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Evaluation of the correlation between body mass index and radiological measurements around the knee: Aydin index

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Abstract

This study aimed to assess the relationship between body mass index (BMI) and the evaluation of bone and soft tissue structures around the knee. Various measurements were obtained from knee radiographs of 984 patients who presented to the outpatient clinic between January 2024 and January 2025. Height, weight, and BMI values were documented at the time of presentation. The correlation between the obtained measurements and BMI was analyzed. The measurements and proportional values with the highest correlation with BMI were identified. In the anteroposterior knee radiographs, the strongest correlation with BMI was observed in the distance between the lateral skin and the lateral femoral cortex in the coronal plane (Pearson correlation; 0.346, $p<0.001$). In the sagittal plane, the strongest correlation with BMI was found in the distance between the posterior skin and the posterior femoral cortex (Pearson correlation; 0.167, $p<0.001$). The strongest correlation with BMI was found in the ratio of the distance between the lateral femoral border at the medial epicondyle level and the skin to the total skin-to-skin distance ($p=0.417$, $p<0.001$). This study demonstrated a statistically significant relationship between various measurements and proportional indices around the knee and BMI. We believe that proportional measurements around the knee can provide a measure of BMI in cases where data records are insufficient or in patients with a history of prior surgery that limits BMI evaluation.

Keywords: Body mass index, femur, knee, lower extremity, outpatient clinic

Introduction

Body mass index (BMI) is calculated by dividing body weight by the square of height in meters. Obesity and high BMI, which play a role in the etiology of various diseases, are also significantly associated with orthopedic conditions. A high BMI is a considerable factor contributing to complications, particularly in lower extremity surgeries, where an increased BMI is strongly correlated with postoperative complications [1-3].

Numerous studies have shown that BMI correlates significantly with subcutaneous fat tissue, particularly in the abdominal region [4,5]. For instance, previous ultrasound-based assessments have revealed that abdominal subcutaneous fat thickness demonstrates a strong positive correlation with BMI, often more so than fat thickness in the limbs [6,7]. Additionally, correlations between BMI and soft tissue thickness in areas such as the arm and thigh have also been documented [8]. These findings support the rationale for investigating similar relationships in other anatomical regions, including the knee.

Building on this evidence, it is plausible that radiological evaluation of soft tissue thickness around the knee could serve as a practical and accessible method to estimate BMI, especially in orthopedic settings where knee radiographs are routinely performed. By examining soft tissue-to-bone distances and proportional indices derived from standard X-rays, clinicians may gain valuable insight into a patient's body habitus without

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the need for additional imaging or clinical measurements. This approach may also aid in predicting surgical risks and outcomes, as increased periarticular fat has been associated with higher complication rates in procedures such as total knee arthroplasty.

The completeness and accuracy of data records are critical for retrospective studies. Data deficiencies can lead to limitations in study outcomes. Many retrospective studies encounter uncertainty due to incomplete records or outdated height and weight details. In orthopedic research, BMI is a crucial component of study analyses.

The primary aim of this study was to assess BMI using measurement methods derived from direct knee radiographs and to evaluate the correlation between BMI and distal femoral/knee circumference measurements. Another objective was to use this index in cases where BMI cannot be directly measured, such as when data records are incomplete, and to guide future research in this area. The secondary aim of the study was to establish a foundation for future investigations on the relationship between the proposed index and knee pathologies.

The main hypothesis of the study is that knee circumference measurements and the proposed index will demonstrate a statistically significant correlation with BMI.

Material and Methods

Patients and Demographics

Between January 1, 2024, and January 2, 2025, data were prospectively collected and radiological measurements performed on patients presenting to the outpatient clinic with knee pain and no additional comorbidities. Patients with a history of neuromuscular diseases, those exhibiting atrophy that could impede extremity function, those who had undergone surgery on the imaged lower extremity, and those with conditions such as cellulitis or lymphedema that can cause regional subcutaneous thickening were excluded from the study. Following these exclusions, 984 patients (270 men and 714 women) were evaluated. The mean age of the study cohort was 48.76±12.08 years. Height and weight were recorded for all patients at the time of presentation, BMI was calculated, and radiological measurements were obtained. After identifying the measurement parameters and ratios that demonstrated the strongest correlation with BMI, the corresponding average BMI values were recorded.

