

Original Article

Ultrasonographic Assessment of Obesity-Induced Alterations in Knee Cartilage Thickness

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ABSTRACT

Background: Obesity is an established risk factor for knee osteoarthritis through mechanical loading and metabolic-inflammatory pathways. Ultrasonography provides a non-invasive method for measuring accessible femoral articular cartilage. **Objective:** To assess knee cartilage thickness ultrasonographically and examine its relationship with body mass index (BMI). **Methods:** This cross-sectional study analyzed 89 adults aged 18–65 years. Knee cartilage was evaluated using a GE Voluson 730 Expert ultrasound system with a 6–12-MHz linear probe. Femoral cartilage measurements were obtained at medial, lateral, and intercondylar regions. BMI-related differences were examined using one-way analysis of variance (ANOVA), and continuous relationships with BMI were assessed using Pearson correlation. **Results:** Women comprised 64/89 participants (71.9%). Mean cartilage thickness ranged from 1.57±0.48 mm at the right lateral femoral condyle to 1.88±1.38 mm at the left intercondylar area. No measured site differed significantly across BMI categories: left medial condyle p=.085, left lateral p=.185, left intercondylar p=.849, right medial p=.373, and right lateral p=.065. Continuous BMI nevertheless showed a small inverse association with right lateral femoral-condyle thickness ($r=-0.265$, $p=.012$; 95% CI -0.449 to -0.060). **Conclusion:** Generalized BMI-related cartilage thinning was not demonstrated. A limited inverse association was identified between BMI and right lateral femoral cartilage thickness, supporting further investigation in larger, standardized longitudinal studies. **Keywords:** Obesity; Body Mass Index; Articular Cartilage; Knee; Ultrasonography; Osteoarthritis.

INTRODUCTION

Obesity is an important modifiable risk factor for knee osteoarthritis. Excess body mass increases mechanical loading across weight-bearing joints, while metabolic abnormalities associated with adiposity may also affect cartilage and synovial tissues through systemic inflammation and adipokine-related pathways (1,2). The association between obesity and knee degeneration is therefore not exclusively mechanical; increased joint loading may coexist with metabolic dysfunction and chronic low-grade inflammation in the development and progression of osteoarthritic changes (1,2).

Biomechanical characteristics may further modify the relationship between body mass and knee-joint structure. Lower-limb alignment, gait characteristics, muscle function, activity patterns, and joint forces influence the distribution of mechanical stress within the knee, while longitudinal imaging evidence indicates that obesity and alignment are associated with compartment-specific femorotibial cartilage change (3). The structural consequences associated with excess body mass may therefore vary across regions of the knee rather than occurring uniformly throughout the joint (2,3).

Articular cartilage provides a low-friction articulating surface and contributes to load distribution and shock absorption during weight-bearing activity. Structural deterioration of articular cartilage is a central feature of osteoarthritis, although cartilage morphology and degeneration vary according to anatomical compartment and individual characteristics. Sex-related differences in cartilage thickness, volume, morphology, and degenerative patterns have been documented, while mechanical alignment may further influence regional cartilage structure and longitudinal change (3,4). Interpretation of cartilage thickness therefore requires consideration of anatomical location and relevant biological and biomechanical characteristics rather than reliance on a single generalized measure.

Longitudinal MRI studies have demonstrated associations among obesity, mechanical alignment, and trajectories of femorotibial cartilage thickness over time (3). MRI provides detailed assessment of cartilage and other intra-articular structures and is particularly valuable for detecting longitudinal morphological change. Nevertheless, cost, examination requirements, and accessibility may restrict its routine use in some clinical and research settings, creating interest in more accessible imaging approaches for quantitative evaluation of superficial cartilage structures.

Musculoskeletal ultrasonography can visualize accessible femoral articular cartilage rapidly and without ionizing radiation. Ultrasonographic measurements of knee cartilage have demonstrated validity when appropriate anatomical landmarks and standardized acquisition procedures are used (5). Comparative studies have also demonstrated reasonable agreement between ultrasound- and MRI-derived cartilage-thickness measurements, while recognizing that the two modalities do not visualize precisely identical regions of the articular surface (6). Knee-flexion angle and measurement position can influence ultrasonographically derived femoral cartilage thickness, and contemporary ultrasound literature further emphasizes standardized patient positioning, probe orientation, anatomical landmarks, and operator technique to improve reproducibility (7–9).

