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Beyond BMI: Predictive Accuracy of Novel Anthropometric Indices for Knee Osteoarthritis and Popliteal Intima–Media Thickness

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Beyond BMI: Predictive Accuracy of Novel Anthropometric Indices for Knee Osteoarthritis and Popliteal Intima–Media Thickness

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Ramy Mohamed suggested the point, made the anthropometric measurements, and made the plagiarism, wrote the manuscript, and made statistical analysis

Moushira zaki revised the manuscript and made the statistical analysis

Mahmoud Ibrahim Risha, Ibrahim Fawzy, Muhammad Magdy Harb, Hatem Galal Abdallah Ibrahim Clinical assessment and measured femoral cartilage thickness

Mahmoud Mohamed Aboumandour Fouda measured popliteal intima media thickness

Abstract

Introduction

Body mass index (BMI) does not adequately capture body fat distribution. Novel anthropometric indices may provide complementary information regarding adiposity and knee osteoarthritis (KOA). However, their associations with KOA and popliteal artery intima–media thickness (IMT), and their predictive performance, require further evaluation.

Aim

To compare popliteal artery intima–media thickness (IMT) between KOA patients and healthy controls, to evaluate the independent association and predictive accuracy of novel anthropometric indices for KOA, and to examine their relationship with knee osteoarthritis, popliteal IMT, and sex-related differences.

Methods

Fifty patients with symptomatic knee OA (aged 34–72, Kellgren–Lawrence grades I–IV, ACR criteria, VAS ≥20 mm) were recruited from a rheumatology clinic at Al-Azhar University hospitals, along with 50 healthy controls (family members with no knee pain or joint disease).

Weight, height, waist and hip circumference, BMI, and WHR were measured, and five indices were calculated from them: WWI, BRI, AVI, CI, and ABSI.

Disease severity was graded as mild, moderate, or severe using clinical presentation and K&L radiographic grading.

Popliteal artery IMT was measured at the popliteal fossa using B-mode and Doppler ultrasonography in both transverse and longitudinal planes.

Exclusions covered severe knee pain (VAS >80 mm), inflammatory arthritis, major knee injury or surgery, statin indications (diabetes, cardiovascular disease, high cholesterol, high 5-year cardiovascular risk), significant renal or liver disease, autoimmune disease, malignancy, hormone replacement therapy, and current smoking.

Results

Compared with controls, patients with knee osteoarthritis (KOA) had significantly higher anthropometric indices and popliteal intima-media thickness (IMT) (all $p < 0.001$ for anthropometric indices; $p = 0.005$ for IMT). No significant sex-based differences were observed among KOA patients. After adjustment for age, sex, and BMI, all five anthropometric indices were significantly associated with KOA ($p < 0.001$), with body roundness index (BRI) and abdominal volume index (AVI) showing the strongest associations. Cross-validated discrimination was good, with adjusted AUCs of 0.881–0.915 for logistic regression and 0.850–0.889 for neural networks. Regarding popliteal IMT, adjusted correlations remained significant for weight-adjusted waist index, conicity index, and A Body Shape Index (ABSI); however, IMT prediction remained limited ($R^2 = 0.006$–0.087). Overall, the anthropometric indices showed stronger associations with KOA than with popliteal IMT, with no consistent predictive advantage of neural networks over logistic regression.

Conclusion

Novel anthropometric indices were associated with KOA and demonstrated moderate-to-high cross-validated discrimination in this small sample. BRI and AVI had the highest cross-validated AUCs in logistic regression, but their superiority over the other indices has not been established. The indices showed limited ability to explain variation in popliteal IMT after adjustment. Larger, independent studies are needed to establish their incremental predictive value and clinical utility.

Keywords
Knee osteoarthritis, Novel Anthropometric indices, Popliteal intima media thickness, Obesity

Introduction

Osteoarthritis (OA) is a complex, chronic musculoskeletal disorder arising from the interaction of mechanical, metabolic, genetic, and environmental determinants. Although traditionally regarded as a degenerative disorder of articular cartilage, OA involves the entire joint and is characterized by progressive cartilage loss, osteophyte development, subchondral bone remodeling and sclerosis, and eventual cartilage ulceration [1–3]. These structural abnormalities are accompanied by clinical manifestations including persistent pain, stiffness, deformity, restricted mobility, and progressive functional limitation, which can substantially impair quality of life. OA represents one of the major causes of disability in older adults, and its worldwide burden has continued to increase, partly in parallel with the rising prevalence of obesity [4]. Epidemiological data suggest that clinical OA affects approximately 3.8% of the global population, corresponding to nearly 250 million individuals [5]. Moreover, the number of people affected by OA is projected to increase considerably by 2050 compared with 2020, driven predominantly by demographic aging and the ongoing global obesity epidemic [6]. These trends emphasize the importance of identifying individuals at increased risk at an earlier stage and developing effective preventive and therapeutic strategies to limit disease progression and its associated societal and healthcare burden [6].

The close relationship between excess adiposity and OA has stimulated interest in anthropometric measures that may characterize body composition and fat distribution more effectively than conventional measures such as body mass index (BMI). In particular, indices incorporating waist circumference and other measures of body size may provide information regarding central adiposity that is not adequately captured by BMI alone. In a large cross-sectional study involving 12,696 participants from the National Health and Nutrition Examination Survey (NHANES), Li et al. demonstrated a significant positive association between the weight-adjusted waist index (WWI) and OA after adjustment for multiple potential confounding variables. The authors further suggested that WWI could have clinical relevance in identifying individuals at increased risk of OA and may provide information beyond that obtained from conventional anthropometric parameters, including BMI and waist circumference [7]. Collectively, these findings highlight the potential importance of body shape and adipose tissue distribution, rather than overall body size alone, in understanding susceptibility to OA.