The study design was approved by the University of Health Sciences Baltalimani Bone Disease and Research Hospital's ethical committee (05.04.2021-2021/5-04), and all patients provided written informed consent.

Radiological Assessment

For the radiological evaluation, measurements were obtained from standing anteroposterior (AP) and lateral knee radiographs. From properly acquired knee AP and lateral radiographs, measurements were performed in the coronal and sagittal planes.

Measurements in the coronal plane were as follows:

At the level of the epicondylar axis, femoral cortical width (a), distance between the medial and lateral skin (d), distance from the medial edge of the skin to the medial cortex of the femur (b), and distance from the lateral edge of the skin to the lateral cortex of the femur (c) were measured (Figure 1).

Similarly, at 4 cm proximal to the femoral medial condyle, the femoral cortical width (e), the distance between the medial and lateral skin (h), the distance from the medial edge of the skin to the medial cortex of the femur (f), and the distance from the lateral edge of the skin to the lateral cortex of the femur (g) were measured (Figure 2).

In the sagittal plane, the following measurements were made at 8 cm proximal to the distal articular surface of the femur:

Femoral cortical width (i), skin-to-skin distance (l), distance from the anterior skin to the anterior cortex of the femur (j), and distance from the posterior skin to the posterior cortex of the femur (k) (Figure 3).

After obtaining each measurement, ratios were calculated between the three different parameters, and the correlations between these ratios and BMI were evaluated. The ratios were determined as follows:

At the medial epicondyle level in the coronal plane;

1. Ratio of the femoral width to the subcutaneous distance (a/d)
2. Ratio of the medial skin-to-femur distance to the subcutaneous distance (b/d)
3. Ratio of the lateral skin-to-femur distance to the subcutaneous distance (c/d)- Aydın Index

At 4 cm proximal to the medial epicondyle in the coronal plane;

1. Ratio of the femoral width to the subcutaneous distance (e/h)
2. Ratio of the medial skin-to-femur distance to the subcutaneous distance (f/h)
3. Ratio of the lateral skin-to-femur distance to the subcutaneous distance (g/h)

At 8 cm proximal to the joint level in the sagittal plane;

1. Ratio of the femoral width to the subcutaneous distance (i/l)
2. Ratio of the distance between the anterior skin and the anterior femur to the subcutaneous distance (j/l)
3. Ratio of the distance between the posterior skin and the posterior femur to the subcutaneous distance (k/l)

The correlation between BMI and each measurement as well as each derived ratio was assessed. Mean BMI values corresponding to the measurements with the strongest correlation were noted.

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Statistical Methods

The statistical analysis was carried out using SPSS 29.0 software (SPSS Inc., IBM, New York, USA). The numerical variables were presented as means and standard deviations. Categorical variables were presented as frequencies and percentages. Normality was assessed using the Kolmogorov–Smirnov test, and Spearman's correlation analysis was used to determine the relationships between the variables. A p value of <0.05 was considered statistically significant in all analyses.

Result

At the medial epicondyle level, significant correlations were observed among the femoral cortical width (a), the skin-to-skin distance (d), the distance from the medial skin edge to the medial femoral cortex (b), and the distance from the lateral skin edge to the lateral femoral cortex (c) (p<0.001, p<0.001, p<0.05, p<0.001, respectively). Notably, the strongest correlation with BMI was observed for the distance between the lateral skin edge and the lateral femoral cortex (Table 1).

Table 1. Measurements at the level of the medial epicondyle

Variable	Pearson correlation	BMI	Femoral cortical width	Skin-to-skin distance	Distance from the medial skin edge to the medial femoral cortex	Distance from the lateral skin edge to the lateral femoral cortex
BMI	**Pearson Correlation**	1	.269**	.149**	.094**	.346**
	Sig. (2-tailed)		<.001	<.001	.003	<.001
	N	984	984	984	984	984
Femoral cortical width	**Pearson Correlation**	.269**	1	.125**	.000	.180**
	Sig. (2-tailed)	<.001		<.001	.994	<.001
	N	984	984	984	984	984
Skin-to-skin distance	**Pearson Correlation**	.149**	.125**	1	.079*	.413**
	Sig. (2-tailed)	<.001	<.001		.013	<.001
	N	984	984	984	984	984
Distance from the medial skin edge to the medial femoral cortex	**Pearson Correlation**	.094**	.000	.079*	1	.013
	Sig. (2-tailed)	.003	.994	.013		.692
	N	984	984	984	984	984
Distance from the lateral skin edge to the lateral femoral cortex	**Pearson Correlation**	.346**	.180**	.413**	.013	1
	Sig. (2-tailed)	<.001	<.001	<.001	.692	
	N	984	984	984	984	984

BMI; body mass index, **: Correlation is significant at the 0.01 level (2-tailed). *: Correlation is significant at the 0.05 level (2-tailed).

