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Associations of Bioelectrical Impedance-Derived Body Composition Parameters with Choroidal Thickness in Healthy Adults

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Abstract

Purpose

To evaluate the associations between bioelectrical impedance-derived body composition parameters and choroidal thickness (ChT) and choroidal vascularity index (CVI) in healthy adults.

Methods

This cross-sectional study involved 40 eyes from 40 healthy individuals. All participants underwent bioimpedance analysis to evaluate body composition parameters. Axial length (AL) was measured using optical biometry. Central and regional choroidal thickness (ChT), central macular thickness, and choroidal vascularity index (CVI) were derived from optical coherence tomography (OCT) images.

Results

The study group consisted of 26 females and 14 males. In univariate analysis, BMI showed the strongest inverse correlation with central ChT ($\rho = -0.493$, $p = 0.001$), although this association didn't remain significant after FDR correction ($q = 0.078$). In multivariable regression adjusted for age, sex, and axial length, BMI ($p = 0.002$) and axial length ($p = 0.008$) were independent predictors of central ChT ($R^2 = 0.492$, $p < 0.001$). The lean tissue index showed a suggestive inverse association with temporal ChT in a separate model $p = 0.021$), although the overall model didn't reach statistical significance ($p = 0.114$).

Conclusions

BMI and AL are independently associated with ChT in healthy adults, with higher BMI linked to a thinner central choroid even after accounting for AL. Body composition characteristics may influence choroidal structure, but the lack of significant associations with CVI suggests that these effects involve overall choroidal thinning rather than selective vascular loss. These findings need confirmation in larger cohorts.

INTRODUCTION

The choroid is located between the retinal pigment epithelium and the sclera, supplying blood vessels to the outer retina and the retinal pigment epithelium (1). It is the body's most vascular tissue relative to its weight, receiving around 70% of ocular blood flow (2). The choroid consists of three vascular layers: the choriocapillaris (the innermost layer with the smallest vessels), Sattler's layer, and Haller's layer, along with melanocytes, stromal tissue, and extracellular fluid. These layers contain progressively larger vessels that form the choroidal structure (1–3). Due to its rich vascular network and significance in ocular metabolism, the choroid plays a crucial role in the development of ocular diseases. Increasing

evidence indicates that systemic conditions such as hypertension, chronic kidney disease, and obesity, which influence systemic blood flow, are linked to changes in choroidal vascularity (4–6).

Enhanced depth imaging optical coherence tomography (EDI-OCT) is currently the most used method for assessing choroidal structure in healthy populations and in the presence of various diseases (7). Choroidal thickness (ChT) measurement indicates the distance between the retinal pigment epithelium and the scleral border, providing information about overall choroidal dimensions. The Choroidal Vascularity Index (CVI), calculated from the ratio of luminal to total choroidal area, serves as an additional quantitative measure related to the proportion of choroidal vascularity (4, 5, 8).

Bioelectrical impedance analysis (BIA) is a quick, non-invasive, and repeatable method used for assessing body composition and fluid distribution (9). This technique measures how electrical current passes through fat, lean tissue, and body fluids, which all have different electrical conductivity properties. Lean tissue and intracellular/extracellular fluids conduct electricity more effectively than fat tissue, enabling the estimation of parameters like total body water (TBW), intracellular water (ICW), extracellular water (ECW), fat mass, lean tissue index (LTI), and phase angle (PhA) (10, 11). Phase angle, a marker of cellular integrity and membrane function, is increasingly seen as an indicator of nutritional and inflammatory status (9). Alterations in fluid distribution and tissue composition have been linked to systemic inflammation, endothelial dysfunction, and microvascular changes (9–11).

Emerging evidence indicates that systemic metabolic changes may affect ocular microcirculation. The choroidal vasculature is highly fenestrated and mainly regulated by systemic perfusion pressure, so changes in body composition and vascular health could potentially impact choroidal structure (12,15). However, choroidal thickness is also greatly influenced by axial length, with longer eyes having thinner choroids, and this relationship must be considered in any analysis of systemic factors affecting choroidal structure. Although some studies have explored the link between systemic metabolic factors and ChT, to our knowledge, no research has examined this relationship using BIA-derived body composition parameters while also accounting for axial length and assessing both ChT and CVI. By combining systemic bioimpedance data with detailed choroidal imaging, our study investigates whether systemic body composition parameters are associated with choroidal structural and vascular indices.

METHODS

This prospective cross-sectional study was carried out by the Departments of Ophthalmology and Internal Medicine at Uşak Training and Research Hospital between January 2026 and February 2026. The study protocol received approval from the Ethics Committee of Uşak University (Approval No: 1054-1054-14) and followed the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

A total of 42 healthy participants were initially enrolled. Two participants were excluded due to unreliable choroidal images, resulting in a final sample of 40 participants. For each participant, one eye was randomly chosen for analysis using a computer-generated randomization sequence. Inclusion criteria

required no history of systemic diseases, chronic ocular pathologies, or surgical interventions, with spherical and cylindrical refractive measurements between − 3.00 and + 3.00 diopters. All participants underwent a comprehensive ophthalmologic examination conducted by the same experienced ophthalmologist (ŞNÇ), including best-corrected visual acuity (BCVA), slit-lamp biomicroscopy, intraocular pressure measurement by Goldmann applanation tonometry, gonioscopy, and dilated fundus examination.

