

Meniscal Sizing Based on Gender, Height, and Weight

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Purpose: Successful meniscus transplantation may depend on accurate sizing. Meniscal sizing is currently determined by measuring a combination of bony landmarks and soft-tissue insertion points through images obtained radiographically or by magnetic resonance imaging (MRI). The literature widely reports inaccuracy in sizing resulting from radiographic errors in magnification, erroneous identification of bony landmarks, and difficulty in differentiating between the soft-tissue and bone interface. In our meniscus transplantations we have observed that when the height and weight of the recipient matched those of the donor, the meniscal size appeared to be a match at surgical implantation; we designed this study to confirm this observation. **Methods:** The MRI-based meniscal sizing of 111 patients (63 male and 38 female patients; mean age, 44 years [range, 15 to 76 years]), totaling 147 menisci (87 lateral and 60 medial), was compared with the height, weight, gender, and body mass index (BMI) of each patient. MRI scans were obtained with a 1.0-Tesla MRI system (ONI Medical Systems, Wilmington, MA). Sizing was performed by an independent musculoskeletal MRI radiologist as established by the literature. Statistical methods include nonparametric Pearson correlation (r) between MRI-based lateral meniscal width, lateral meniscal length, medial meniscal width, medial meniscal length, total tibial plateau width, and patient height, weight, gender, and BMI. Significance at the $P = .05$ level was used. **Results:** Height was found to have a linear relationship to total tibial plateau, which has a good predictive correlation with meniscal dimensions of $r > 0.7$. Female patients generally present with smaller dimensions than male patients. High-BMI groups present with significantly larger meniscal dimensions than low-BMI groups at any given height. **Conclusions:** Height, weight, and gender are easily obtained variables and are proportional to meniscal tissue dimensions. These exploratory statistics establish correlations between height, weight, gender, total tibial plateau width, and meniscal size. **Clinical Relevance:** Height, weight, and gender should be considered by both tissue banks and surgeons as fast and cost-effective variables by which to predict meniscal dimensions. **Key Words:** Meniscal sizing—Height—Weight—Gender—Tibial plateau—Magnetic resonance imaging—Radiography.

A meniscus transplant must closely match the recipient dimension to rotate with the knee motion, to absorb force, and to distribute stress optimally.¹⁻⁸ To match a recipient with a donor, the dimensions of both menisci must be known before surgery; yet, the

donor is deceased and pre-mortem radiographs and magnetic resonance imaging (MRI) scans are not usually obtained, and the recipient is obviously missing the tissue that needs to be sized. To overcome these difficulties, radiographic and MRI measurement techniques were developed and subsequently found to be cumbersome and relatively inaccurate.^{5,9-14} There is no standardized protocol for meniscal sizing.^{5,9-11} Meniscus transplantation is currently indicated in patients who have previously undergone meniscectomy who present with unicompartamental pain or in patients in whom meniscal preservation is not possible.^{9,15} Successful results have been reported for the transplantation of a meniscus into a deficient knee, but the procedure is surgically challenging.¹⁵⁻¹⁸ We have ob-

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served in our last 100 meniscus transplantations that when the height, weight, and gender of the recipient matched those of the donor, the meniscal size appeared to be an appropriate match at surgical implantation. We designed this study to confirm this observation. We postulate that height, weight, and gender are correlated with meniscal dimensions.

