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How do choroidal metrics evolve with age? A Wide-Field Swept- Source OCT Angiography study

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How do choroidal metrics evolve with age? A Wide-Field Swept-Source OCT Angiography study

Short title: Age-Related Changes in Choroidal Metrics

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Abstract

The purpose of this study is to establish age-stratified normative values for choroidal thickness (CT) and choroidal vascularity index (CVI) in healthy adult eyes using 24×20 mm widefield swept-source OCTA (WF-OCTA), and to evaluate regional variations across the posterior pole and retinal periphery.

While CT is widely used to assess choroidal structure, it varies with physiologic factors such as age and refractive status. CVI has been proposed as a more stable marker because it reflects the proportion of vascular luminal area within the choroid. However, normative widefield data for CT and CVI across age groups remain limited.

This was a cross-sectional observational study analyzing 24×20 mm WF-OCTA exams.

A total of 122 eyes from 64 subjects were included. Choroidal thickness decreased considerably with age, with the strongest decline in the central sector. The age-related thinning was not homogeneous, showing regional variation across sectors. CVI remained relatively stable with age, with only limited sector-specific variation. CVI was generally highest in the superior-temporal sector and lowest in the central sector.

Ultra-widefield OCTA provides useful normative data for assessing choroidal structure in healthy eyes. Our findings suggest that CVI may be a more robust biomarker for evaluating choroidal changes.

Introduction

Choroidal vasculature is the main source of oxygen and nutrients for the retinal pigment epithelium (RPE) and the photoreceptors in the outer retina. Retinal imaging has proven to be particularly useful in assessing the health and functionality of the choroid through various biomarkers such as choroidal thickness (CT) or choroidal vascularity index (CVI). CT is classically measured from the Bruch's membrane to the sclera, therefore incorporating both the stroma and the vasculature. Moreover, CT is dependent on several factors, such as age, axial length, sex [1], circadian rhythm [2], hydration [3], exercise [4], etc. Furthermore, CVI is a newer metric, defined as the ratio between luminal choroidal area (LCA) and total choroidal area (TCA) [5], that has proven less sensitive to the different factors that influence CT. CVI variations have been extensively studied in recent years in a number of retinal diseases, as well as in healthy eyes. The major limitation, however, was that these previous studies assessed CVI on a single B-scan passing through the macula or, at most, on a 6x6 mm acquisition window.

The recent introduction of wide-field optical coherence tomography angiography (WF-OCTA) has allowed unprecedented analysis of not only retinal, but also choroidal parameters in regions further away from the macula, ultimately enabling an improved understanding of both CT and CVI in healthy and diseased eyes. This is relevant because aging-related changes may not be uniform across regions; relying solely on macular measurements may therefore overlook meaningful peripheral trends or underestimate the extent of global choroidal remodeling. Despite growing interest in CT and CVI as quantitative biomarkers, normative widefield data describing how these parameters evolve with age remain limited. Establishing age-related trajectories across an extended field of view is necessary to define reference ranges, improve inter-study comparability, and provide a baseline against which early disease-related deviations can be detected. Such normative characterization is also essential for the interpretation of widefield choroidal biomarkers in clinical research, where age is a major confounder. Herein, we present a study aiming to determine the variability across ages of choroidal-related metrics using a single 24x20mm WF-OCTA.

Results

Demographics and Baseline Measures

The final cohort comprised 122 eyes from 64 patients, age raging from 19 to 90, with a mean of 45.73 ± 19.32 years. Overall, 67.20% of participants were female (43/64), contributing 83 eyes (68%), while males accounted for 28.79% (21/64), contributing 39 eyes. Mean age was comparable between sexes: 45.86 ± 18.24 years in females and 45.64 ± 22.19 years in males.

Participants were stratified into decade-based age groups. The distribution of eyes across age categories was as follows: 19–29 years, 33 eyes; 30–39 years, 33 eyes; 40–49 years, 10 eyes; 50–59 years, 14 eyes; 60–69 years, 11 eyes; and ≥70 years, 22 eyes [able 1, Figure 2].