OCT Imaging

OCT measurements were taken between 9:00 and 11:00 a.m. after pharmacological pupil dilation with 1% tropicamide to reduce diurnal variation. Imaging was conducted using the Canon OCT-HS100 (Canon Inc., Tokyo, Japan) along with its proprietary software (v.4.5.3). Since this device lacks an enhanced depth imaging module, images including the scleral border were manually captured for choroidal thickness measurements. ChT was measured at three points: subfoveal (central), 750 µm nasal to the fovea, and 750 µm temporal to the fovea. The CVI was calculated using the binarization method described by Sonoda et al (16). All measurements were performed by a single trained grader (AB) and independently verified by a second grader (ŞNÇ). Intragrader and intergrader reliability were assessed with intraclass correlation coefficients (ICC). The ICC for subfoveal ChT was 0.96 (95% CI: 0.93–0.98) for intragrader and 0.94 (95% CI: 0.89–0.97) for intergrader reliability.

When the OCT device exported images in pseudocolor format (e.g., Topcon devices using a blue-to-red colormap), a custom preprocessing step was applied prior to binarization. The pseudocolor images were converted to 8-bit grayscale using an HSV-based hue-to-intensity mapping algorithm implemented in Python (version 3.x; Python Software Foundation, Wilmington, DE, USA). In this conversion, the hue channel was used to reconstruct signal intensity: blue hues (corresponding to low OCT signal) were mapped to low grayscale values, while red hues (high signal) were mapped to high values, consistent with the device's native lookup table. This step was necessary because direct 8-bit conversion of pseudocolor images yields arbitrary intensity values unsuitable for threshold-based binarization. When native grayscale or raw signal exports were available from the device, this preprocessing step was omitted.

Composite four-panel figures were generated using a custom Python script (Pillow 10.x, NumPy 1.x) to ensure pixel-accurate reproduction of the analysis results at full original resolution. Each figure consisted of: (A) the original OCT B-scan with the choroidal ROI outlined in yellow; (B) the Niblack-binarized image with the ROI outlined; (C) the color-coded choroidal map, where luminal areas within the ROI were rendered in yellow and stromal areas in blue, blended over the original grayscale image; and (D) the luminal overlay, showing only the vascular luminal areas highlighted in yellow against the original grayscale background (Fig. 1). Panel labels, color legends, and CVI values were annotated on the composite figure.

Axial length was measured using optical biometry (IOLMaster 500, Carl Zeiss Meditec, Jena, Germany) before pupil dilation. Five measurements were taken for each eye, and the average value was used for

analysis. Body composition was assessed with a multifrequency bioelectrical impedance spectroscopy device (Body Composition Monitor; Fresenius Medical Care, Bad Homburg, Germany). Participants lay supine and rested for 5 minutes before measurement; electrodes were placed on the dorsum of the foot and hand. Parameters measured included overhydration (OH), total body water (TBW), extracellular water (ECW), intracellular water (ICW), ECW/ICW ratio (E/I), lean tissue index (LTI), fat tissue index (FTI), total lean mass (LTM), relative lean mass, fat mass, and phase angle at 50 kHz. Systolic and diastolic blood pressures were measured with a calibrated sphygmomanometer.

Statistical Analysis

All statistical analyses were performed using GraphPad Prism version 10.6.1. for macOS (GraphPad Software, Boston, Massachusetts, USA). Continuous variables were tested for normality with the Shapiro-Wilk test and visually examined using histograms and Q- Q plots. Variables that were normally distributed were expressed as mean ± standard deviation (SD), while non- normally distributed variables were reported as median (interquartile range). Categorical variables were summarized with frequencies and percentages. Comparisons based on sex used the independent samples t- test for normally distributed data and the Mann- Whitney U test for non- normal data. Relationships between bioimpedance parameters, anthropometric measures, and retinal variables were analyzed with Spearman's rank correlation. Because of numerous pairwise comparisons (16 bioimpedance/anthropometric parameters × 6 retinal outcomes = 96 tests), the Benjamini-Hochberg false discovery rate (FDR) method was applied to control for multiple comparisons, with a corrected significance threshold of $p < 0.05$. To identify independent predictors of choroidal thickness, multiple linear regression analyses were performed. Candidate predictors included variables showing suggestive univariate associations (uncorrected $p < 0.05$). All models were adjusted for age, sex, and axial length as predetermined confounders, given their known influence on choroidal thickness. Results are presented with both unstandardized (B) and standardized (β) regression coefficients, 95% confidence intervals, R^2, adjusted R^2, and F-statistics. Multicollinearity was evaluated using variance inflation factors (VIF), with values over 5 indicating potential issues. Model assumptions of linearity, homoscedasticity, and residual normality were checked through residual plots. A two- tailed p- value less than 0. 05 was considered statistically significant in regression analyses. Due to the relatively small sample size (N = 40), these findings should be viewed as exploratory and hypothesis- generating.

RESULTS

A total of 40 eyes from 40 healthy participants were included. The study population consisted of 26 females (65.0%) and 14 males (35.0%), with a mean age of 36.2 ± 8.1 years (range: 20.7–46.7 years). The average BMI was 26.6 ± 4.8 kg/m², and the mean axial length was 23.17 ± 0.59 mm. Demographic, bioimpedance, and retinal characteristics of the study group are summarized in Table 1.