These characteristics make ultrasonography a potentially useful research method for examining relationships between anthropometric variables and accessible femoral-cartilage morphology. However, a cross-sectional cartilage-thickness measurement represents structural morphology at a single examination and cannot establish the temporal direction of cartilage change (3). The present study therefore used ultrasonography to quantify knee cartilage at selected femoral and intercondylar sites and evaluated whether these measurements differed across BMI categories or correlated with continuous BMI.

MATERIALS AND METHODS

Study Design

A cross-sectional observational study was conducted over a four-month period following institutional approval of the research synopsis. The final analytical sample comprised 89 participants aged 18–65 years who were recruited using convenience sampling. Ethical approval was obtained from the Institutional Review Board of Superior University, Lahore, Pakistan. Written informed consent was obtained from all participants, and confidentiality was maintained throughout the study.

Ultrasonographic Assessment

Ultrasonographic examinations were performed using a GE Voluson 730 Expert system equipped with a 6–12-MHz high-frequency linear transducer. Participants were initially positioned in dorsal decubitus. The examined knee was flexed, and transverse axial images were obtained for assessment of anterior femoral cartilage. Participants were also examined in ventral decubitus to permit axial and longitudinal evaluation of the posterior knee region.

Femoral articular cartilage was assessed with the knee in flexion. The examination included the left medial femoral condyle, left lateral femoral condyle, left intercondylar area, right medial femoral condyle, right lateral femoral condyle, and right intercondylar area. Flexed-knee transverse ultrasonographic

assessment of distal femoral cartilage is consistent with established approaches used for quantitative evaluation of accessible femoral cartilage (5,6).

The examination protocol additionally included measurement of tibial cartilage at the sulcus, medial tibial condyle, and lateral tibial condyle with the knee flexed to approximately 90°. The principal statistical analysis of cartilage thickness incorporated five locations: the left medial femoral condyle, left lateral femoral condyle, left intercondylar area, right medial femoral condyle, and right lateral femoral condyle.

Body Mass Index

BMI was recorded for each participant and analyzed both as a continuous variable and categorically. For categorical analysis, participants were classified into normal-weight, overweight, and obese groups, and cartilage-thickness measurements were compared across the three BMI categories.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 25. Continuous variables were summarized using the mean, standard deviation, minimum, quartiles, median, and maximum where applicable. One-way ANOVA was used to compare cartilage thickness among the three BMI categories. For $n=89$ and three groups, effect size was additionally expressed as eta squared, calculated from the reported F statistic. Pearson correlation was used to examine the continuous association between BMI and cartilage thickness. Statistical significance was set at $p<0.05$. For the relationship between BMI and right lateral femoral-condyle cartilage thickness, a Fisher-z 95% confidence interval for the correlation coefficient was calculated using $n=89$.

RESULTS

Participant Characteristics

A total of 89 participants were included in the analysis, comprising 64 women (71.9%) and 25 men (28.1%). Overall, 85.39% of participants were categorized as obese, and the mean BMI was approximately 32.28 kg/m². Participants were aged between 18 and 65 years.

Table 1. Participant Characteristics

Characteristic	Value
Total participants	89
Female	64 (71.9%)
Male	25 (28.1%)
Obese proportion	85.39%
Mean BMI	32.28 kg/m ²
Age range	18–65 years

Cartilage Thickness

Mean cartilage thickness ranged from 1.57±0.48 mm at the right lateral femoral condyle to 1.88±1.38 mm at the left intercondylar area. Most mean measurements were therefore within an approximate range of 1.6–1.9 mm. The left intercondylar measurement displayed substantially greater dispersion than the other locations and included a maximum measurement of 14.0 mm.