Choroidal Thickness (CT) Analysis

The mean choroidal thickness (CT) across the entire cohort was 178.43 ± 64.08 µm [Table 1]. CT was greatest in the central (subfoveal) sector (234.53 ± 75.84 µm) and lowest in the inferonasal sector (114.02 ± 40.84 µm). Sector-specific CT values for all nine regions are detailed in Table 1.

In analyses treating age as a continuous variable, CT showed a modest correlation with age [Table 2, Figure 3]. The rate of CT decline varied by sector: the steepest decrease was observed in the middle sector (27.11 µm per decade), while the smallest decline occurred in the superior-temporal sector (11.76 µm per decade). A decline in CT became apparent from the 30–39-year age group onward, with a more pronounced reduction in the central sector and a comparatively smaller change in the superior-temporal sector.

When stratified by sex, the mean CT was 176.14±49.13 µm in women and 188.97±65.23 µm in men [Table 3]. However, there were no statistically significant sex-related differences in CT in any of the nine sectors. Comparisons between right and left eye revealed no significant inter-eye differences across sectors, with a strong inter-eye correlation [Table 4].

Choroidal Vascularity Index (CVI) Analysis

The mean choroidal vascularity index (CVI) for the overall cohort was 43.79% ± 4.46% [Table 1]. CVI was highest in the superior-temporal sector (46.25% ± 3.79%) and lowest in the central sector (39.64% ± 2.78%).

CVI remained relatively stable up to 40 years of age, followed by a modest increase (45.29%) and then a slight decline thereafter [Table 2, Figure 3]. The most pronounced decrease was observed in the nasal sector (1.23% per decade), whereas the smallest decline occurred in the superior-middle sector (0.23% per decade).

Consistent with the CT results, mean CVI was similar between sexes: 43.93% ± 4.46% in women and 43.49% ± 5.44% in men [Table 2]. No statistically significant sex-related differences in CVI were found in any of the nine sectors.

Right–left eye comparisons showed no significant differences across sectors, except for the infero-nasal and infero-temporal sectors. Inter-eye correlation for CVI was moderate [Table 4].

Discussion

Using widefield SS-OCTA metrics, this study provides a normative characterization of choroidal structure across age, with emphasis on the regional (sectoral) behavior of CT and CVI. The principal findings are: (1) CT shows a clear age-related decline, most pronounced centrally; (2) mean CVI is relatively stable through early adulthood, rose slighty around 40-49 age group (45.29%) and declined modestly thereafter (Table 1); and (3) neither CT nor CVI demonstrated meaningful sex-related differences, while inter-eye agreement was generally strong (with a limited sectoral exception for CVI).

Across our cohort, CT was thickest in the middle (subfoveally) (234.18±74.96μm) and thinnest in the inferior-nasal sector (114.02±40.84), consistent with a non-uniform, posterior pole architecture.

This “center-dominant” thinning pattern is clinically intuitive for two reasons. First, the macular choroid is anatomically distinct: it is generally the thickest region and supports the highest metabolic demand of the outer retina/RPE complex. Second, regional thinning gradients likely reflect a combination of vascular involution, stromal remodeling, and biomechanical constraints at the choroidoscleral interface that do not operate uniformly across the fundus.

Moreover, the observation that thinning becomes apparent from the 30–39 decade onward and is more pronounced centrally than in superior-temporal regions, further supports the concept of asymmetric, region-specific aging rather than a global, homogeneous “shrinkage” phenomenon.

This finding is consistent with that of Manjunath et al., who, in 2010, showed that choroidal thickness was moderately negatively correlated with age ($r = -0.61$, $p < 0.0001$), using a 6mm 1-line raster. [6]

In contrast to CT, CVI showed a smaller magnitude of age association. Overall, CVI averaged ~44% and displayed sectoral variability, being highest in the superior-temporal sector and lowest centrally in this dataset.

Notably, CVI remained relatively stable through early adulthood, with only modest changes thereafter. This pattern was not formally tested for nonlinearity and should be interpreted cautiously given the small size of the cohort.