METHODS

The MRI-based meniscal sizing of 111 patients (63 male and 38 female; mean age, 44 years [range, 15 to 76 years]), totaling 147 menisci (87 lateral and 60 medial), was compared with the height and weight of each patient. MRI scans were obtained with a 1.0-Tesla MRI system (ONI Medical Systems, Wilmington, MA). Sizing was performed by an independent musculoskeletal MRI radiologist using radiographic and MRI bony landmarks and insertion points (Fig 1). The method of meniscal sizing by MRI was performed as established in the literature.¹⁹

Meniscal Sizing

Manipulation of the meniscal images on the workstation permitted generation of cuts in the optimal plane. The axial plane provided the optimal identification of the maximum anteroposterior and mediolateral dimensions in 1 view. Because the axial view can be angled to exclude a portion of the meniscus, this plane was triangulated to the coronal and sagittal planes, where more accurate and consistent meniscal measurements could be obtained. The anteroposterior meniscal length of the medial (Fig 1A) and lateral menisci was measured from sagittal images, which best bisected the respective medial and lateral knee com-

partments. Spatially, the measurement equals the distance between the anterior peripheral edge of the meniscus and the posterior peripheral edge of the meniscus. The mediolateral meniscal width of the medial and lateral menisci was measured from coronal images. Spatially, the measurement equals the distance between the peripheral edge and a reference line connecting the insertion points at the respective medial or lateral tibial spines (Fig 1B). The total tibial plateau width was also determined, because a correlation between tibial plateau dimensions and true meniscal body dimensions has been established.²⁰ The total tibial plateau width was measured from coronal images taken at the level of the tibial spines.

Inclusion and Exclusion Criteria

All patients who had MRI of the knee between 2001 and 2004 were serially entered into the study. Inclusion criteria included skeletally mature patients who had entered puberty at the time of MRI. Exclusion criteria included (1) patients whose height and weight were not obtained; (2) patients with a meniscal tear, which disturbed the meniscus dimensions, making measurements unobtainable; and (3) patients who had undergone previous meniscal surgery on the knee in question.

Statistical Methods

Statistical methods include nonparametric Pearson correlation (r) between MRI-based lateral meniscal width, lateral meniscal length, medial meniscal width, medial meniscal length, total tibial plateau width, and patient height, weight, and body mass index (BMI). Significance at the $P = .05$ level was used. Data were

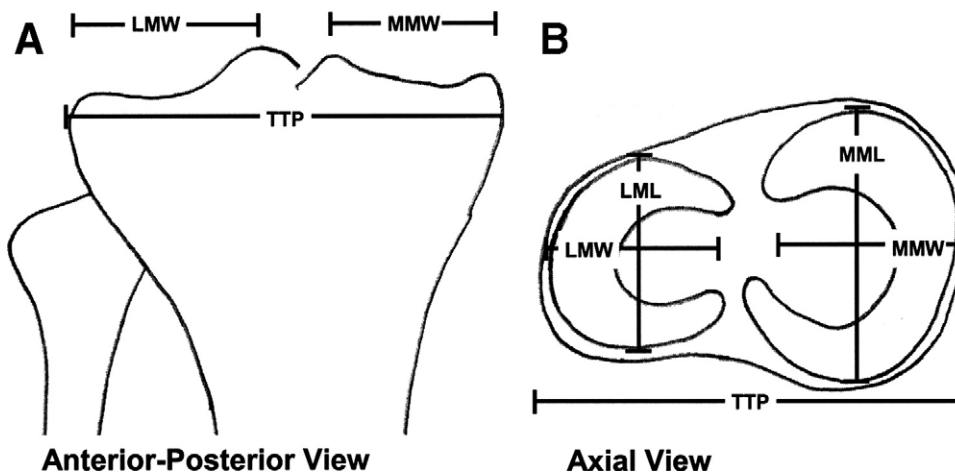


FIGURE 1. Line drawing of right knee representing meniscal measurements. (A) Total tibial plateau width (TTP) was measured by use of anteroposterior MRI. (LMW, lateral meniscal width; MMW, medial meniscal width.) (B) LMW and MMW were measured from the peripheral edge of the meniscosynovial junction on the tibial plateau to a reference line drawn between the respective lateral and medial anterior and posterior tibial spines. (LML, lateral meniscal length; MML, medial meniscal length.)