The Body Roundness Index (BRI) is another relatively novel anthropometric parameter developed to characterize body shape using waist circumference and height. Emerging evidence has demonstrated an association between BRI and OA, supporting the possibility that measures reflecting abdominal adiposity and body configuration may provide additional information beyond BMI. Nevertheless, evidence specifically addressing the relationship between BRI and knee osteoarthritis (KOA) remains limited. Further investigation is therefore warranted to determine whether BRI may represent a practical anthropometric marker of KOA risk [8].

The Conicity Index (CI) is designed to reflect central fat accumulation by incorporating waist circumference, body weight, and height into a single anthropometric measure. Evidence from a large NHANES-based investigation has demonstrated that higher CI values are significantly

associated with an increased risk of OA. These findings suggest that CI may provide useful information regarding the relationship between central adiposity and the development of OA [9].

Several additional anthropometric indices have been introduced to overcome some of the limitations of conventional measures of obesity. Among these, the A Body Shape Index (ABSI) has received increasing attention because it incorporates waist circumference in relation to height and body weight, thereby providing a measure of body shape that is relatively independent of overall body size. By combining these anthropometric dimensions, ABSI may offer complementary information regarding central adiposity and body fat distribution compared with BMI alone [10]. Recent studies have also reported an independent association between ABSI and OA, raising the possibility that this index could contribute to the identification of individuals at increased risk of obesity-related OA, including KOA [11].

The Abdominal Volume Index (AVI) is another anthropometric parameter proposed as an indicator of abdominal adiposity. Although its specific relationship with KOA has not been extensively investigated, available evidence supports an association between AVI and abdominal adiposity as well as metabolic risk [12–14]. Given the recognized contribution of visceral adiposity and metabolic disturbances to low-grade inflammation and the pathophysiological processes involved in OA, AVI may represent a potentially relevant marker for exploring the relationship between abdominal adiposity and KOA.

Knee osteoarthritis (KOA) is increasingly recognized as a disease influenced not only by mechanical factors but also by systemic metabolic, inflammatory, and vascular abnormalities. Popliteal artery intima-media thickness (IMT), assessed by ultrasonography, provides a noninvasive measure of arterial wall remodeling. Increased popliteal arterial wall thickness has been associated with cartilage loss and structural progression in KOA, while recent studies have demonstrated peripheral arterial abnormalities in patients with knee OA [15–17]. These findings support a possible interaction between vascular dysfunction, metabolic abnormalities, and joint degeneration [18–20].

To the best of our knowledge, no previous study has examined the predictive accuracy of these novel anthropometric indices for popliteal intima–media thickness.

Materials and Methods

Study Design

This cross-sectional study investigated popliteal artery intima media thickness in patients with Knee Osteoarthritis and healthy controls using high-resolution musculoskeletal ultrasound.

Participants were recruited from the Rheumatology Clinic at Al-Azhar University Hospitals, **Al-Hussein Hospital.** between January 2025 and December 2025. The study adhered to the Declaration of Helsinki and was approved by Al-Azhar institutional review board (IRB No. (58)).

Written informed consent was obtained from all participants prior to inclusion in the study, in accordance with institutional and ethical guidelines.

Anthropometric Measurements and Derived Indices

Anthropometric measurements were obtained from all participants and included body weight, height, waist circumference (WC), hip circumference (HC), body mass index (BMI), waist-to-hip ratio (WHR). Several established anthropometric indices were subsequently derived from these measurements using previously validated mathematical equations.The weight-adjusted waist index (WWI) was calculated as waist circumference divided by the square root of body weight: $WWI = WC/\sqrt{weight}$, where WC was expressed in centimeters and body weight in kilograms [21]. The body roundness index (BRI) was calculated according to the geometric model described by Thomas et al., which uses waist circumference and height to quantify body shape and estimate adiposity [22]. The abdominal volume index (AVI) was calculated using the following equation: $AVI = [2(WC)^2 + 0.7(WC - HC)^2]/1000$, where WC and HC represented waist and hip circumferences, respectively, both measured in centimeters [23].The conicity index (CI) was calculated as $CI = WC/[0.109 \times \sqrt{(weight/height)}]$, with waist circumference and height expressed in meters and body weight expressed in kilograms [24].

The A Body Shape Index (ABSI) was calculated using the equation $ABSI = WC/(BMI^{2/3} \times height^{1/2})$, where WC represented waist circumference, BMI represented body mass index, and height was expressed in meters [25].

Disease Severity

Disease severity was classified as mild, moderate, or severe based on the clinical presentation and radiographic Kellgren–Lawrence (K&L) grading system [26].

Popliteal Artery Intima–Media Thickness

The popliteal artery was evaluated at the level of the popliteal fossa using B-mode and Doppler ultrasonography. The popliteal artery and vein were identified at approximately the level of the femoral intercondylar region. Popliteal artery intima–media thickness (IMT) and other relevant arterial parameters were assessed in both transverse and longitudinal planes using standardized ultrasonographic techniques [27].