In the coronal plane at 4 cm proximal to the medial epicondyle, significant correlations were noted among the femoral cortical width (e), the skin-to-skin distance (h), and the distance between the lateral skin edge and the lateral femoral cortex (g) (p<0.001 for all variables). However, no significant correlation was found between BMI and the distance from the medial skin edge to the medial femoral cortex. Notably, the strongest correlation with BMI was observed for the distance between the lateral skin edge and the lateral femoral cortex. (Pearson correlation coefficient=0.332, p<0.001) (Table 2)

In the sagittal plane, measurements obtained 8 cm proximal to the joint line revealed significant correlations between BMI and both the femoral cortical width (i) (p=0.05) and the distance between the posterior skin and the posterior femoral cortex (k) (p<0.001). The strongest correlation with BMI in the sagittal plane was found for the distance between the posterior skin and the posterior femoral cortex (Pearson correlation coefficient=0.110, p<0.001) (Table 3).

When the ratios derived from the coronal and sagittal measurements were evaluated in relation to BMI, the strongest correlation was found for the ratio of the lateral skin-to-femoral distance at the epicondylar level to the skin-to-skin distance (c/d). Table 4,5) Analysis of this index revealed that patients with a BMI of 25–30 had a mean index of 0.19±0.075 (range, 0.07–0.39), those with a BMI of 30–35 had a mean index of 0.24±0.076 (range, 0.08–0.41), patients with a BMI of 35–40 had a mean index of 0.27±0.082 (range, 0.09–0.42), and patients with a BMI above 40 had a mean index of 0.29±0.081 (range, 0.15–0.46) (Table 6).

Due to the absence of any patients with a BMI below 25, the average index for that subgroup could not be determined.

Table 2. Measurements 4 cm proximal to the medial epicondyle

Variable	Pearson correlation	BMI	Femoral cortical width	Skin-to-skin distance	Distance from the medial skin edge to the medial femoral cortex	Distance from the lateral skin edge to the lateral femoral cortex
BMI	Pearson Correlation	1	.173**	−.138**	.032	.332**
	Sig. (2-tailed)		<.001	<.001	.323	<.001
	N	984	984	984	984	984
Femoral cortical width	Pearson Correlation	.173**	1	.500**	.147**	.093**
	Sig. (2-tailed)	<.001		<.001	<.001	.004
	N	984	984	984	984	984
Skin-to-skin distance	Pearson Correlation	.138**	.500**	1	.616**	.617**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001
	N	984	984	984	984	984
Distance from the medial skin edge to the medial femoral cortex	Pearson Correlation	.032	.147**	.616**	1	.106**
	Sig. (2-tailed)	.323	<.001	<.001		<.001
	N	984	984	984	984	984
Distance from the lateral skin edge to the lateral femoral cortex	Pearson Correlation	.332**	.093**	.617**	.106**	1
	Sig. (2-tailed)	<.001	.004	<.001	<.001	
	N	984	984	984	984	984

BMI; body mass index, **: Correlation is significant at the 0.01 level (2-tailed). *: Correlation is significant at the 0.05 level (2-tailed).

Table 3. Sagittal plane measurements 8 cm proximal to the joint level

Variable	Pearson correlation	BMI	Femoral cortical width	Skin-to-skin distance	Distance from the medial skin edge to the medial femoral cortex	Distance from the lateral skin edge to the lateral femoral cortex
BMI	Pearson Correlation	1	.089**	-.025	.167**	.028
	Sig. (2-tailed)		.005	.425	<.001	.387
	N	984	984	984	984	984
Femoral cortical width	Pearson Correlation	.089**	1	.592**	.382**	.139**
	Sig. (2-tailed)	.005		<.001	<.001	<.001
	N	984	984	984	984	984
Skin-to-skin distance	Pearson Correlation	.025	.592**	1	.889**	.508**
	Sig. (2-tailed)	.425	<.001		<.001	<.001
	N	984	984	984	984	984
Distance from the medial skin edge to the medial femoral cortex	Pearson Correlation	.167**	.382**	.889**	1	.143**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001
	N	984	984	984	984	984
Distance from the lateral skin edge to the lateral femoral cortex	Pearson Correlation	.028	.139**	.508**	.143**	1
	Sig. (2-tailed)	.387	<.001	<.001	<.001	
	N	984	984	984	984	984