Males were significantly younger than females (30.96 ± 9.57 vs. 39.08 ± 5.53 years, $p = 0.012$) and had significantly higher total body water (46.39 ± 6.97 vs. 33.28 ± 5.43 L, $p < 0.001$), extracellular water

(19.33 ± 2.75 vs. 14.63 ± 2.48 L, $p < 0.001$), intracellular water (27.07 ± 4.59 vs. 18.64 ± 3.33 L, $p < 0.001$), lean tissue index (19.26 ± 3.41 vs. 14.61 ± 2.76 kg/m², $p < 0.001$), lean tissue mass (59.71 ± 11.54 vs. 37.99 ± 7.17 kg, $p < 0.001$), and phase angle (7.01 ± 1.01 vs. 6.00 ± 0.82°, $p = 0.002$). Males also had significantly longer axial lengths (23.42 ± 0.66 vs. 23.04 ± 0.51 mm, $p = 0.044$). Conversely, females had significantly higher fat tissue index, fat mass, and E/I ratio. BMI did not differ between sexes (26.63 ± 5.22 vs. 26.60 ± 4.16 kg/m², $p = 0.987$).

Table 1
Demographic, bioimpedance, and retinal characteristics of the study population

Variable	Overall (n = 40)	Female (n = 26)	Male (n = 14)	p
Demographic and anthropometric parameters				
Age (years)	36.24 ± 8.09	39.08 ± 5.53	30.96 ± 9.57	**0.012** (MW)
Height (cm)	166.45 ± 9.69	161.38 ± 5.19	175.86 ± 9.14	**< 0.001** (MW)
Weight (kg)	73.83 ± 15.13	69.54 ± 15.29	81.79 ± 11.51	**0.013** (MW)
BMI (kg/m²)	26.62 ± 4.82	26.63 ± 5.22	26.60 ± 4.16	0.987 (t)
BP systolic (mmHg)	108.12 ± 11.42	107.50 ± 11.94	109.29 ± 10.72	0.554 (MW)
BP diastolic (mmHg)	72.38 ± 8.16	71.35 ± 8.89	74.29 ± 6.46	0.200 (MW)
Axial length (mm)	23.17 ± 0.59	23.04 ± 0.51	23.42 ± 0.66	**0.044** (MW)
Bioimpedance analysis parameters				
OH (L)	−0.35 ± 1.47	−0.43 ± 1.37	−0.19 ± 1.67	0.744 (MW)
TBW (L)	37.87 ± 8.67	33.28 ± 5.43	46.39 ± 6.97	**< 0.001** (MW)
ECW (L)	16.27 ± 3.41	14.63 ± 2.48	19.33 ± 2.75	**< 0.001** (MW)
ICW (L)	21.59 ± 5.54	18.64 ± 3.33	27.07 ± 4.59	**< 0.001** (MW)
E/I ratio	0.77 ± 0.14	0.80 ± 0.15	0.72 ± 0.08	**0.018** (MW)
LTI (kg/m²)	16.23 ± 3.71	14.61 ± 2.76	19.26 ± 3.41	**< 0.001** (t)
FTI (kg/m²)	10.57 ± 4.89	12.19 ± 4.66	7.54 ± 3.84	**0.003** (t)
LTM (kg)	45.59 ± 13.69	37.99 ± 7.17	59.71 ± 11.54	**< 0.001** (MW)
Relative LTM (%)	61.95 ± 14.12	55.86 ± 10.84	73.28 ± 12.63	**< 0.001** (t)
Fat (kg)	21.12 ± 9.48	23.49 ± 9.63	16.72 ± 7.68	**0.029** (t)
ATM (kg)	28.73 ± 12.89	31.95 ± 13.10	22.74 ± 10.45	**0.029** (t)
Phase angle 50 kHz (°)	6.36 ± 1.01	6.00 ± 0.82	7.01 ± 1.01	**0.002** (t)
Retinal parameters				
CMT (µm)	262.95 ± 17.77	263.12 ± 17.11	262.64 ± 19.61	0.865 (MW)
CT nasal-750 (µm)	281.32 ± 53.73	275.88 ± 49.10	291.42 ± 62.10	0.390 (t)
CT central (µm)	285.90 ± 59.32	279.88 ± 50.16	297.09 ± 74.24	0.388 (t)
CT temporal-750 (µm)	281.88 ± 54.36	284.43 ± 53.40	277.16 ± 57.83	0.692 (t)
CVI	0.66 ± 0.03	0.65 ± 0.03	0.67 ± 0.03	**0.036** (t)

Variable	Overall (n = 40)	Female (n = 26)	Male (n = 14)	p
Demographic and anthropometric parameters				
IOP (mmHg)	14.12 ± 2.64	13.69 ± 2.66	14.93 ± 2.50	0.097 (MW)

Values are presented as mean ± standard deviation. Bold p-values indicate statistical significance (p < 0.05). MW: Mann-Whitney U test; t: Independent samples t-test. BMI: body mass index; OH: overhydration; TBW: total body water; ECW: extracellular water; ICW: intracellular water; E/I: extracellular/intracellular water ratio; LTI: lean tissue index; FTI: fat tissue index; LTM: lean tissue mass; ATM: adipose tissue mass; CMT: central macular thickness; CT: choroidal thickness; CVI: choroidal vascularity index; IOP: intraocular pressure.