Participants and Eligibility Criteria

Fifty patients aged 34–72 years with knee osteoarthritis (KOA) were identified from medical records at the rheumatology Clinic at al-Azhar university hospitals, Al-Hussein Hospital. KOA was diagnosed on the basis of compatible clinical and radiographic findings according to the Kellgren–Lawrence (K&L) grading system, with eligible participants having grades I–IV.

Inclusion Criteria

Participants were eligible for inclusion if they had symptomatic knee OA, defined as knee pain occurring on most days during the preceding month, with symptoms persisting for at least 6 months. Additional eligibility criteria included a pain intensity of ≥20 mm on a 100-mm visual analogue scale (VAS) and fulfillment of the American College of Rheumatology (ACR) clinical criteria for knee OA.

Fifty normal healthy dults were enrolled as a control group from the family members of patients attending or accompanying patients in the Physical Medicine and Rehabilitation Department. Controls had no current complaints of knee pain and no history of joint disease.

Exclusion Criteria

Participants were excluded if they had severe knee pain, defined as a VAS score >80 mm on standing, inflammatory arthritis, or a significant previous knee injury. Additional exclusion criteria included indications for statin therapy, including familial hypercholesterolemia, established atherosclerotic cardiovascular disease, or diabetes mellitus; current use of lipid-lowering medications; a previous adverse reaction to statins; or an estimated absolute cardiovascular risk of >15% over the subsequent 5 years according to the Framingham Risk Equation.

Participants were also excluded if they had a fasting total cholesterol concentration >7.5 mmol/L, clinically significant renal disease, abnormal liver function, or a history of arthroscopy or open surgery involving the index knee within the preceding 12 months.

Additional exclusion criteria included autoimmune disease, previous major trauma, malignancy, a positive family history of dyslipidemia, occupational heavy lifting, use of hormone replacement therapy in women, and current smoking.

Statistical Analysis

Data were analyzed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Statistical analyses were performed to compare anthropometric, body-shape, and ultrasonographic parameters between patients with knee osteoarthritis (KOA) and controls. Continuous variables were summarized as mean ± standard deviation (SD). Between-group comparisons and sex-based comparisons among KOA patients were performed using appropriate parametric or nonparametric tests, depending on the distribution of the variables. Categorical variables, when applicable, were summarized as frequencies and percentages and compared using the chi-square test or Fisher's exact test. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significantly.

Multivariable logistic regression analyses were conducted to evaluate the associations between individual anthropometric indices and KOA status. Separate models were constructed for the body roundness index (BRI), abdominal volume index (AVI), weight-adjusted waist index (WWI), conicity index (CI), and a body shape index (ABSI). Each model included one anthropometric index as the primary predictor and was adjusted for age, sex, and body mass index (BMI). Associations were expressed as adjusted odds ratios (ORs) with 95% confidence intervals (CIs). For comparability, the indices were standardized before regression, and ORs were interpreted per one-standard-deviation increase, where applicable.

Receiver operating characteristic (ROC) curve analysis was used to assess the discriminatory performance of the anthropometric indices for distinguishing KOA patients from controls. The area under the ROC curve (AUC) was used to quantify discrimination. The performance of a base model incorporating age, sex, and BMI was compared with that of models incorporating each anthropometric index in addition to these covariates. Both logistic regression and neural-network approaches were evaluated. Crude models included the individual anthropometric index, whereas adjusted models included the index together with age, sex, and BMI. Five-fold cross-validation was used to assess predictive performance and reduce optimism associated with evaluating models on the same data used for model development. Cross-validated AUCs and their 95% CIs were reported where available.

Associations between anthropometric indices and popliteal artery intima–media thickness (IMT) were evaluated using correlation analysis and multivariable regression. Crude associations were assessed using correlation coefficients, with Spearman's rank correlation used where appropriate. Adjusted partial correlations were calculated to account for relevant covariates. Separate multivariable linear regression models were fitted to estimate standardized regression coefficients (β) for the association between each anthropometric index and popliteal IMT. Models for the individual indices were adjusted for age, sex, and BMI, whereas the BMI model was adjusted for age and sex. Effect estimates and corresponding p-values were reported.

The predictive performance of models for continuous popliteal IMT was evaluated using cross-validated coefficients of determination (R^2). Separate regression and neural-network models were assessed using individual anthropometric indices, both before and after covariate adjustment. Models incorporating age, sex, and BMI alone were used as reference models. Negative cross-validated R^2 values were interpreted as indicating performance inferior to that of predicting the outcome using its mean.

All analyses were interpreted with consideration of the observational, cross-sectional design. Statistical significance was distinguished from predictive performance, and comparisons between model AUCs were not interpreted as evidence of superiority unless supported by formal statistical testing.