Table 2. Ultrasonographic Cartilage Measurements

Cartilage Site	Mean ± SD, mm	Minimum	25th Percentile	Median	75th Percentile	Maximum
Left medial femoral condyle	1.59±0.50	0.6	1.2	1.5	1.8	3.2
Left lateral femoral condyle	1.67±0.58	0.6	1.3	1.6	1.9	3.8
Left intercondylar area	1.88±1.38	0.8	1.4	1.8	2.1	14.0
Right medial femoral condyle	1.64±0.53	0.7	1.3	1.6	1.9	4.0
Right lateral femoral condyle	1.57±0.48	0.6	1.2	1.6	1.9	2.7

Comparison Across BMI Categories

None of the five analyzed cartilage measurements differed significantly among the three BMI categories at the prespecified $p<0.05$ threshold. The largest categorical effect was observed at the right lateral femoral condyle, where the between-group comparison approached but did not reach statistical significance ($F=2.82$, $p=.065$, $\eta^2=0.062$).

Table 3. Cartilage Thickness Across BMI Categories

Site	F Statistic	p Value	η^2
Left medial femoral condyle	2.54	.085	0.056
Left lateral femoral condyle	1.72	.185	0.038
Left intercondylar area	0.16	.849	0.004
Right medial femoral condyle	0.99	.373	0.023
Right lateral femoral condyle	2.82	.065	0.062

The eta-squared value of 0.062 for the right lateral femoral condyle corresponded to approximately 6% of the variance in cartilage thickness associated with categorical BMI grouping in the unadjusted analysis. However, the observed between-group difference did not meet the prespecified threshold for statistical significance.

Continuous BMI Association

Continuous BMI showed a statistically significant inverse association with right lateral femoral-condyle cartilage thickness ($r=-0.265$, $p=.012$). The corresponding 95% confidence interval for r was approximately -0.449 to -0.060 .

The magnitude of the correlation was small, indicating that higher BMI was associated with slightly lower cartilage thickness at the right lateral femoral condyle. This association was compartment specific and did not indicate generalized cartilage thinning across all measured locations.

DISCUSSION

The present study evaluated ultrasonographically measured knee cartilage in relation to BMI and found limited evidence of generalized BMI-related cartilage alteration. Four of the five analyzed cartilage sites showed no statistically significant differences across BMI categories, while the right lateral femoral condyle also remained non-significant in the categorical ANOVA at $p=.065$. The principal positive finding was a statistically significant but modest inverse correlation between continuous BMI and right lateral femoral-condyle cartilage thickness. The magnitude of this relationship indicates limited shared variation between BMI and cartilage thickness and does not support a uniform effect across the examined knee compartments.

Obesity is consistently recognized as an important risk factor for knee osteoarthritis, but the relationship between excess body mass and joint degeneration is multifactorial (1,2). Increased mechanical loading provides one pathway through which obesity may affect weight-bearing joints, whereas adipokines, metabolic dysfunction, and chronic low-grade inflammation provide additional biological mechanisms through which adiposity may influence cartilage and synovial tissues (2). Consequently, an elevated population-level risk of knee osteoarthritis among individuals with obesity does not imply that every individual with obesity will demonstrate uniformly reduced femoral cartilage thickness during a single cross-sectional examination (1,2).

The cross-sectional nature of the present findings is particularly important when interpreting cartilage morphology. Longitudinal MRI evidence indicates that obesity and lower-limb alignment are associated with subsequent femorotibial cartilage-thickness trajectories (3). A measurement obtained at one time point, in contrast, cannot distinguish progressive cartilage loss from pre-existing anatomical variation or other between-person differences. The current findings are therefore compatible with a relationship between BMI and regional cartilage morphology but do not establish that higher BMI caused the observed difference in right lateral femoral cartilage thickness (3).

The compartment-specific association is also consistent with the heterogeneous mechanical environment of the knee. Mechanical loading is not distributed uniformly throughout the joint, and alignment may influence regional cartilage loading and longitudinal thickness change (3). Sex-related differences in cartilage morphology, composition, and degeneration have also been documented and can contribute to between-person variation in cartilage measurements (4). Physical activity, muscle function, previous injury, occupational loading, and joint geometry may further alter local mechanical stresses. The isolated right lateral association observed in the present study may therefore reflect regional biomechanical heterogeneity, sampling variation, or residual confounding rather than generalized obesity-related cartilage thinning (1–4).