TABLE 1. Correlations of Height, Weight, Meniscal Size, and Total Tibial Plateau Width for 147 Menisci

	Pearson Correlation (<i>r</i>)						
	Height	Weight	TTP	MMW	MML	LMW	LML
Height	1.0000	0.6536	0.7194	0.6509	0.5259	0.5171	0.5290
Weight		1.0000	0.5470	0.5959	0.3853	0.3787	0.4594
TTP			1.0000	0.7386	0.70400	0.7209	0.7209
MMW				1.0000	0.6283	0.0941	0.0001
MML					1.0000	0.0461	0.1873
LMW						1.000	0.4785
LML							1.0000

Abbreviations: TTP, total tibial plateau width; MMW, medial meniscal width; MML, medial meniscal length; LMW, lateral meniscal width; LML, lateral meniscal length.

NOTE. A good correlative value is represented by $r \geq 0.65$. A fair correlative value is represented by $r \geq 0.50$. A poor correlative value is represented by $r < 0.50$.

further stratified by gender. A paired *t* test was used to compare the differences in mean dimensions in the low-BMI patient group versus high-BMI patient group.

RESULTS

Height was found to have a linear relation with total tibial plateau width, which has a highly predictive correlation with meniscal dimensions of $r > 0.7$. Height had a good correlation with total tibial plateau width ($r = 0.7194$) and, though less significant, still exhibited correlations between all medial and lateral meniscal width and length measurements. Total tibial plateau had a good correlation with all medial and lateral measurements. The width of the medial meniscus had the highest correlation of all meniscal dimensions. Correlations between all measured variables are summarized by Table 1.

Female patients generally present with smaller total tibial plateau widths than male patients (Table 2).²¹ The variance observed at any given height (Fig 2) can be adjusted by considering weight. BMI is calculated

TABLE 2. Height Versus Total Tibial Plateau Width: Gender Stratification

Group	No. of Menisci	Line Equation	Pearson Correlation (<i>r</i>)
Height v TTP			
All	147	$y = 0.0828x + 2.151$	0.72
Men	89	$y = 0.1296x - 1.3339$	0.45
Women	58	$y = 0.0541x + 3.4126$	0.38

Abbreviation: TTP, total tibial plateau width.

by the following equation: $BMI = ((\text{Weight [in pounds]})/(\text{Height [in inches]}^2) \times 703$, with a value of 25 being taken as the cutoff between the high- and low-BMI groups, as defined by the Centers for Disease Control and Prevention. High-BMI groups present with significantly larger meniscal dimensions than low-BMI groups at any given height for all dimensions with the exception of medial meniscal length (Table 3).

DISCUSSION

Meniscal dimensions are currently determined by measuring a combination of bony landmarks and soft-tissue insertion points through preoperative images obtained radiographically or by MRI.^{11,22} In the meniscus-deficient knee, imaging is used to estimate meniscal size based on an established anatomic relation between the tibial plateau and the meniscus, which is then compared with donor cadaver measurements of

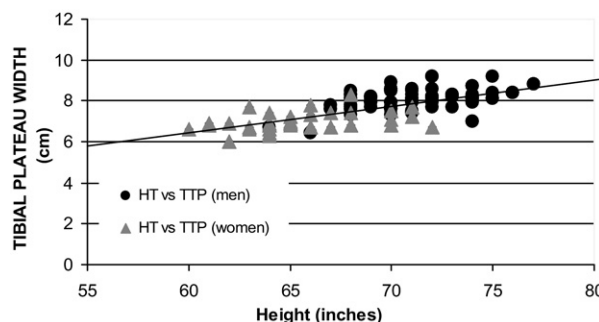


FIGURE 2. Height (HT) versus total tibial plateau width (TTP) in male and female patients.