Conceptually, this divergence between CT and CVI is important. CT is a composite structural measure influenced by both vascular lumen and stromal compartment thickness. CVI, by design, reflects the proportion of vascular lumen (LCA) within the choroid (TCA), and therefore may remain relatively stable even when the overall choroid thins, particularly if stromal reduction dominates or if luminal and stromal components decline proportionally. This mechanistic distinction likely explains why CT often shows a stronger age signal than CVI, and why CVI is frequently discussed

as a potentially more robust biomarker in conditions where CT alone is confounded by physiological or anatomic variability.

Another essential point is that while CVI has been defined in two dimensions, on a single OCT scan. For instance, Thompson et al, who analyzed the central CVI 1500μm using 21 lines enhanced depth imaging (EDI) foveal scan at the fovea of the Zeiss Cirrus HD 5000 SD-OCT and reported no strong association between CVI and age. [7]

However, more recent imaging technologies now allow three-dimensional evaluation of the choroid, which may better capture age-related structural variation. This was supported by the study by Qu et al. [8], who analyzed three-dimensional CVI over a 120° field of view in healthy Chinese adults and found a negative correlation between CVI and age, suggesting an age-related reduction in luminal choroidal volume. They also reported a slightly lower mean CVI, around 31%, with the highest values observed in the central sector, as well as strong inter-eye agreement.

Valsecchi et al proved that CT and CVI differ in individuals having pachychoroid syndrome vs controls. In their group, the CT of pachychoroid-like eyes was thickest than that of healthy controls (269.8 ± 71.2 μm vs 224.0 ± 43.4 μm) while the CVI did not vary substantially (37.23% vs 40.65%). Their finding that CT was the thickest centrally matches ours. [9]

Our findings reinforce the concept that the choroid is neither a homogeneous vascular bed nor a uniformly curved structure, but rather a complex, segmental, and biomechanically dynamic tissue whose geometry is determined by both intrinsic vascular anatomy and extrinsic ocular growth parameters.

This study is intended as a normative dataset for future comparisons in different pathologies such as high myopia and pachychoroid syndrome.

Several limitations should be considered. First, children were not included, which restricts inference about developmental choroidal trajectories. Second, the sample size—particularly within some decade strata—was modest, which may limit power for detecting subtle sectoral effects or nonlinear age relationships. Third, diurnal variation was not controlled, as imaging occurred once per subject at varying times; this may add noise to the measurement, especially for CT. Finally, because both eyes from some participants were included, future analyses may benefit from mixed-effects modeling to explicitly account for within-subject correlation.

Future work should prioritize longitudinal follow-up to distinguish true aging trajectories from cross-sectional cohort effects. Incorporating additional OCTA-derived vascular flow metrics and exploring curvature/contour parameters alongside CT and CVI may also clarify how structure, vascular composition, and biomechanical determinants interact across the lifespan and in disease.

In conclusion, our study provides a normative database across age using WF-OCTA, demonstrating that, in addition to other well-known middle-aged decline of CT, there is an asymmetric, region-specific decline in CT. In contrast to CT, CVI remained stable throughout age groups, but showed an asymmetrical, sector-specific decline.

Methods

Patient selection

This is a cross-sectional observational study in adult patients. This study was approved by the Federation France Macula number 17/2025. It corresponds to ethical principles of the Helsinki Declaration. It was conducted in the Department of Ophthalmology, Créteil Intercommunal Hospital between April 2025 and November 2025. Written informed consent was obtained from all participants prior to enrollment in the study, in accordance with the Declaration of Helsinki.

Inclusion criteria consisted of healthy consenting individuals, without any prior ophthalmological history, except cataract surgery (minimum 3 months prior). The exclusion criteria were any previous diagnosis of Alzheimer disease, diabetes, ophthalmological diseases such as age-related macular degeneration (AMD), retinal vascular diseases, glaucoma, high myopia or hyperopia (>6 dioptres in absolute value), pachychoroid spectrum, prior retinal laser, optic neuropathy or non-cooperating patients.