**: Correlation is significant at the 0.01 level (2-tailed)

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Table 4. Correlation between ratios derived from coronal plane measurements and BMI

Variable	Pearson correlation	BMI	a/d	b/d	c/d	e/h	f/h	g/h
BMI	**Pearson Correlation**	1	.015	.012	.417**	.309**	.144**	.341**
	Sig. (2-tailed)		.647	.713	<.001	<.001	<.001	<.001
	N	984	984	984	984	984	984	984
a/d	**Pearson Correlation**	.015	1	.263**	-.241**	.276**	-.092**	-.041
	Sig. (2-tailed)	.647		<.001	<.001	<.001	.004	.204
	N	984	984	984	984	984	984	984
b/d	**Pearson Correlation**	.012	.263**	1	-.014	-.008	.122**	.072*
	Sig. (2-tailed)	.713	<.001		.661	.792	<.001	.025
	N	984	984	984	984	984	984	984
c/d	**Pearson Correlation**	.417**	.241**	-.014	1	.329**	.109**	.340**
	Sig. (2-tailed)	<.001	<.001	.661		<.001	<.001	<.001
	N	984	984	984	984	984	984	984
e/h	**Pearson Correlation**	.309**	.276**	.008	.329**	1	.229**	.374**
	Sig. (2-tailed)	<.001	<.001	.792	<.001		<.001	<.001
	N	984	984	984	984	984	984	984
f/h	**Pearson Correlation**	.144**	.092**	.122**	.109**	.229**	1	.769**
	Sig. (2-tailed)	<.001	.004	<.001	<.001	<.001		<.001
	N	984	984	984	984	984	984	984
g/h	**Pearson Correlation**	.341**	.041	.072*	.340**	.374**	.769**	1
	Sig. (2-tailed)	<.001	.204	.025	<.001	<.001	<.001	
	N	984	984	984	984	984	984	984

**: Correlation is significant at the 0.01 level (2-tailed). *: Correlation is significant at the 0.05 level (2-tailed). a: femoral width, b: medial skin distance, c: distance between the lateral femoral cortex and the skin, d: subcutaneous distance, e: femoral width (at 4 cm proximal level), f: medial skin distance (at 4 cm proximal level), g: distance between the lateral femoral cortex and the skin (at 4 cm proximal level), h: skin-to-skin distance (at 4 cm proximal level)

Table 5. Correlation between ratios derived from coronal plane measurements and BMI

Variable	Pearson correlation	BMI	i/l	j/l	k/l
BMI	**Pearson Correlation**	1	.156**	.035	.163**
	Sig. (2-tailed)		<.001	.274	<.001
	N	984	984	984	984
i/l	**Pearson Correlation**	.156**	1	−.170**	.422**
	Sig. (2-tailed)	<.001		<.001	<.001
	N	984	984	984	984
j/l	**Pearson Correlation**	.035	−.170**	1	−.801**
	Sig. (2-tailed)	.274	<.001		<.001
	N	984	984	984	984
k/l	**Pearson Correlation**	−.163**	−.422**	−.801**	1
	Sig. (2-tailed)	<.001	<.001	<.001	
	N	984	984	984	984

**: Correlation is significant at the 0.01 level (2-tailed). i: femoral width in the sagittal plane, j: distance between the anterior thigh skin and the anterior femoral cortex in the sagittal plane, k: distance between the posterior thigh skin and the posterior femoral cortex in the sagittal plane, l: subcutaneous distance

Table 6. Mean BMI values corresponding to the measurements and ratios with the strongest correlation