Retinal parameters were largely similar between sexes. Central macular thickness (263.12 ± 17.11 vs. 262.64 ± 19.61 μm, p = 0.865), choroidal thickness at all three measurement points (all p > 0.38), and intraocular pressure (13.69 ± 2.66 vs. 14.93 ± 2.50 mmHg, p = 0.097) showed no significant sex differences. The choroidal vascularity index was slightly higher in males (0.67 ± 0.03 vs. 0.65 ± 0.03, p = 0.036) (Fig. 2–3).

Spearman's rank correlation analysis revealed several associations between bioimpedance parameters and choroidal thickness at the uncorrected p < 0.05 level (Table 2). BMI showed the strongest inverse correlation with central ChT (ρ = -0.493, p = 0.001), followed by overhydration, which had a positive correlation (ρ = 0.456, p = 0.003). Additional significant correlations at the uncorrected level included fat tissue index (ρ = -0.331, p = 0.037), body weight (ρ = -0.346, p = 0.029), and phase angle (ρ = -0.308, p = 0.053) with central ChT.

Table 2
Spearman correlation coefficients between bioimpedance/anthropometric and retinal parameters

Variable	CMT	ChT-N750	ChT-C	ChT-T750	CVI	IOP
OH (L)	0.008	−0.005	**0.456****	**0.448****	0.241	−0.014
TBW (L)	−0.008	0.097	−0.171	−0.355*	0.052	0.226
ECW (L)	0.002	0.176	−0.129	−0.271	0.102	0.204
ICW (L)	0.020	0.087	−0.148	−0.373*	0.031	0.261
E/I ratio	−0.111	0.041	0.083	0.317*	0.121	−0.115
LTI (kg/m²)	0.201	0.096	−0.196	**−0.443****	−0.015	0.224
FTI (kg/m²)	−0.168	0.216	−0.331*	0.013	−0.156	0.003
LTM (kg)	0.075	0.039	−0.086	−0.370*	0.030	0.251
Rel LTM (%)	0.166	−0.100	0.208	−0.153	0.099	0.074
Fat (kg)	−0.225	0.200	−0.292	0.004	−0.088	0.043
ATM (kg)	0.064	0.008	−0.308	**−0.482****	−0.123	0.154
Phase angle (°)	−0.001	−0.029	−0.142	−0.120	−0.186	0.007
Age (years)	−0.050	0.190	−0.346*	−0.322*	−0.042	0.192
Weight (kg)	−0.022	0.220	**−0.493****	−0.298	−0.139	0.098
BMI (kg/m²)	−0.347*	0.119	−0.119	−0.004	−0.262	0.217
BP diastolic	−0.106	0.246	−0.199	−0.009	−0.270	0.153
AL (mm)	0.008	−0.005	**0.456****	**0.448****	0.241	−0.014

Values represent Spearman ρ coefficients. p < 0.05, **†***p < 0.01. After Benjamini-Hochberg FDR correction for 96 comparisons, no correlation reached corrected significance (q < 0.05). The lowest q-values were: BMI vs ChT-C (q = 0.078), PhA vs ChT-T750 (q = 0.078), OH vs ChT-C (q = 0.081), LTI vs ChT-T750 (q = 0.081).*. CMT: central macular thickness; ChT-N750: choroidal thickness nasal-750 µm; ChT-C: choroidal thickness central; ChT-T750: choroidal thickness temporal-750 µm; CVI: choroidal vascularity index; IOP: intraocular pressure.*

Temporal ChT (ChT-T750) showed the most consistent pattern of associations with lean body composition parameters at the uncorrected level. Phase angle exhibited the strongest inverse correlation (ρ = -0.482, p = 0.002), followed by lean tissue index (ρ = -0.443, p = 0.004), intracellular water (ρ = -0.373, p = 0.018), lean tissue mass (ρ = -0.370, p = 0.019), total body water (ρ = -0.355, p = 0.025), and body weight (ρ = -0.322, p = 0.043). Overhydration was positively correlated (ρ = 0.448, p = 0.004). Axial length did not show significant correlations with any retinal parameter at the univariate level in this sample.

However, after applying the Benjamini-Hochberg FDR correction for the 96 simultaneous tests, none of the individual correlations reached corrected significance at $q < 0.05$. The associations with the lowest FDR q-values were BMI vs. central ChT ($q = 0.078$), phase angle vs. temporal ChT ($q = 0.078$), overhydration vs. central and temporal ChT ($q = 0.081$), and LTI vs. temporal ChT ($q = 0.081$). No bioimpedance parameter showed a significant correlation with CVI or IOP at either the uncorrected or corrected level.

Although there was no FDR-corrected univariate significance, multiple linear regression was conducted as an exploratory analysis to assess independent associations while controlling for confounders. The regression model for central choroidal thickness was statistically significant ($R^2 = 0.492$, adjusted $R^2 = 0.417$, $F = 6.58$, $p < 0.001$) and included age, sex, BMI, overhydration, and axial length as predictors (Table 3). BMI emerged as an independent predictor, with each 1 kg/m² increase linked to roughly a 6.1 µm decrease in central ChT ($B = -6.135$, 95% CI: -9.86 to -2.41, $p = 0.002$; standardized $\beta = -0.499$). Axial length was also an independent predictor, with each 1 mm increase in AL associated with a 40.7 µm decrease in central ChT ($B = -40.731$, 95% CI: -70.04 to -11.42, $p = 0.008$; standardized $\beta = -0.405$). Overhydration showed a trend toward a positive association but did not reach significance ($B = 10.057$, $p = 0.075$). All VIF values were below 2.1, indicating no problematic multicollinearity.