If both eyes met the inclusion criteria, both were included in the study; otherwise, the single qualifying eye was included.

All patients underwent a complete ophthalmological workup including best corrected visual acuity, intraocular pressure measurements, slit lamp examination and posterior pole photographs.

Imaging

Ultra-widefield SS-OCTA (TowardPi BMizar; TowardPi Medical Technology, Beijing, China) was used to acquire 24 × 20 mm fundus images at a scan rate of 400 kHz. A fovea-centered rectangular scan (24 × 20 mm) corresponds to a 120° field of view. The built-in software automatically segmented the choriocapillaris, defined as the slab extending from the basal border of the RPE–Bruch's membrane complex to 20 µm below it. The CVI was defined as the ratio between the LCA and the TCA, which was calculated for each region across Sattler's layer and Haller's layer using the typical binarization method [10] by the built-in software. For analysis, each 24 × 20 mm image was partitioned into nine equal sectors (8 × 6.7 mm each) : superior-temporal, superior-middle, superior-nasal, nasal, inferior-nasal, inferior-middle, inferior-temporal, temporal, and middle [Figure 1]. Poor quality images were excluded. Overall grid statistics for CT and CVI [Table 1] were computed automatically by the software.

Statistics

Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) served as the software for data analysis. We first determined descriptive statistics for the cohort, reporting the mean and standard deviation for the continuous variables (CVI and CT),

alongside demographic characteristics (age, sex, and presence of systemic disease). The influence of sex and systemic disease on CVI and CT was assessed by comparing means using Generalized Estimating Equations. Furthermore, linear regression models were used to explore the relationship between age and CVI. Statistical significance was set at $p < 0.05$.

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Ioana Albutiu, Nika Vrabic, Kamal El Madjoubi El Idrissi, Andreea Sorana Pacurariu: no financial disclosures.

Data availability: The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions
I.A. and A.M. designed the study. I.A., N.V., K.E.M.E.I. and A.S.P. contributed to data collection and image review. I.A. performed the initial data analysis and drafted the manuscript. A.M. and E.S. supervised the study and critically revised the manuscript. All authors reviewed and approved the final manuscript.

Competing interests
The authors declare no competing interests.

Additional information
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Figure legends