BMI value	Mean measurement in the coronal plane	Mean measurement in the sagittal plane	Mean ratio in the coronal plane c/d	Mean ratio in the sagittal plane
BMI 25–29.9 (overweight)	**27.98±10.88 (9–51)**	87.65±18.56 (46–117)	0.19±0.075 (0.07–0.39)	0.52±0.05 (0.41–0.64)
BMI 30–34.9 (Obese class 1)	**35.81±12.73 (12–56 mm)**	89.46±18.11 (53–118)	0.24±0.076 (0.08–0.041)	0.53±0.05 (0.42–0.65)
BMI 35–39.9 (Obese class 2)	**38.08±12.06 (15–59)**	93.61±11.05 (53–117)	0.27±0.082 (0.09–0.42)	0.54±0.04 (0.44–0.67)
BMI ≥ 40 (Obese class 3)	**39.37±12.93 (19–61 mm)**	94.67±15.63 (56–123)	0.29±0.081 (0.15–0.46)	0.56±0.05 (0.44–0.69)

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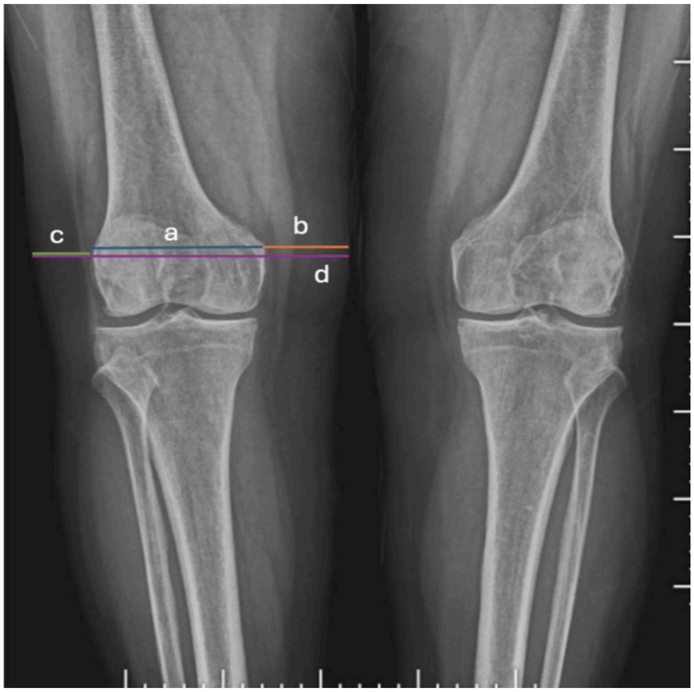

Figure 1. a: Femoral cortical width, b: distance from the medial edge of the skin to the medial cortex of the femur, c: distance from the lateral edge of the skin to the lateral cortex of the femur, d: distance from the medial edge of the skin to the medial cortex of the femur

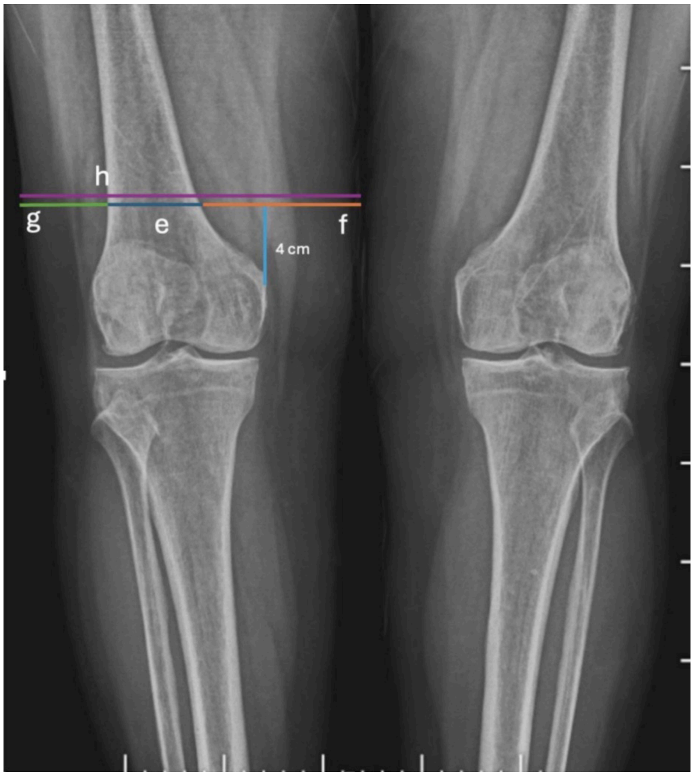

Figure 2. e: Femoral cortical width, f: distance from the medial edge of the skin to the medial cortex of the femur, g: distance from the lateral edge of the skin to the lateral cortex of the femur, h: distance between the medial and lateral skin (measurements were taken at the same level but are presented with intervals to avoid confusion)