The categorical and continuous analyses are not inherently contradictory because they evaluate the BMI-cartilage relationship differently. ANOVA compared mean cartilage thickness among three BMI groups, whereas Pearson correlation retained the full continuous distribution of BMI values. Categorization of

continuous predictors can cause loss of information and reduced statistical power, particularly when an underlying relationship is gradual rather than characterized by true biological thresholds (10). It is therefore statistically plausible for an association based on continuous BMI to reach significance while a corresponding comparison across broader BMI categories does not.

Ultrasonography provides a practical approach for quantitative evaluation of accessible femoral cartilage. Validation studies have demonstrated that knee-cartilage thickness can be measured ultrasonographically with acceptable validity, while direct comparisons have demonstrated reasonable correspondence between ultrasound and MRI measurements (5,6). Nevertheless, ultrasonography evaluates only accessible portions of the articular surface, and measurement precision depends on technique. Knee position can materially influence femoral cartilage measurements, while standardized patient positioning, anatomical landmark identification, probe orientation, and operator technique are important for reproducible knee ultrasonography (7,8). More recent reliability data similarly demonstrate that reproducibility of quantitative musculoskeletal ultrasound measurements is influenced by standardized examination procedures and observer-related factors (9).

The left intercondylar cartilage measurements showed substantially greater variability than measurements at the other locations. The maximum value of 14.0 mm was markedly higher than the remaining cartilage observations and contributed to the large standard deviation for this site. Because ultrasonographic cartilage measurements are sensitive to anatomical localization, knee position, probe alignment, and observer technique, unusually dispersed measurements should be interpreted cautiously in relation to these technical determinants (5,7-9). This variability further underscores the importance of standardized imaging protocols and repeated reliability assessment in quantitative cartilage research.

Longitudinal imaging provides stronger evidence regarding structural progression because within-person cartilage change can be observed directly over time. Moyer et al. demonstrated associations among obesity, alignment, and longitudinal MRI-based femorotibial cartilage-thickness change (3). Studies from the Osteoarthritis Initiative have further shown that weight reduction among overweight and obese individuals was associated with less progression of MRI-detected cartilage degeneration over 48 months and with reduced cartilage degeneration over a longer 96-month follow-up period (11,12). These longitudinal observations provide important context for the relationship between body weight and cartilage health but do not establish that weight reduction would necessarily reverse the compartment-specific ultrasonographic association identified in the present cross-sectional study.

The predominance of women in the present sample may influence generalizability. Sex-related differences have been demonstrated in cartilage thickness, morphology, composition, volume, and patterns of degeneration, indicating that sex may be relevant when structural cartilage outcomes are compared across heterogeneous populations (4). Because women represented 71.9% of participants, the overall measurements primarily characterize a female-predominant sample, and cartilage outcomes were not analyzed separately by sex. Future studies with more balanced recruitment and sex-stratified analyses may help distinguish BMI-related relationships from underlying sex-associated differences in cartilage structure (4).

Several potentially relevant biomechanical and metabolic variables were not incorporated into the association analyses. Knee alignment, physical activity, occupational loading, muscle function, previous injury, and metabolic characteristics can contribute to knee-OA risk or influence regional cartilage loading and structural change (1-4). The observed relationship between BMI and right lateral femoral cartilage thickness should therefore be interpreted as an unadjusted bivariate association rather than an independent effect of BMI.

The BMI distribution of the study population also warrants consideration. Although cartilage thickness was compared across normal-weight, overweight, and obese categories, 85.39% of participants were classified as obese. The eligibility framework specified BMI ≥ 30 kg/m², whereas the analytical categorization included normal-weight, overweight, and obese participants. This inconsistency in the sampling and analytical framework may affect interpretation of the categorical findings. In addition, unequal representation across BMI categories can reduce the information available for between-group comparisons, whereas analysis of BMI on its continuous scale retains more of the measured variation (10).