Results

Table 1. Comparison of anthropometric and ultrasonographic parameters between knee osteoarthritis patients and controls

Variable	Cases Mean ± SD N= 50	Control Mean ± SD N=50	p-value
Age	**49.58 ± 8.65**	**39.42 ± 7.63**	<0.001
Weight (kg)	83.14±14.51	77.26±12.87	<0.001
Height (cm)	165.84 ± 8.87	168.04 ± 8.42	0.28
BMI (kg/m^2)	30.27±4.64	27.38±3.75	<0.001
Waist circumference (cm)	107.02±14.00	84.36±8.02	<0.001
Hip circumference (cm)	115.96±12.96	86.72±7.99	<0.001

ABSI (BSI)	0.0851 ± 0.0085	0.0752 ± 0.0052	<0.001i
Weight-adjusted waist index (WWI)	11.648 ± 1.176	9.919 ± 0.675	< 0.001
Abdomen Volume Index	23.370 ± 6.061	14.368 ± 3.013	< 0.001
Conicity index (C-index)	1.378 ± 0.136	1.181 ± 0.081	< 0.001
Body roundness index (BRI)	6.942 ± 3.035	3.373 ± 0.901	< 0.001
Popliteal artery intima media thickness (cm)	0.0797 ± 0.0120	0.0713 ± 0.0171	0.005

Comment: Compared with controls, KOA patients were older and had greater weight, BMI, waist and hip circumferences, while height did not differ significantly. All examined body-shape/adiposity indices (ABSI, BRI, AVI, WWI, and C-index) were significantly higher in KOA (all $p < 0.001$). Popliteal artery intima-media thickness also differed significantly ($p = 0.005$). Overall, the findings demonstrate significant differences in anthropometric/adiposity measures and popliteal intima media thickness between KOA cases and controls.

Table 2. Sex-based comparison of anthropometric, vascular and ultrasonographic parameters in patients with knee osteoarthritis

Variable / Parameter	Males (n = 20) Mean ± SD	Females (n = 30) Mean ± SD	p-value
Age (years)	48.94 ± 6.93	50.01 ± 9.72	0.671
Height (cm)	165.83±8.00	167.60±6.91	0.42
Weight (kg)	85.3±12.9	84.2±13.8	0.77
BMI (kg/m²)	30.5±4.6	30.0±4.8	0.7
Waist circumference (cm)	107.4±12.7	106.4±16.1	0.8
Hip circumference (cm)	116.3±11.8	115.4±14.9	0.81
Weight-adjusted waist index (WWI)	11.612 ± 1.274	11.655 ± 1.144	0.858
Abdomen Volume Index (AVI)	23.204 ± 6.995	23.279 ± 5.458	0.877
Conicity index (C-index)	1.379 ± 0.152	1.3758± 0.126	0.987
Body roundness index (BRI)	6.426 ± 2.367	6.715 ± 2.248	0.301

A Body Shape Index (ABSI)	0.085 ± 0.009	0.085 ± 0.008	0.815
Popliteal artery thickness (cm)	0.0830 ± 0.0100	0.0776 ± 0.0129	0.119

Comment: Among patients with KOA, no statistically significant differences were observed between males and females for any of the assessed variables. Age, height, weight, BMI, waist and hip circumference showed comparable values between sexes (all $p > 0.05$). Likewise, none of the evaluated anthropometric indices—including WWI, Abdomen Volume Index, C-index, BRI, and ABSI—differed significantly between males and females (all $p > 0.05$). Popliteal artery thickness was also similar between males and females (0.0830 ± 0.0100 vs.0.0776 ± 0.0129, respectively; $p = 0.119$). Overall, the measured anthropometric and vascular were comparable between male and female KOA participants.

Table 3. Multivariable logistic regression analysis of anthropometric indices associated with knee osteoarthritis

Model	Anthropometric index	Adjusted OR*	95% CI	p-value
1	BRI	26.69	6.15–115.83	<0.001
2	AVI	20.71	5.01–85.68	<0.001
3	WWI	7.94	3.10–20.38	<0.001
4	CI	7.65	2.95–19.83	<0.001
5	ABSI/BSI	5.38	2.34–12.38	<0.001

Abbreviations: ABSI, A Body Shape Index; AVI, Abdominal Volume Index; BMI, body mass index; BRI, Body Roundness Index; CI, Conicity Index; KOA, knee osteoarthritis; OR, odds ratio; WWI, Weight-Adjusted Waist Index; BSI, Body Shape Index.

Comment: Five separate multivariable logistic regression models were constructed to evaluate the associations between individual anthropometric indices and knee osteoarthritis (KOA). Each model included one anthropometric index as the primary predictor and was adjusted for age, sex, and BMI. A 1-SD increase in BRI was associated with higher odds of KOA (adjusted OR [aOR] 26.69, 95% CI 6.15–115.83; $p<0.001$). Similarly, AVI (aOR 20.71, 95% CI 5.01–85.68; $p<0.001$), WWI (aOR 7.94, 95% CI 3.10–20.38; $p<0.001$), CI (aOR 7.65, 95% CI 2.95–19.83; $p<0.001$), and ABSI/BSI (aOR 5.38, 95% CI 2.34–12.38; $p<0.001$) were each independently associated with KOA after adjustment for age, sex, and BMI.