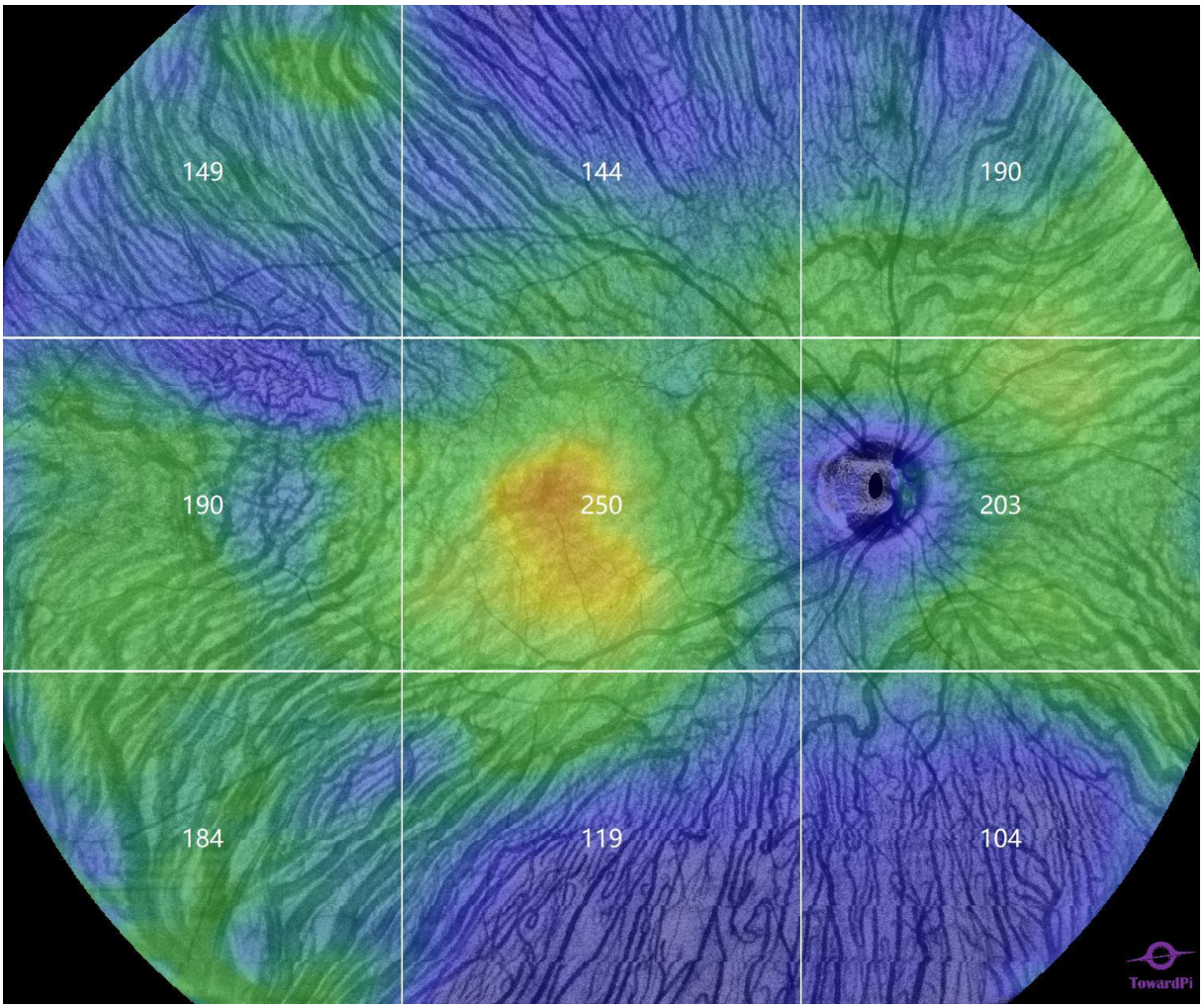
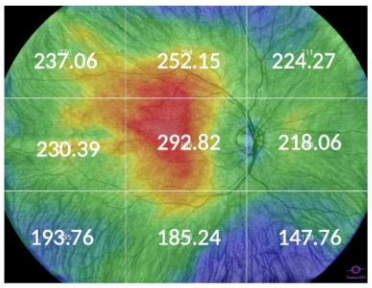
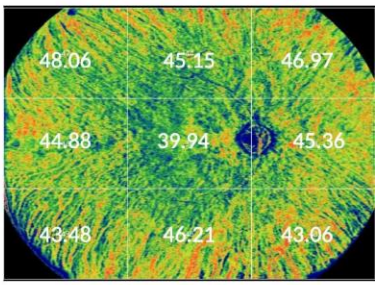
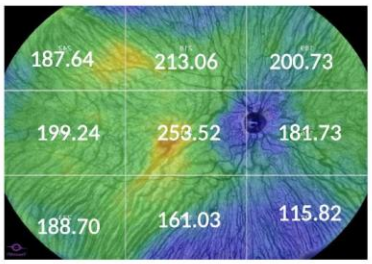
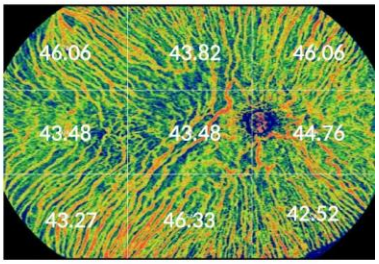
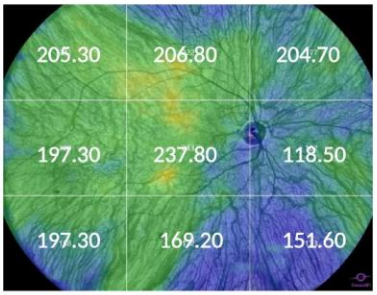
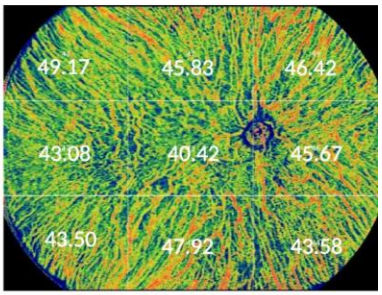