TABLE 3. Comparison of High-BMI and Low-BMI Groups

	Measurement [mean (SD)]		P Value (<i>t</i> test)
	Low-BMI Group	High-BMI Group	
LMW (cm)	2.84 (0.32)	2.98 (0.32)	.0346
LML (cm)	3.48 (0.36)	3.70 (0.33)	.0012
MMW (cm)	2.95 (0.25)	3.22 (0.33)	.0003
MML (cm)	4.38 (0.43)	4.51 (0.36)	.0951
TTP (cm)	7.37 (0.65)	7.84 (0.71)	.0013

Abbreviations: LMW, lateral meniscal width; LML, lateral meniscal length; MMW, medial meniscal width; MML, medial meniscal length; TTP, total tibial plateau width.

the meniscus and tibial plateau obtained by the tissue bank.^{11,19,20} Because MRI scans and radiographs are usually not available for the donor, different modalities are used to derive measurements in the patient compared with the donor. Obtaining a direct measurement in the patient would require an additional arthroscopic procedure with resultantly questionable accuracy in a knee that has already undergone meniscectomy. Although radiographs and MRI scans are considered the gold standard for sizing, the literature reports inaccuracy resulting from radiographic errors in magnification, erroneous identification of bony landmarks, and difficulty in differentiating between the soft-tissue and bone interface. These complications are further augmented by variable sizing protocols, and studies have suggested a tolerance of no more than 5 mm to preserve the biomechanical and anatomic limitations of the original meniscus.^{11,22} The question then arises: is there a faster, more cost-effective means by which to measure bony landmarks and, therefore, meniscal dimensions?

Meniscal sizing studies in human beings have been performed by Haut et al., Shaffer et al., McDermott et al., and Pollard et al., among others.^{5,11,19,20} McDermott et al. studied 44 cadaveric tibial plateaus with intact medial and lateral menisci to determine the correlation between tibial plateau dimensions and meniscal dimensions. Correlations with tibial plateau and the following meniscal dimensions were found: lateral width, $r^2 = 0.752$; lateral length, $r^2 = 0.582$; medial width, $r^2 = 0.544$; and medial length, $r^2 = 0.295$. Meniscal dimensions could be predicted from the corresponding tibial plateau dimensions with a mean error of $5.0\% \pm 6.4\%$. The greatest errors in estimation were 13.4 mm too large (32%) and 12.4 mm too small (31%). No statistically significant differences were found in measurements of the contralateral knee.

The study by Pollard et al. establishes a correlation between bony landmarks and meniscus tissue size.¹⁹ A tantalum powder–cyanoacrylic paint was applied to 21 cadaveric specimens (12 female, 7 male, and 2 unknown gender; mean height, 5 ft 9.5 in for male specimens and 5 ft 6 in for female specimens), and radiographic measurements were compared with caliper measurements of the tissue. An anteroposterior film was used to derive meniscal width by measuring the distance from the peak of the tibial spine to the metaphyseal margin. A lateral film was obtained to measure meniscal length, which was found to be $80\% \pm 7.4\%$ of the corresponding tibial plateau dimension for the medial meniscus and $70\% \pm 8\%$ for the lateral meniscus. Meniscal dimensional relations were reported as “consistent” with bony landmarks. Radiographic measurements showed the following correlations with anatomic meniscal dimensions: lateral width, $r^2 = 0.98$; lateral length, $r^2 = 0.68$; medial width, $r^2 = 0.98$; and medial length, $r^2 = 0.82$. Pollard et al. concluded that radiographs can predict meniscal dimensions within 8.4% (3.8 mm) once adjusted for magnification.