Figure 1: Discriminative Performance of Models Adding Each Index (ROC Analysis)

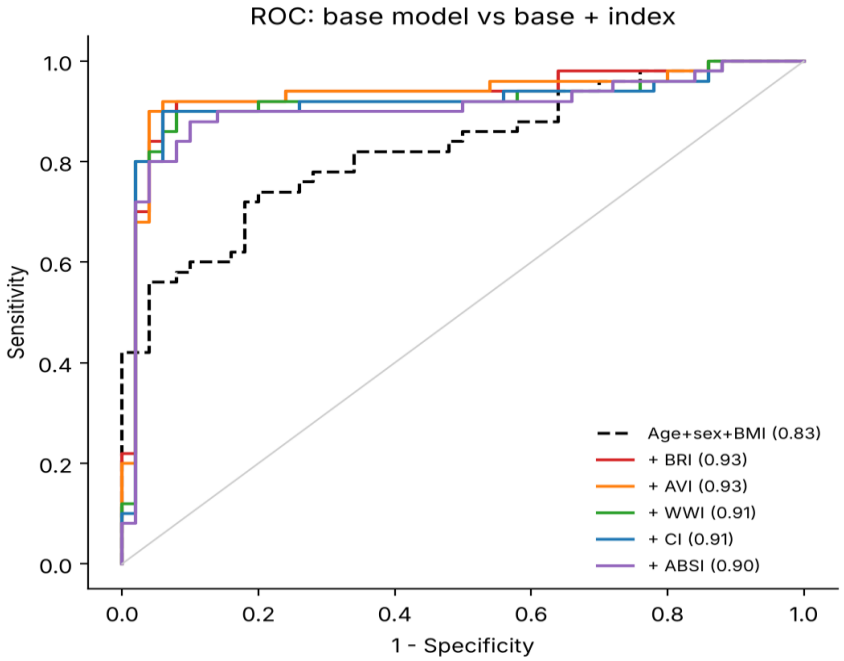


Figure 1. ROC curves comparing the base model (age + sex + BMI) with models adding each anthropometric index (BRI, AVI, WWI, CI or ABSI) for discriminating knee osteoarthritis from controls. The dashed black line is the base model, and the diagonal is the reference line.

Comment: The base model of age, sex and BMI had good discrimination (AUC 0.83), and adding any one anthropometric index clearly improved it. AUCs rose to 0.93 with BRI, 0.93 with AVI, 0.91 with WWI, 0.91 with CI and 0.90 with ABSI, a gain of about 0.07-0.10 AUC units. The curves for all five augmented models sit well above the base curve across nearly the whole range. The largest separation is at low false-positive rates (1 – specificity below about 0.2), where sensitivity rose from about 0.55-0.70 for the base model to about 0.90 with an index added. At high specificity, the indices therefore detect many more true cases.

BRI and AVI gave the largest improvement, followed by WWI and CI, with ABSI last. The five augmented curves overlap heavily, so the differences between indices are small. The main finding is that central adiposity indices add information beyond BMI, not that one index is superior.

These AUCs match the full-sample adjusted values reported earlier, so they appear to be apparent (resubstitution) estimates and are likely slightly optimistic. The cross-validated figure gave values about 0.01 lower.

Figure 2. ROC Curves of Covariate-Adjusted Neural Network Models Using Anthropometric Indices to Discriminate Knee Osteoarthritis from Controls

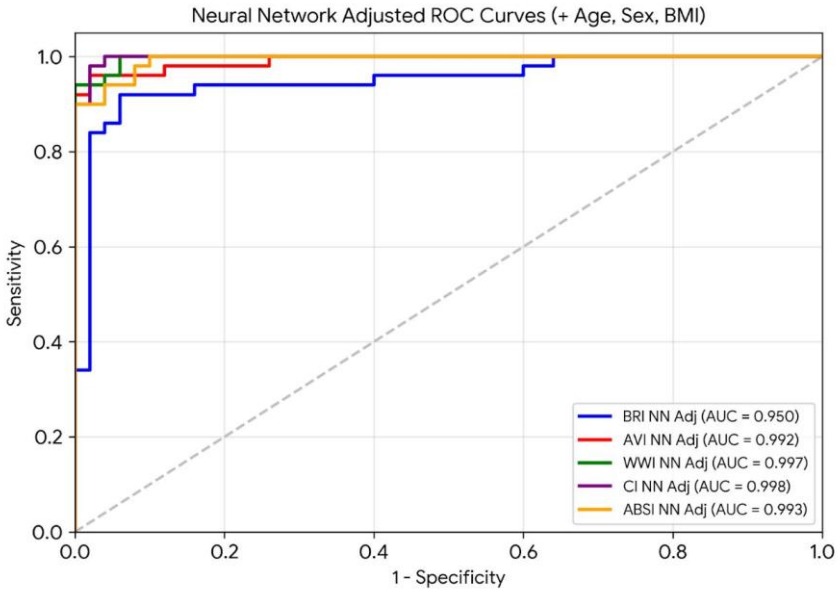


Figure 2. ROC curves of neural network models using each anthropometric index (BRI, AVI, WWI, CI or ABSI) adjusted for age, sex and BMI for discriminating knee osteoarthritis from controls. The dashed diagonal is the reference line (AUC = 0.50).

Comment: The neural network models showed very high discrimination for knee osteoarthritis, with AUCs of 0.998 for CI, 0.997 for WWI, 0.993 for ABSI, 0.992 for AVI and 0.950 for BRI. All five curves rise almost vertically at the left edge, reaching sensitivity of about 0.9 or higher at very low false-positive rates. CI, WWI, ABSI and AVI approach perfect classification, with sensitivity near 1.0 at about 10% false positives or less. BRI was the lowest, with a slower early rise (sensitivity about 0.35 at the lowest false-positive rates) and a plateau around 0.92-0.96.