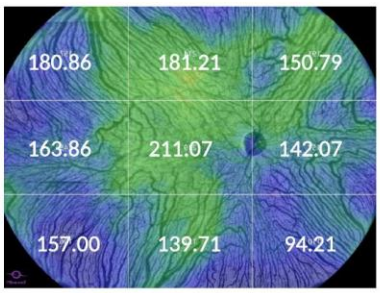
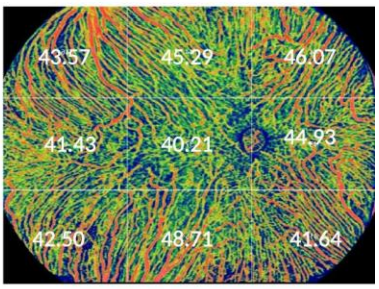
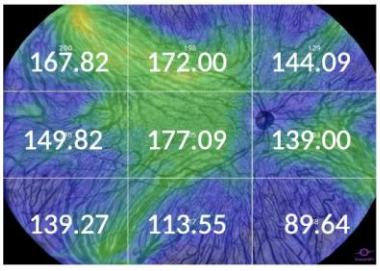
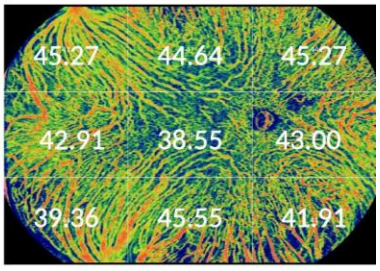
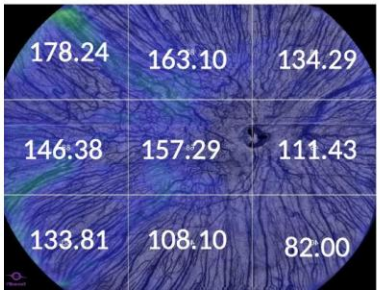
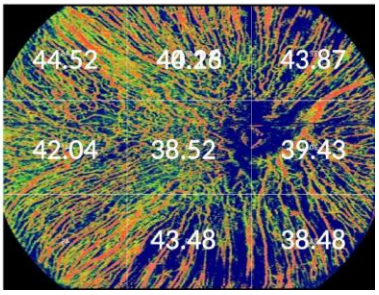