Table 3
Multiple linear regression analysis for choroidal thickness parameters

Predictor	B	SE	t	p	95% CI	β_std
DV: ChT central (µm) — R² = 0.492, Adj R² = 0.417, F = 6.58, p < 0.001						
Age	0,092	1,273	0,073	0,943	−2.50, 2.68	0,013
Sex (male)	30,830	18,178	1,696	0,099	−6.11, 67.77	0,251
BMI	**-6,135**	**1,835**	**-3,343**	**0,002**	**−9.86, − 2.41**	**-0,499**
OH	10,057	5,479	1,835	0,075	−1.08, 21.19	0,249
Axial length	**-40,731**	**14,424**	**-2,824**	**0,008**	**−70.04, − 11.42**	**-0,405**
DV: ChT temporal-750 (µm) — Model A — R² = 0.285, Adj R² = 0.155, F = 2.19, p = 0.069						
Age	-1,340	1,412	-0,949	0,349	−4.21, 1.53	—
Sex (male)	6,921	24,340	0,284	0,778	−42.60, 56.44	—
BMI	-0,396	2,065	-0,192	0,849	−4.60, 3.81	—
OH	4,736	8,450	0,561	0,579	−12.46, 21.93	—
Phase angle	-24,641	14,253	-1,729	0,093	−53.64, 4.36	—
Axial length	-3,564	16,096	-0,221	0,826	−36.31, 29.18	—
DV: ChT temporal-750 (µm) — Model B — R² = 0.222, Adj R² = 0.107, F = 1.94, p = 0.114 ‡						
Age	-0,230	1,400	-0,164	0,871	−3.08, 2.62	-0,034
Sex (male)	27,483	24,255	1,133	0,265	−21.81, 76.78	0,244
BMI	-0,886	2,117	-0,418	0,678	−5.19, 3.42	-0,079
LTI	**-7,677**	**3,174**	**-2,419**	**0,021**	**−14.13, − 1.23**	**-0,525**
Axial length	-2,487	16,630	-0,150	0,882	−36.28, 31.31	-0,027

B: unstandardized regression coefficient; SE: standard error; CI: confidence interval; β_std: standardized coefficient.

Bold red values indicate statistical significance (p < 0.05). All models adjusted for age and sex. ‡ The overall F-test for Model B was non-significant (p = 0.114). Individual predictor p-values from this model should be interpreted with caution as hypothesis-generating observations only

For temporal choroidal thickness, two exploratory models were assessed. In Model A, which included age, sex, BMI, overhydration, phase angle, and axial length, the overall model did not reach significance ($R^2 = 0.285$, $F = 2.19$, $p = 0.069$), though phase angle showed a trend ($B = -24.641$, $p = 0.093$). In Model B, lean tissue index replaced phase angle and overhydration. This model also did not achieve overall

statistical significance (R^2 = 0.222, F = 1.94, p = 0.114), though LTI showed a suggestive association (B = -7.677, p = 0.021; standardized β = -0.525). Because these overall models did not reach significance, the individual predictor findings for temporal ChT should be interpreted with caution as hypothesis-generating observations. Models for CVI (R^2 = 0.112, p = 0.226) and IOP (R^2 = 0.060, p = 0.523) were not statistically significant, indicating that the bioimpedance parameters examined do not predict these retinal measures in the current sample.

DISCUSSION

In this exploratory cross-sectional study, we investigated the relationship between bioelectrical impedance-derived body composition parameters and choroidal structural and vascular indices in healthy adults, with the addition of axial length as a key ocular confounder. The most robust finding is the independent inverse association between BMI and central choroidal thickness, which persists after adjusting for age, sex, and axial length in a model that explains nearly 50% of the variance in central ChT. Additionally, axial length itself emerged as a significant independent predictor of central choroidal thickness, underscoring the importance of accounting for this parameter in choroidal research (1).

The BMI-central ChT association is consistent with prior literature. Multiple studies have demonstrated a negative correlation between BMI and subfoveal choroidal thickness in both adult and pediatric populations (17–19). Obesity and elevated BMI contribute to endothelial dysfunction, vascular stiffness, decreased nitric oxide availability, and low-grade systemic inflammation, mechanisms that could promote microvascular remodeling and reduced choroidal perfusion (20–22). Importantly, our findings strengthen this evidence by demonstrating that the BMI association remains significant even after controlling for axial length, a confounder not always accounted for in previous studies. Since BMI may correlate with body size and consequently with eye size, the persistence of this association after axial length adjustment suggests a genuine vascular or metabolic pathway rather than a purely anatomical confound.

The independent contribution of axial length to the central ChT model is consistent with the well-established inverse relationship between axial length and choroidal thickness (23, 24). Each 1 mm increase in AL was associated with an approximately 41 μm decrease in central ChT. This finding reinforces the necessity of including axial length as a covariate in any analysis of choroidal determinants, as failure to do so may lead to confounded associations.