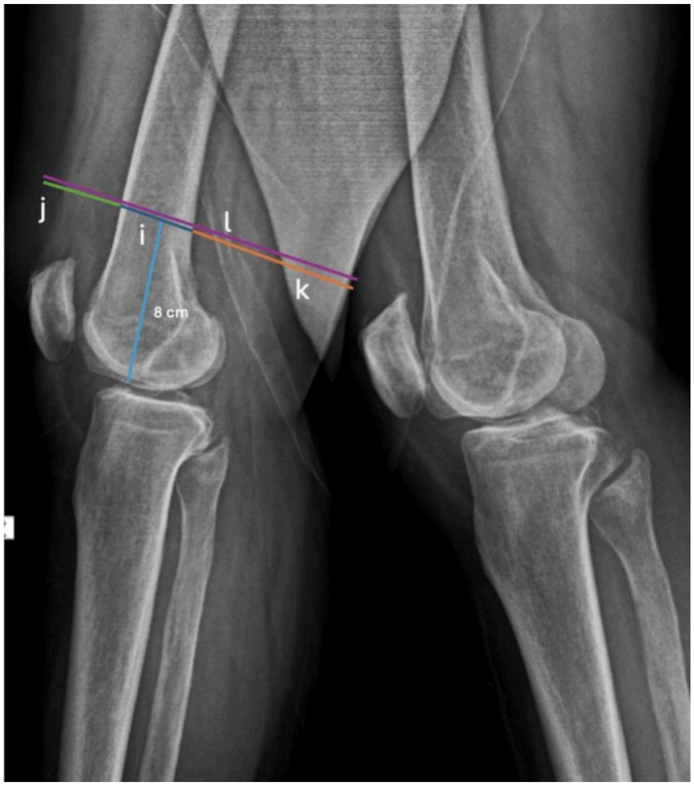

Figure 3. i: Femoral cortical width, j: distance from the anterior skin to the anterior cortex of the femur, k: distance from the posterior skin to the posterior cortex of the femur, l: distance from the anterior skin to the anterior cortex of the femur

Discussion

Results obtained in the present study demonstrated that among the primary measurements, the distance between the lateral skin edge and the lateral femoral cortex (c) exhibited the strongest correlation with BMI. Moreover, when examining the proportional measurements, the strongest correlation with BMI was found for the ratio of the lateral skin-to-femoral distance at the medial epicondyle level relative to the skin-to-skin distance (c/d). These findings suggest that, for BMI assessment, the direct measurement of the lateral skin-to-lateral femoral cortex distance and the derived ratio of the lateral skin-to-femoral distance relative to the skin-to-skin distance (c/d) may serve as useful indices.

BMI, calculated by dividing body weight by the square of height, is a fundamental measure in the etiology of numerous diseases [9]. Initially introduced by physiologist Ancel Keys, BMI is a simple yet widely applied metric in clinical medicine and surgery [10]. It is also recognized as a key factor in the etiology of various orthopedic pathologies. Alternative measures to BMI have been proposed [11-13]. One such alternative is Dual-Energy X-ray Absorptiometry (DEXA), but its use has been limited for various reasons [14]. DEXA scans are among the most accurate methods for evaluating body fat, muscle mass, and bone density. DEXA uses low-level X-rays to generate detailed images of body composition and provides a definitive picture of fat distribution in the body. One of DEXA's most important advantages is its ability to distinguish between different tissue types, offering a level of accuracy far superior to BMI. However, this technology faces challenges in terms of cost and availability. As direct imaging is more readily accessible and simpler to perform, defining a new index based on direct imaging is important. Thus, we prioritized the evaluation of direct radiographs in the present study.