Figure 1: Name and distribution of the sectors

Age group (years old)	N° of patients	CT (µm)	CVI (%)
19-29	33		
30- 39	33		
40-49	11		
50-59	14		
60-69	11		
>70	22		

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Figure 2: CT and CVI distribution of sectors and group mean

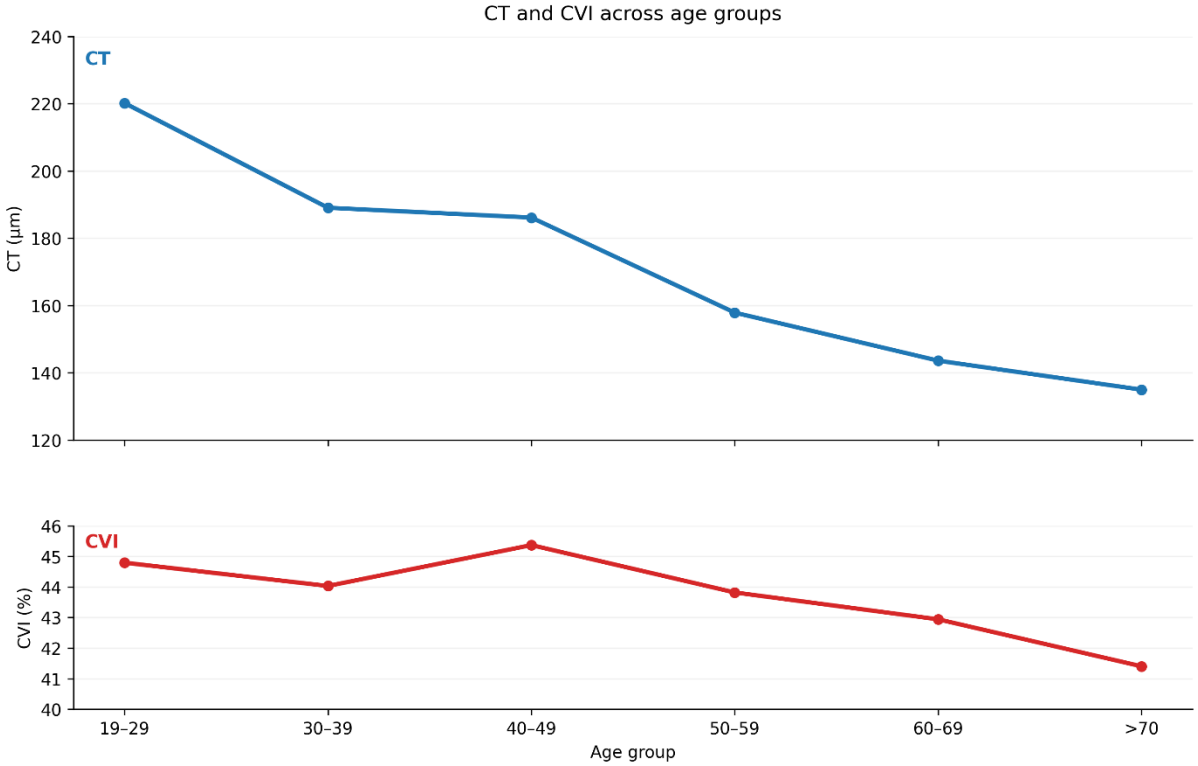


Figure 3: CT and CVI age correlation

CT											
Age group	*Number of eyes*	*SUPERIOR-TEMPORAL*	*SUPERIOR-MIDDLE*	*SUPERIOR-NASAL*	*NASAL*	*INFERIOR-NASAL*	*INFERIOR-MIDDLE*	*INFERIOR-TEMPORAL*	*TEMPORAL*	*MIDDLE*	*Overall average*
19-29	33	237.06	252.15	224.27	218.06	147.76	185.24	193.76	230.39	292.82	220.17
30-39	33	187.64	213.06	200.73	181.73	115.82	161.03	188.70	199.24	253.52	189.05
40-49	10	205.30	206.80	204.70	184.00	118.50	151.60	169.20	197.30	237.80	186.13
50-59	14	180.86	181.21	150.79	142.07	94.21	139.71	157.00	163.86	211.07	157.87
60-69	11	167.82	172.00	144.09	139.00	89.64	113.55	139.27	149.82	177.09	143.59
>70	21	178.24	163.10	134.29	111.43	82.00	108.10	133.81	146.38	157.29	134.96
CVI											
19-29	33	48.06	45.15	46.97	45.36	43.06	46.21	43.48	44.88	39.94	44.79
30-39	33	46.06	43.82	46.06	44.76	42.52	46.33	43.27	43.48	39.97	44.03
40-49	10	49.30	46.20	46.10	45.40	43.20	48.50	43.80	45.10	40.70	45.37
50-59	14	43.57	45.29	46.07	44.93	41.64	48.71	42.50	41.43	40.21	43.82
60-69	11	45.27	44.64	45.27	43.00	41.91	45.55	39.36	42.91	38.55	42.94
>70	21	44.38	44.00	43.57	39.24	38.33	43.43	39.95	41.48	38.24	41.40

Table 1: Choroidal thickness (CT) and choroidal vascularity index (CVI)