Table 4. Crude and adjusted association of each anthropometric index with popliteal intima–media thickness (IMT)

Index	Crude ρ (p)	Adjusted partial ρ (p)	Adjusted std β (p)
BMI	0.17 (0.088)	0.05 (0.60)	0.07 (0.50)
BRI	0.36 (0.0003)	0.13 (0.21)	0.13 (0.32)
AVI	0.33 (0.0008)	0.14 (0.17)	0.17 (0.17)
WWI	0.37 (0.0002)	0.21 (0.041)	0.19 (0.087)
CI	0.37 (0.0002)	0.22 (0.029)	0.22 (0.050)
ABSI	0.34 (0.0006)	0.23 (0.021)	0.22 (0.039)

"Each index is adjusted for age, sex and BMI; BMI itself is adjusted for age and sex only.".

Comment: Crude analyses showed significant positive correlations between popliteal IMT and BRI, AVI, WWI, C-index, and ABSI, whereas BMI was not significantly correlated with IMT. After adjustment for age, sex, and BMI, significant partial correlations persisted for WWI, C-index, and ABSI. In adjusted linear regression, only ABSI remained statistically significant, while C-index showed a borderline association. These findings suggest that certain central adiposity indices, particularly ABSI, may be independently associated with popliteal IMT.

Table 5. Cross-validated AUC for Popliteal intima media thickness: crude versus covariate-adjusted models

Index	Crude regression	Crude neural net	Adjusted regression (95% CI)	Adjusted neural net (95% CI)
BRI	0.919	0.915	0.915 (0.85–0.97)	0.889 (0.82–0.96)
AVI	0.917	0.915	0.913 (0.84–0.97)	0.873 (0.83–0.97)
WWI	0.887	0.869	0.897 (0.82–0.96)	0.883 (0.80–0.96)
CI	0.879	0.866	0.897 (0.82–0.96)	0.877 (0.80–0.96)
ABSI	0.825	0.815	0.881 (0.80–0.95)	0.850 (0.78–0.94)

Adjusted models include the index plus age, sex and BMI. Age, sex and BMI alone: regression 0.80, neural network 0.75.

Comment: Both logistic regression and neural-network models demonstrated good discrimination between KOA patients and controls. After adjustment for age, sex, and BMI, logistic regression consistently achieved numerically higher AUCs than neural networks. BRI and AVI showed the highest discrimination with logistic regression, while BRI performed best in the adjusted neural-network models. Adding anthropometric indices appeared to improve discrimination compared with the base model. However, the observed differences do not establish statistical superiority of either method without formal comparison.

Figure 3. Crude and Adjusted Associations Between Anthropometric Indices and Popliteal Intima–Media Thickness in Knee Osteoarthritis Patients and Controls

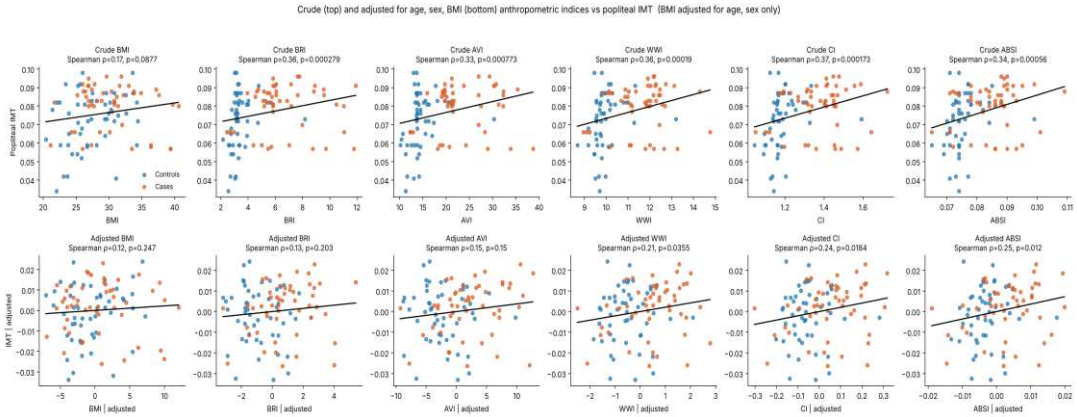


Figure 3. Crude (top row) and adjusted (bottom row) anthropometric indices versus popliteal IMT. Orange: knee osteoarthritis patients; blue: controls.

Comment: In crude analyses, all anthropometric indices except BMI showed significant positive correlations with popliteal IMT, with BRI, AVI, WWI, CI, and ABSI demonstrating modest-to-moderate associations. After adjustment for age, sex, and BMI, the associations weakened substantially; only WWI, CI, and ABSI remained statistically significant. These findings suggest that central adiposity-related indices may provide additional information about popliteal IMT beyond conventional confounders, although the observed correlations remain relatively weak.

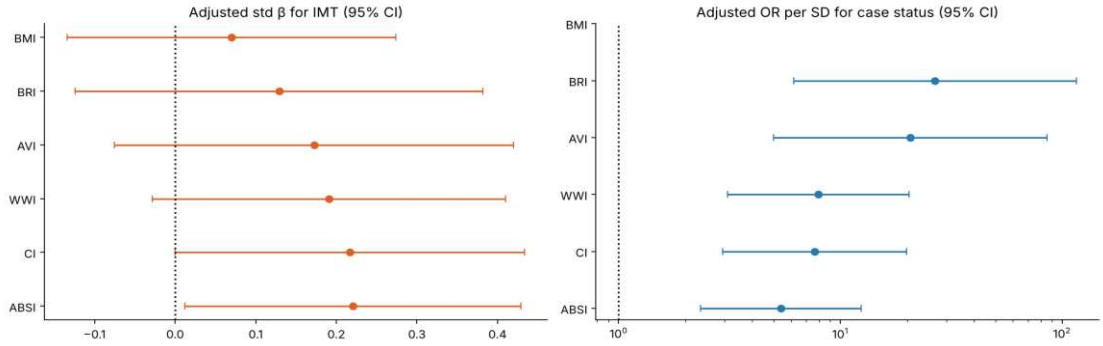


Figure 4. Forest plots of the adjusted standardized β for popliteal IMT (left) and the adjusted odds ratio per SD for knee osteoarthritis (right, log scale).