The lean tissue index showed a suggestive inverse association with temporal choroidal thickness. While ophthalmic literature has focused primarily on adiposity, cardiovascular studies have reported that lean body mass correlates with cardiac output, vascular compliance, and systemic hemodynamic load (25, 26). Regional heterogeneity in choroidal vascular architecture has been previously described, with peripheral and temporal regions potentially demonstrating different susceptibility to systemic influences (27), which may explain the regional specificity of this association. However, because the overall regression model for temporal ChT did not reach statistical significance, this finding should be

interpreted cautiously and considered hypothesis-generating. Future studies with larger cohorts are needed to determine whether lean body composition independently influences regional choroidal thickness.

Overhydration showed a positive univariate association with choroidal thickness, consistent with the known effect of acute fluid loading and systemic hemodynamic shifts on choroidal thickness through hydrostatic and osmotic mechanisms (28–29). However, this relationship did not remain after multivariable adjustment, indicating that extracellular fluid shifts may affect choroidal measurements but are not independent factors once body composition, adiposity, and axial length are accounted for.

No independent predictors of CVI were identified in this study. CVI has been shown to decrease in systemic inflammatory and metabolic disorders such as diabetes mellitus and cardiovascular disease (30–32). However, data in healthy individuals are limited. The absence of CVI associations suggests that systemic body composition influences absolute choroidal thickness without notably altering the vascular-to-stromal ratio. This is consistent with the interpretation that the structural thinning associated with higher BMI is uniform rather than reflecting selective loss of vascular components.

The sex-based analysis showed the expected differences in bioimpedance parameters, indicating physiological variations in lean and fat distribution. Retinal structural parameters did not differ significantly between sexes, except for a slightly higher CVI in males. Since there were no independent CVI predictors in multivariable models, this isolated difference likely reflects normal physiological variation rather than systematic microvascular differences.

It is important to recognize the limitations of univariate correlation analysis. Although 13 of the 96 tested correlations showed nominal significance ($p < 0.05$), none remained significant after correction for multiple comparisons with the Benjamini-Hochberg method. The strongest associations (BMI vs. central ChT, phase angle vs. temporal ChT) had FDR q-values around 0.078, which are suggestive but do not meet the corrected threshold. This underscores the exploratory nature of these findings and the need for validation in larger samples.

Several additional limitations should be recognized. First, the sample size of 40 participants limits statistical power and generalizability, and the subject-to-predictor ratio in some regression models was at the lower recommended threshold. Second, the cross-sectional design prevents establishing causality. Third, the Canon OCT-HS100 does not feature an enhanced depth imaging module, requiring manual capture of choroidal images; although reliability was good (ICC > 0.94), this method may introduce some measurement variability compared to automated EDI-OCT. Fourth, males were significantly younger than females (about 8 years difference), which, despite adjustment for age in regression models, may cause residual confounding or interaction effects. Fifth, ocular perfusion pressure was not measured and could independently affect choroidal thickness.

In this regard, to the best of our knowledge, our study is among the first to explore the association between BIA-derived body composition parameters and both ChT and CVI while simultaneously

adjusting for axial length. Despite the limitations inherent to the small sample size, the robust finding that BMI independently predicts central choroidal thickness, even after controlling for axial length, provides a foundation for future research. Larger, longitudinal studies that incorporate comprehensive ocular hemodynamic parameters are needed to confirm these exploratory findings and elucidate the underlying mechanisms.

Declarations

Conflict of Interest:

The authors declare that they have no conflicts of interest.

Funding Statement:

The study did not receive any funding.

Author Contribution

ŞNÇ, AB, and MÜK equally contributed to the design and implementation of the research; AB, ŞNÇ, and MÜK contributed to data collection and analysis of the results. Literature review, editing, and supervision were conducted by EH, and all authors contributed to the final manuscript writing.