Several studies have examined the correlation between liver size and BMI by assessing soft tissue [15,16]. Studies evaluating the relationship between soft tissue and BMI are easier to interpret. In a study conducted by Torun et al. evaluating the correlation between subcutaneous adipose tissue and BMI, it was observed that the strongest correlation with BMI was found in the umbilical subcutaneous adipose tissue, followed sequentially by the subcutaneous tissue in the arm and leg [17]. In an anthropological study on bone structure, the correlation between proximal femur morphometrics and gender, weight, height/length, and BMI was evaluated, and evaluation of 50 randomized patients over the age of 50 revealed a strong correlation with BMI [18]. In a radiological study on an Indian population, a positive correlation between the proximal femur morphometrics and BMI was observed in 168 patients [19]. In the present study, the correlation between the soft tissue around the knee together with the bone tissue and BMI was evaluated. When the correlation between subcutaneous tissue and BMI was assessed, among the coronal plane measurements, the strongest correlation was observed between the lateral subcutaneous tissue at the epicondylar level and BMI. In the sagittal plane, the strongest and statistically significant correlation was observed between the subcutaneous tissue in the posterior thigh and BMI.

Although obtaining BMI—a fundamental parameter recorded regularly in patient files—is very simple when the patient is present, it becomes difficult to obtain when the patient is absent or when the data records are inadequately maintained. The main starting point of the present study was to determine whether a measurement could be used in place of BMI, which was evaluated as a risk factor due to insufficient data on BMI in a knee replacement study we conducted previously. Furthermore, although height remains relatively constant over the years, body weight can vary over time, and it may not always be possible to accurately determine the BMI at the time of surgery. With the present study, even if there is a deficiency in the data records, it becomes possible to obtain information about BMI directly from radiographs, especially in patients who have undergone lower extremity surgery. A particular limitation of BMI is that it does not differentiate between lean body mass and fat mass; that is, a person may have a high BMI while still having a very low fat mass, or vice versa [20-23]. Some of the measurements we obtained also assess the thickness of the subcutaneous adipose tissue. Additionally, we used measurements that evaluate the bone structure to account for this effect. The variability in body fat distribution, and the possibility that the load may concentrate in different areas of the body, leads us to believe that knee pathologies cannot be directly correlated with BMI. Even though the present study found statistically significant relationships for various measurements and ratios, it may not always be appropriate to use this index as the sole explanatory factor for orthopedic pathologies.

There are several studies focusing on radiological measurements around the knee. In a study previously conducted by Davulcu et al., the relationship between fat-pad thickness measured from knee MR images and BMI was evaluated, and a high degree of correlation was found [24]. However, although MRI is frequently used in orthopedics, it is not as widely available as plain radiographs. Plain radiographs are obtained from nearly every patient presenting to the outpatient clinic, and access to these images is easy. Thus, this practical measurement method will provide great convenience. In a study evaluating the radiological measurement of periarticular subcutaneous tissue—where the effect of preoperative subcutaneous tissue on readmission following knee arthroplasty was assessed—a significant correlation was observed between the soft tissue thickness around the joint and readmission [25]. In another study by Wagner et al., measurements performed on lateral knee radiographs were used to obtain the prepatellar fat thickness ratio, which provided insights regarding fat deposition in the surgical field of the knee, and an increase in this ratio was associated with an increased risk of postoperative infection [26].We believe that a retrospective study using the indices we have proposed could specifically evaluate the relationship between BMI and the incidence of pathology.

Moreover, we are confident that the index we have defined—with the strongest observed correlation—will be useful in estimating BMI. Similarly, we anticipate that this data may eventually be used as an alternative to BMI in studies involving the lower extremity.

The most important limitations of this study include the fact that it was conducted in a population of a single race, and that subcutaneous thickness varies anthropologically between genders and among different races. The relatively small number of patients in the study population is another limitation. The fact that the measurements were performed on a single joint is also one of the limitations. Future studies using different radiographs may provide further clarification regarding this.

Conclusion

The results obtained in the present study demonstrated a strong correlation between BMI and the ratio of the distance from the lateral femoral border at the medial epicondyle level to the skin and the total skin-to-skin distance. The analyses revealed the corresponding BMI values for each interval, and we believe that, in patients where access to BMI-related data is insufficient, this ratio obtained from knee radiographs will be beneficial in evaluating the patient's BMI.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

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Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
The study received ethical approval from the the University of Health Sciences Baltalimani Bone Disease and Research Hospital's ethical committee (05.04.2021-2021/5-04)

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