The categorical BMI analysis was not accompanied by group-specific participant counts and cartilage-thickness means, which limits detailed assessment of the distributions underlying the ANOVA results. The principal statistical analysis was also restricted to five cartilage locations despite the broader set of femoral and tibial locations included in the imaging protocol. These features do not invalidate the

reported comparisons but limit the completeness with which regional and category-specific patterns can be interpreted.

The present study did not establish a diagnostic or referral threshold for ultrasonographic cartilage thickness. The analysis examined associations between BMI and cartilage morphology rather than diagnostic accuracy, discrimination, or prediction of clinically meaningful structural outcomes. Consequently, a fixed cartilage-thickness threshold such as 1.5 mm cannot be inferred from these findings. Development of clinically applicable thresholds would require independent validation against an appropriate structural or clinical reference standard.

Taken together, the findings support a cautious interpretation of obesity-related cartilage morphology. BMI was not associated with generalized reductions in cartilage thickness across the examined locations, but a small inverse association was identified at the right lateral femoral condyle. This regional finding is compatible with the broader concept that obesity interacts with mechanical, metabolic, anatomical, and individual factors rather than exerting a uniform structural effect throughout the knee (1–4). Longitudinal studies using standardized imaging protocols and multivariable analytical approaches are required to determine whether compartment-specific cross-sectional associations predict subsequent cartilage change (3,7–9).

CONCLUSION

Ultrasonographic cartilage thickness did not differ significantly across BMI categories at the five analyzed knee sites. A small but statistically significant inverse association was identified between continuous BMI and right lateral femoral-condyle cartilage thickness. The findings therefore indicate a limited compartment-specific relationship rather than generalized obesity-related cartilage thinning. Ultrasonography provides a practical method for quantitative assessment of accessible femoral cartilage, but longitudinal studies using standardized imaging, balanced representation across BMI categories, and adjustment for relevant biomechanical and metabolic factors are required before causal conclusions or clinical screening thresholds can be established.

LIMITATIONS

The cross-sectional design prevented assessment of temporal cartilage change and does not permit causal interpretation of the observed BMI–cartilage association. Convenience sampling may limit generalizability, and the study population was predominantly female. Cartilage outcomes were not analyzed separately by sex, and potential confounding by knee alignment, physical activity, occupational loading, muscle function, previous minor injury, family history, and metabolic characteristics was not addressed.

The BMI eligibility framework specified BMI ≥ 30 kg/m², whereas the analytical sample was categorized into normal-weight, overweight, and obese groups and 85.39% of participants were classified as obese. The categorical analysis was not accompanied by group-specific sample sizes and cartilage means, limiting detailed interpretation of between-group patterns. The principal statistical analysis also included five cartilage locations despite additional femoral and tibial locations being incorporated into the imaging protocol.

No MRI or other independent structural reference measure was used in the study cohort. In addition, the left intercondylar measurements demonstrated substantial dispersion, including a maximum value of 14.0 mm, which may reduce the precision and interpretability of measurements at that location.

RECOMMENDATIONS

Future studies should prospectively define and consistently apply BMI eligibility and analytical categories, recruit sufficient participants across BMI strata, and retain BMI as a continuous variable for analyses in which the underlying relationship is expected to be graded rather than threshold based (10). Participant-level longitudinal follow-up would permit direct estimation of cartilage-thickness change and help distinguish progressive structural alteration from between-person anatomical variation (3). Future analyses should also account for sex, age, knee alignment, physical activity, occupational exposure, muscle function, previous injury, and relevant metabolic characteristics (1–4).

Ultrasonographic assessment should use standardized anatomical landmarks, knee-flexion angles, probe positioning and orientation, acquisition procedures, repeated measurements, and formal intra- and interobserver reliability assessment because technical and positional factors can influence quantitative cartilage measurements (5,7–9). Ultrasound-derived screening or referral thresholds should

be introduced only after validation against clinically meaningful structural, symptomatic, or diagnostic outcomes.

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