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Figures

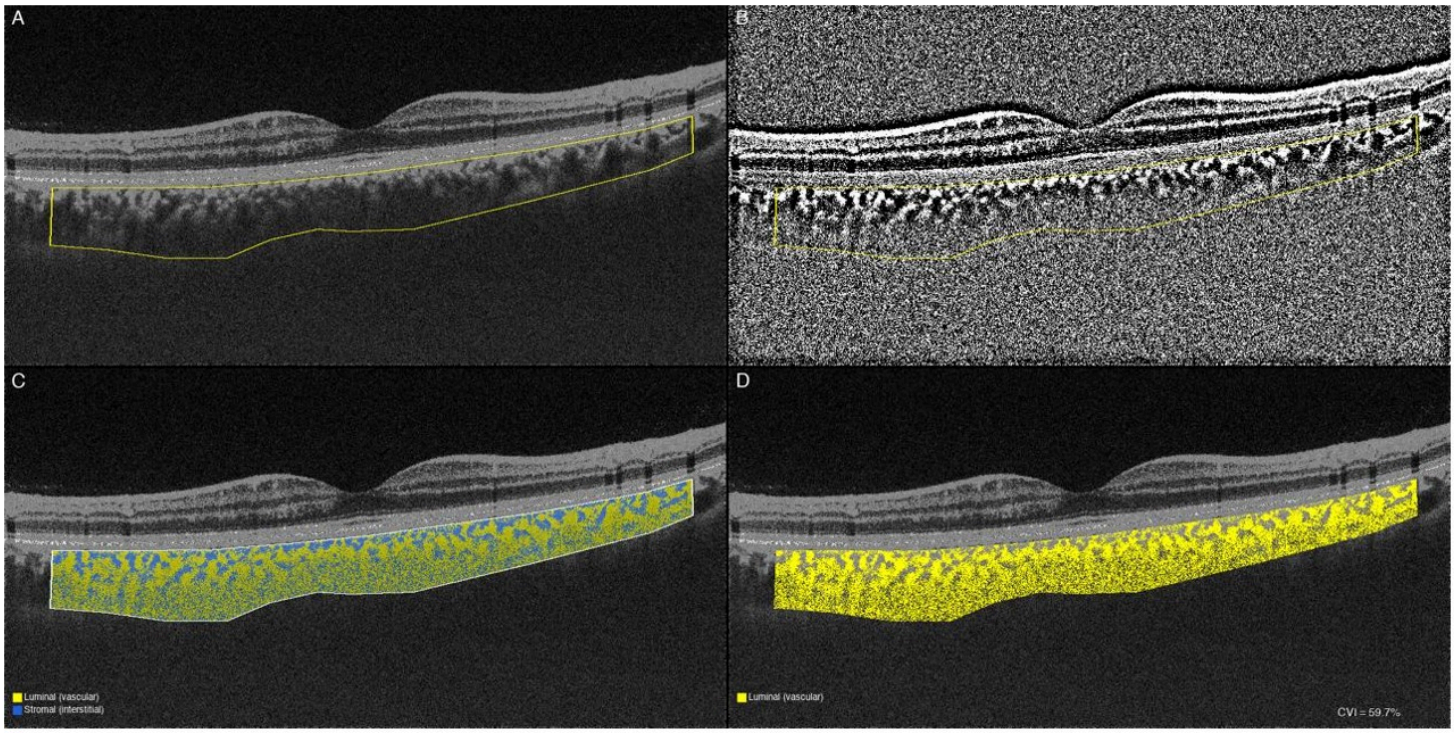


Figure 1

Composite four-panel figures using CVI calculation. (A) the original OCT B-scan with the choroidal ROI outlined in yellow; (B) the Niblack-binarized image with the ROI outlined; (C) the color-coded choroidal map, where luminal areas within the ROI were rendered in yellow and stromal areas in blue, blended over the original grayscale image; (D) the luminal overlay, showing only the vascular luminal areas highlighted in yellow against the original grayscale background.