Comment: After adjustment, all anthropometric indices showed positive associations with popliteal intima-media thickness (IMT), although the confidence intervals for BMI, BRI, AVI, and WWI crossed zero, suggesting limited statistical precision. In contrast, all indices were positively associated with knee osteoarthritis, with adjusted odds ratios substantially above 1. BRI and AVI showed the strongest associations, followed by WWI, CI, and ABSI. These findings suggest that the indices may be more informative for identifying knee osteoarthritis than for explaining variation in popliteal IMT. Statistical significance should be confirmed using the exact estimates and confidence intervals.

Figure 5: Covariate-Adjusted Regression and Neural Network Models

Adjustment was also done by entering age, sex and BMI as covariates alongside each index, in a logistic regression and in a neural network (5×5 cross-validation). Models with age, sex and BMI alone reached an AUC of 0.80 (regression) and 0.75 (neural network).

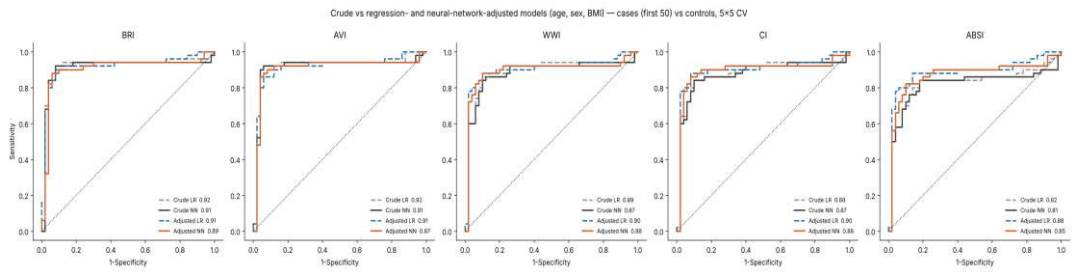


Figure 5. ROC curves for each anthropometric index: crude and covariate-adjusted logistic regression and neural network models.

Comment: After adjustment for age, sex, and BMI, the anthropometric indices generally maintained good discriminatory performance, with AUCs remaining high across both logistic regression and neural network models. However, the incremental value of these

indices beyond the covariates alone appears limited, as the covariate-only models achieved AUCs of 0.80 and 0.75, respectively. Overall, logistic regression performed comparably to or better than the neural network, suggesting no consistent advantage of the more complex model.

Table 6. Cross-validated R^2 for continuous popliteal IMT

Index	Crude regression	Crude neural net	Adjusted regression	Adjusted neural net
BRI	0.009	0.060	0.012	0.023
AVI	0.025	0.086	0.021	0.006
WWI	0.043	0.078	0.033	0.010
CI	0.060	0.087	0.044	0.022
ABSI	0.058	0.072	0.049	0.044

Age, sex and BMI alone: regression $R^2 = 0.020$, neural network $R^2 = -0.002$.

Comment: Cross-validated models demonstrated limited predictive performance for continuous popliteal IMT, with all R^2 values remaining low (0.006–0.087). The highest R^2 was observed with the crude neural-network model using C-index (0.087), while adjusted regression performed best with ABSI (R^2 = 0.049). The base models showed minimal explanatory power (regression R^2 = 0.020; neural network R^2 = −0.002). Overall, these findings suggest that the evaluated anthropometric indices explain only a small proportion of IMT variability, with no clear predictive advantage of neural networks over regression models.

Discussion

Anthropometric Characteristics and Knee Osteoarthritis

Patients with knee osteoarthritis (KOA) had significantly higher body weight, BMI, waist circumference, and hip circumference than controls, whereas height was comparable between groups. The higher values of weight-adjusted waist index (WWI), abdominal volume index (AVI), conicity index (CI), and body roundness index (BRI) further suggest differences in body size and fat distribution between the groups. These findings are consistent with the established role of obesity in KOA through increased mechanical loading and metabolic-inflammatory pathways [28,29]. Previous studies have reported associations between WWI and osteoarthritis (OA) [7] and between BRI and both prevalent OA and incident KOA [30,31]. Furthermore, recent evidence suggests that BRI and other adiposity indices increase with KOA severity [32], highlighting the potential relevance of body shape and fat distribution beyond conventional BMI.

Popliteal Artery Intima–Media Thickness and Knee Osteoarthritis

Popliteal artery intima–media thickness (IMT) was significantly higher in patients with KOA than in controls (0.0797 ± 0.0120 vs 0.0713 ± 0.0171; p = 0.005). This finding is consistent with previous research reporting vascular alterations in patients with knee OA. Olansen et al. observed increased IMT, greater arterial stiffness, and higher volumetric flow in the lower-limb arteries of patients with knee OA compared with individuals without OA [17]. Greater popliteal artery wall thickness has also been associated with lower medial tibial cartilage volume and faster cartilage loss [15]. Similarly, popliteal IMT has been associated with patellar cartilage defects and infrapatellar fat pad volume [27].