CT	**SUPERIOR-TEMPORAL**	**SUPERIOR-MIDDLE**	**SUPERIOR-NASAL**	**NASAL**	**INFERIOR-NASAL**	**INFERIOR-MIDDLE**	**INFERIOR-TEMPORAL**	**TEMPORAL**	**MIDDLE**
R-square	0.15	0.27	0.33	0.36	0.28	0.32	0.22	0.40	0.40
Mean	198.27	207.16	185.15	171.24	114.02	150.97	170.93	189.89	234.53
SD	48.34	59.75	61.45	60.97	40.84	48.14	51.75	47.33	75.84
Mean decline/decade (µm/decade)	11.76	17.81	18.00	21.33	13.15	15.43	11.99	16.80	27.11
95% CI	[-14.31 ; -3.73]	[-21.69 ; -9.01]	[-23.74 ; -12.74]	[-25.22 ;-12.29]	[-15.17 ; -6.64]	[-19.07 ; -9.08]	[-16.94 ; -8.15]	[-19.52 ; -10.87]	[-32.11; -17.36]

CVI

R-square	0.13	0.01	0.10	0.24	0.10	0.05	0.07	0.10	0.05
Mean	46.22	44.65	45.81	43.89	41.84	46.18	42.36	43.36	39.62
SD	3.84	2.08	3.45	3.76	4.84	3.68	6.09	3.96	2.78
Mean decline/decade (%/decade)	0.74	0.23	0.68	1.23	0.95	0.56	0.71	0.68	0.34
95%CI	[-0.98 ; -0.42]	[-0.33 ; 0.22]	[-0.96 ; -0.11]	[-1.43 ; -0.49]	[-1.31 ; -0.25]	[-0.91 ; 0.08]	[-1.42 ; -0.21]	[-0.96 ; 0.05]	[-0.81 ; -0.33]

SD=standard deviation ; CI=confidence interval

Table 2: CT and CVI age correlation

CT	*SUPERIOR-TEMPORAL*	*SUPERIOR-MIDDLE*	*SUPERIOR-NASAL*	*NASAL*	*INFERIOR-NASAL*	*INFERIOR-MIDDLE*	*INFERIOR-TEMPORAL*	*TEMPORAL*	*MIDDLE*	*Overall average*
P	0.21	0.15	0.10	0.27	0.06	0.28	0.20	0.19	0.78	
Mean ♀	194.52	201.87	178.84	167.02	109.22	147.70	166.81	186.01	233.23	176.14
SD ♀	44.38	52.29	53.48	53.69	37.80	42.34	49.81	41.78	66.64	49.13
Mean ♂	206.26	218.44	198.56	180.21	124.23	157.92	179.69	198.15	237.31	188.97
SD ♂	55.61	72.65	74.71	74.14	45.50	58.64	55.29	57.12	93.39	65.23

CVI										
P	0.42	0.12	0.71	0.19	0.77	0.67	0.98	0.44	0.25	
Mean ♀	46.04	44.48	45.72	43.57	41.78	46.00	42.35	43.24	39.41	43.62
SD ♀	4.07	2.16	3.44	3.91	4.86	3.90	5.39	3.93	2.95	4.47
Mean ♂	46.64	45.13	45.97	44.51	42.05	46.31	42.38	43.85	40.03	44.12
SD ♂	3.26	1.96	3.49	3.30	4.59	3.20	7.43	4.16	2.25	4.49

SD=standard deviation

Table 3: Statistical differences between men and women

CT	*SUPERIOR-TEMPORAL*	*SUPERIOR-MIDDLE*	*SUPERIOR-NASAL*	*NASAL*	*INFERIOR-NASAL*	*INFERIOR-MIDDLE*	*INFERIOR-TEMPORAL*	*TEMPORAL*	*MIDDLE*
P	0.72	0.90	0.94	0.99	0.22	0.91	0.07	0.73	0.64
R square	0.83	0.89	0.86	0.91	0.77	0.85	0.55	0.90	0.96
CVI									
P	0.83	0.44	0.52	0.53	0.00	0.54	0.01	1.00	0.36
R square	0.57	0.69	0.54	0.74	0.58	0.70	0.45	0.55	0.77

Table 4: Right versus left eye comparison