Haut et al. used radiography and MRI to measure the 3-dimensional geometry of meniscal tissue under the assumption that for contact mechanics to be restored by a meniscal transplant, a geometric match between the donor and recipient must be retained.⁵ They analyzed 10 cadaveric knees (4 from men and 6 from women; mean age, 65 years) (1) using a tissue bank’s measuring protocol via 2 radiographic measurements, (2) using the tissue bank protocol in addition to a third radiographic measurement for each meniscus, and (3) using transverse MRI measurements from the contralateral knee. With the tissue bank protocol, only 1 of 4 radiographic measurements was predictive of standard transverse parameters of the medial meniscus and 0 of 4 measurements were predictive in the lateral meniscus. The addition of a third transverse radiographic measurement resulted in 3 of 4 medial meniscus measurements being predicted and 2 of 4 lateral meniscus measurements being predicted. MRI of the contralateral knee was the most accurate, requiring only 2 of 6 MRI measurements to predict 3 of 4 meniscal parameters in the medial meniscus and 4 of 4 in the lateral meniscus. The study concluded that MRI has a more accurate predictive value than radiographs in determining transverse meniscal dimensions and 3-dimensional geometry.

Shaffer et al. compared the value of radiographs versus MRI in predicting meniscal dimensions against cadaveric measurements.¹¹ They studied 12 cadaveric

knees (7 male and 5 female; mean age, 58 years). Of these knees, 10 were paired and came from the same donors. Despite 1 of 3 blinded examiners being an “experienced musculoskeletal radiologist,” “careful fluoroscopic positioning,” and consistent appearance preserved by retaining identical spatial parameters, approximation of landmarks was required in a few uncertain cases. In a highly variable clinical model, similar accuracy would be hard to reproduce. Radiography resulted in 37% of specimen measurements being accurate to 2 mm and 79% being accurate to 5 mm. MRI resulted in 37% of measurements being accurate to 2 mm and 83% being accurate to 5 mm. Radiographs overestimated 77% of the measurements, and MRI overestimated 56%. Contralateral knee tissue dimensions were widely variable; however, the difference was not statistically significant because of the small number studied ($n = 5$). MRI scans were determined to be slightly more accurate than radiographic measurements and also provided a significantly lower intraobserver error. However, the study concluded with the same concern about the inability to determine bony landmarks or to accurately predict size within reported 5% tolerances.

In our study we found that the total tibial plateau width had a good correlative value for meniscal dimensions. The width of the medial meniscus had the highest correlation among measured meniscal dimensions. We speculate that this is because it is the variable with the largest numeric value in the group. Cadaveric height, weight, and gender data were collected, but correlations could not be calculated because donor imaging data are not collected by banks at the time of tissue harvest. Furthermore, these data would be skewed by the length of hospitalization and disease duration of the donor. Weight loss is expected with prolonged illness, and weight gain is expected with trauma-associated fluid transfusion and third-space accumulation.

Within gender groups, at any given height, a variance was observed, reinforcing that height, though highly predictive, is not the sole determinant of meniscal dimensions. Weight, though fairly correlative with tibial plateau width ($r = 0.547$) and medial meniscal width ($r = 0.5959$), is less correlative than height. Gender should be considered in determining appropriate sizing. This observation is confirmed by Shelbourne and Kerr, who reported bony femoral and tibial dimensions as a function of height, weight, and gender in patients with intact anterior cruciate ligaments.²¹ Among 315 men and 163 women with intact anterior cruciate ligaments, a statistically significant

correlation was found between wider femoral bicondylar widths and increased height for men ($r = 0.670$, $P < .01$) and women ($r = 0.785$, $P < .01$), and it was found that men and women have different intercondylar notch widths.

CONCLUSIONS

Current imaging techniques extract meniscal dimensions from bony landmarks. Height, weight, and gender are easily obtained variables and are correlated with bony landmarks and, to a lesser degree, meniscal dimensions. Statistical power is compromised by each stratification of the data because the power is dependent on sample size; however, these exploratory statistics establish promising correlations between height, weight, gender, and meniscal size that can be extended to estimating meniscal size. Practically, this correlation has been supported in our parallel clinical experience of more than 100 meniscus transplantations using gender, height, and weight as the sizing methodology. Height, weight, and gender should be considered by both tissue banks and surgeons as a fast and cost-effective method for meniscal sizing.

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