Potential shared mechanisms include obesity, insulin resistance, low-grade systemic inflammation, and endothelial dysfunction, which may contribute to both arterial remodeling and joint degeneration [18–20]. The metabolic and inflammatory pathways linking adiposity to KOA [28] may therefore also be relevant to vascular changes. Nevertheless, because the case–control difference in IMT was not adjusted for potential confounders, the observed difference cannot be attributed independently to KOA.

Associations Between Anthropometric Indices and Popliteal IMT

In crude analyses, all five anthropometric indices were positively associated with popliteal IMT (β = 0.0034–0.0045 per 1-SD increase; p = 0.001–0.016), and these associations remained significant after Holm correction (corrected p = 0.005–0.016), although the effect sizes were small. However, the associations were no longer statistically significant after adjustment for age, sex, BMI, and case status (β = −0.0006 to +0.0015; all p ≥ 0.33).

Similarly, correlations between the BMI-adjusted indices and IMT were weak (r = 0.097–0.197). Only ABSI reached nominal statistical significance (p = 0.049), but this association did not remain significant after correction for multiple comparisons (corrected p = 0.245). No index was significantly associated with IMT when patients and controls were analyzed separately. The direction of the associations was consistently positive among patients (β = +0.0018 to +0.0022) but inconsistent among controls (β = −0.0047 to +0.0006).

Overall, these findings suggest that the crude associations between anthropometric indices and popliteal IMT may largely reflect differences in age, sex, overall body size, and case–control status rather than independent associations between body shape and arterial wall thickness. Thus, although the indices showed promising discriminatory performance for KOA, they did not demonstrate significant independent associations with popliteal IMT after multivariable adjustment in this sample.

Sex-Related Differences in Anthropometric Indices and Popliteal IMT

Among patients with KOA, no statistically significant sex-related differences were observed in WWI, AVI, CI, BRI, ABSI, or popliteal IMT. Mean IMT was 0.0830 ± 0.0100 in males and 0.0776 ± 0.0129 in females (p = 0.119). These findings suggest that no clear sex-related differences were detected in the anthropometric and vascular parameters examined. However, the subgroup sizes (20 males and 30 females) limit the ability to exclude smaller differences.

Discriminatory Performance of Anthropometric Indices for Knee Osteoarthritis

The discriminatory performance of BRI is consistent with previous cross-sectional and longitudinal studies linking body shape with OA and incident KOA [30,31]. Similarly, the performance of BRI and AVI is biologically plausible given emerging evidence linking central and regional adiposity with knee structural abnormalities [33–35]. Unlike BMI, which reflects body mass relative to height without directly characterizing fat distribution, these indices incorporate additional anthropometric information related to abdominal adiposity and body shape. Their discriminatory performance may therefore reflect obesity-related mechanical and metabolic characteristics associated with KOA.

In the present study, BRI, CI, WWI, ABSI, and AVI showed statistically significant associations with KOA after adjustment for age, sex, and BMI. Their apparent AUROCs ranged from 0.914 to 0.936. Although BRI yielded the highest numerical AUROC, pairwise ROC comparisons did not demonstrate robust evidence of superiority after accounting for multiple comparisons. Therefore, the results suggest that several anthropometric indices may be associated with KOA beyond conventional BMI, but they do not establish that any single index is diagnostically superior.

The strong apparent discriminatory performance should be interpreted cautiously because the regression models and ROC analyses were evaluated in the same 100-participant dataset used to develop the models. This approach may produce optimistic estimates of diagnostic performance. Moreover, adjustment for BMI requires careful interpretation because the investigated indices are mathematically related to body size and adiposity, potentially introducing collinearity or complicating the interpretation of their independent associations.

The exploratory neural-network analysis using five-fold cross-validation yielded lower AUROCs, ranging from 0.842 to 0.869. This difference highlights the importance of validation procedures and the potential influence of sample size on model performance. These results should therefore be considered preliminary rather than definitive evidence of diagnostic superiority.

Potential Pathophysiological and Clinical Implications

Collectively, the findings are consistent with a multifactorial model of KOA involving excessive mechanical loading and adipose tissue–mediated metabolic and inflammatory pathways [28,29]. Central adiposity may contribute to KOA through increased loading across the knee and through systemic or local inflammatory mechanisms that adversely affect cartilage and other joint tissues.

The combination of anthropometric indices and ultrasonographic vascular parameters such as popliteal IMT may offer a broader framework for investigating the relationship between adiposity, vascular health, and KOA. However, because the independent associations between anthropometric indices and IMT were not statistically significant after adjustment, the present findings do not establish that combining these measures improves clinical diagnosis or prediction. Further research is required to determine whether such a combined approach provides clinically meaningful information beyond established risk factors.

Limitations

This study was limited by its small sample size (100 participants), which may reduce statistical power and increase the risk of model overfitting. The cross sectional design precludes causal inference and may limit generalizability. Internal cross-validation does not replace external validation, and the predictive performance of the anthropometric indices should therefore be interpreted cautiously. Potential collinearity and overadjustment may arise from adjusting for BMI when evaluating related anthropometric indices. Finally, the associations with popliteal IMT were weak after adjustment, and the models explained only a limited proportion of its variability. Larger prospective studies with independent validation are needed to confirm these findings and establish clinical utility.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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