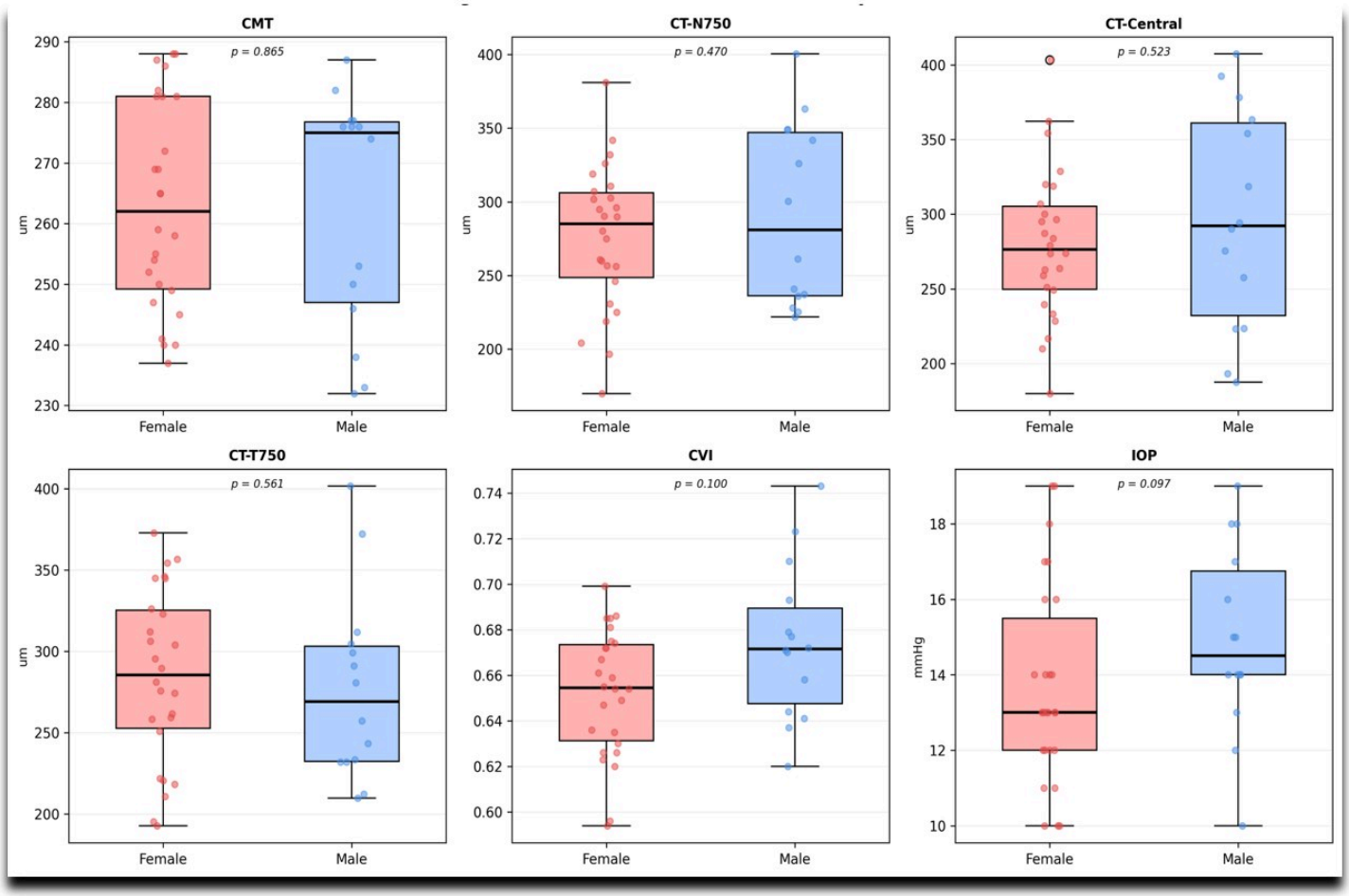


Figure 2

Scatter plots illustrating the strongest univariate correlations between bioimpedance/anthropometric and retinal parameters, stratified by sex.

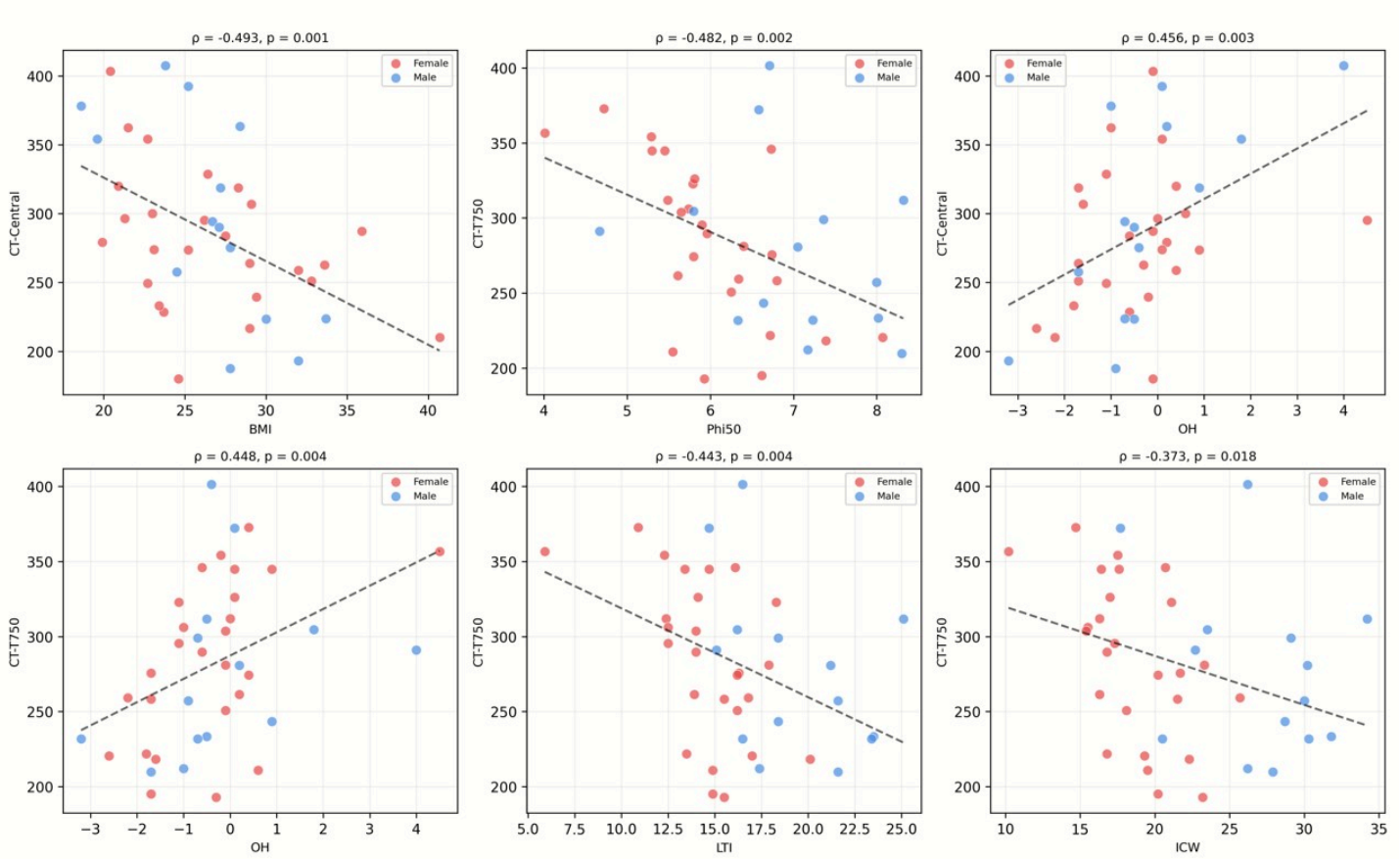


Figure 3

Distribution of retinal parameters by sex with individual data points.