.70 µm) than the non-HM group (−1.85±16.95 µm, p=0.004). Multivariate regression analysis showed that a greater reduction of ChT was associated with baseline PPA area (β=−26.646, p<0.001) and the change in AL (β=−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.

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.

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 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 ≤−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≥20/25, IOP≤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 ≤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 µm and an axial resolution of 8 µm.[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 µm, and the 95% limits of agreement ranged from −7 to 6 µm. 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 mm^2) 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 mm^2 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, µm	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, µm								
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 $\chi 2$ 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.

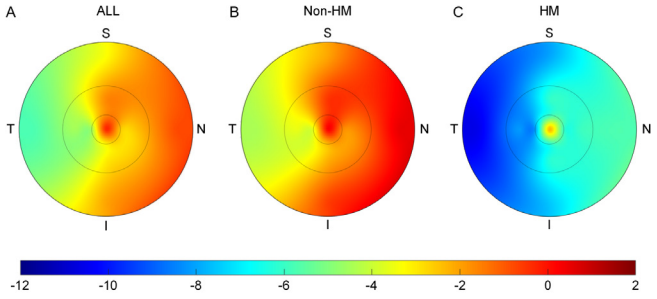

Figure 1 Topographic variation of the changes in choroidal thickness in all participants, non-high myopia (non-HM) group and HM group (A, B and C, respectively).

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 µm (range −83.53 to 43.90 µm). 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

	Non-high myopia (N=342)		High myopia (N=89)	
Variables	**N**	**Average ChT, µm**	**N**	**Average ChT, µm**
Baseline average ChT				
<200 µm	80	−6.08 (13.03)	49	−9.15 (11.06)
≥200 µm	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)
≥0.15 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.

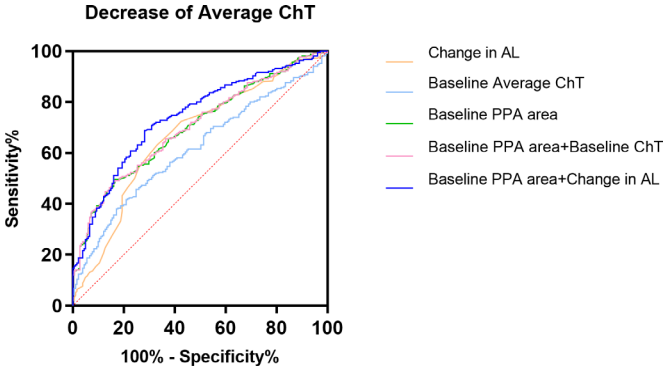

Figure 2 Receiver operating characteristic curves of the decrease of average ChT. AL, axial length; ChT, choroidal thickness; PPA, peripapillary atrophy.

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 (β=−36.216, p<0.001) in the non-HM group compared with that in the HM group (β=−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 study[10] 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 substantively 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.

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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.

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Table S1. Logistic Regression Analysis of Associated Factors With the Decrease of Average ChT

Variables	Univariate			Multivariate		
	OR	95%CI	P value	OR	95%CI	P value
Gender, male vs female	1.061	0.724 to 1.555	0.762	0.691	0.443 to 1.078	0.104
Age, per 1 y increase	1.114	1.014 to 1.223	0.024	1.127	1.017 to 1.249	0.022
Baseline average ChT, per 1 μm	0.994	0.991 to 0.998	0.001	1.001	0.997 to 1.006	0.488
Baseline PPA area, per 0.01 mm^2	1.062	1.043 to 1.080	< 0.001	1.063	1.042 to 1.084	< 0.001
Change in AL, per 0.01 mm	1.051	1.032 to 1.070	< 0.001	1.045	1.025 to 1.066	< 0.001

AL = axial length; ChT = choroidal thickness; CI = confidence interval; OR = odds ratio; PPA = parapapillary atrophy.

Figure S1. Bland-Altman plot illustrating the reproducibility of the average choroidal thickness (ChT) measured twice by one technician.

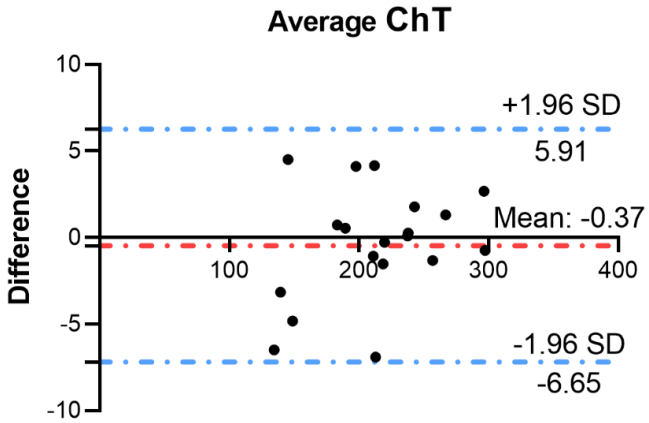
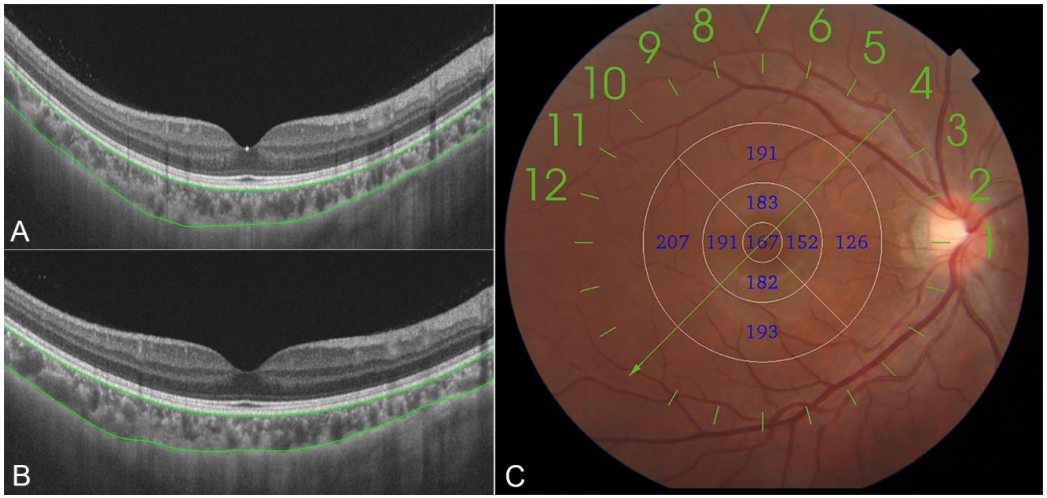


Figure S2. A map showing the choroidal thickness (ChT) in an 18-year-old man (right eye) obtained by swept-source optical coherence tomography in 2016 (**A**) and 2018 (**B**). The Early Treatment Diabetic Retinopathy Study grid was applied to the map, and the mean ChT was obtained for each sector (**C**).



STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3-4
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6-7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	/
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	6-8
Study size	10	Explain how the study size was arrived at	-
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	-
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	-
		(*e*) Describe any sensitivity analyses	-

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	9
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9
		(b) Indicate number of participants with missing data for each variable of interest	9
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	9
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	9
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	-
		Cross-sectional study—Report numbers of outcome events or summary measures	-
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-11
		(*b*) Report category boundaries when continuous variables were categorized	9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-10
Discussion			
Key results	18	Summarise key results with reference to study objectives	11,14,15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	11-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	-
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.