Demographics and Distal Tibial Dimensions of Suitable Distal Tibial Allografts for Glenoid Reconstruction

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Purpose: To evaluate whether characteristics such as age, height, weight, sex, or body mass index affected the distal tibial dimensions and radius of curvature (ROC) of a potential donor for anterior glenoid augmentation. **Methods:** A retrospective review of magnetic resonance imaging of ankles without bony trauma was performed, and the anteroposterior (AP) and medial-lateral (ML) distances and ROC of the tibial plafond articular surface were measured. Demographic characteristics, including age, sex, height, weight, and body mass index, were recorded. **Results:** A total of 141 imaging studies were included (73 men and 68 women; average age, 38.2 $\pm$ 12.65 years). All potential specimens accommodated harvest of a 10 $\times$ 22−mm distal tibial allograft bone block. Men had greater ML (42.74 cm [95% confidence interval (CI), 42.09-43.39 cm] vs 38.01 cm [95% CI, 37.30-38.72 cm]; $P < .001$) and AP (38.16 cm [95% CI, 37.47-38.85 cm] vs 34.57 cm [95% CI, 33.97-35.17 cm]; $P < .001$) dimensions. Significant moderately positive correlations were found for AP dimensions with height ($r = 0.584$, $P < .001$) and weight ($r = 0.383$, $P < .001$) and for ML dimensions with height ($r = 0.711$, $P < .001$) and weight ($r = 0.467$, $P < .001$). ROC was positively correlated with height ($r = 0.509$, $P < .001$) and weight ($r = 0.294$, $P < .001$). Patient age was not related to either the AP or ML distal tibial dimensions or ROC. **Conclusions:** After magnetic resonance imaging analysis, all potential donors permitted harvest of a standard-sized distal tibial allograft irrespective of sex or common anthropometric measures, and 85.8% showed distal tibial morphology acceptable for glenoid augmentation. AP and ML graft dimensions and ROC correlated significantly with height and weight. **Level of Evidence:** Level II, diagnostic study.

Recurrent anterior glenohumeral instability has a direct correlation with attritional bone loss of the anterior glenoid.[1] This glenoid bone loss serves as a risk factor for failure after an arthroscopic labral repair, and recent literature has suggested that even 13.5% bone loss can be considered a critical value regarding the necessity of a bony reconstructive procedure for the glenoid.[2] Traditional bony reconstructive procedures for the anterior glenoid have consisted of autograft coracoid transfer (i.e., Latarjet procedure) and procedures using iliac crest autograft (i.e., Eden-Hybinette procedure) and various allograft sources, as well as newer consideration of distal clavicle autograft.[3] A recent study looked at various allograft types in the restoration of glenoid width, depth, curvature, and articular step-off.[4] Aside from a glenoid allograft, distal tibial allograft (DTA) had the best coronal radius of curvature (ROC) and the smallest amount of articular step-off. The study also found that the DTA increased

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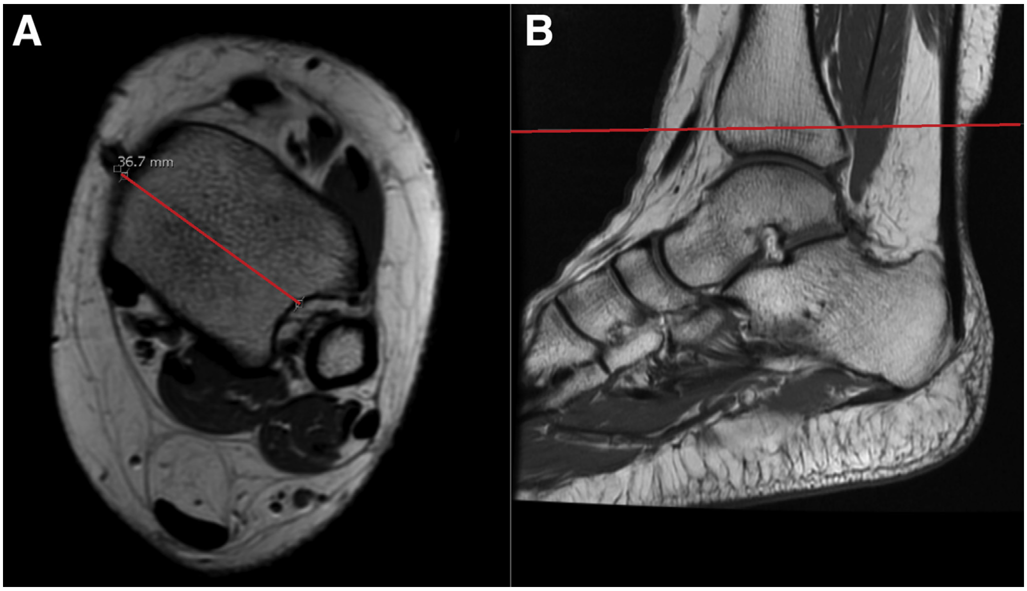

Fig 1. Axial (A) and sagittal (B) magnetic resonance images of a right ankle. The red line in (A) depicts the medial to lateral length measurement made. The red line in (B) represents the position of the corresponding axial magnetic resonance imaging cut of the physeal scar chosen to make the measurements in (A).

the surface area and width of the articular surface in relation to the native glenoid. Among the aforementioned options, DTA has emerged as an established surgical option for reconstruction of either the anterior or posterior glenoid in cases of glenohumeral instability with glenoid bone loss.[5-7] The proposed benefits of DTA include a similar ROC to the glenoid,[8-10] the presence of articular cartilage, and the lack of any donor site morbidity. Previous studies have evaluated the lateral tibial cortex to determine the likelihood of obtaining an allograft with a straight lateral border so that the cortical bone can be retained with the graft, theoretically increasing the compression strength of the fixation.[11] The aim of this study was to evaluate whether characteristics such as age, height, weight, sex, or body mass index (BMI) affected the distal tibial dimensions and ROC of a potential donor for anterior glenoid augmentation. We hypothesized that male sex and increased height among potential tissue donors evaluated on magnetic resonance imaging (MRI) would be associated with lower rates of ROC mismatch or inadequate distal tibial sizing for glenoid augmentation.

Methods

After obtaining study approval from the institutional review board, we performed a retrospective review of MRI scans of the ankle at a single institution. All studies performed among patients aged 18 years or older as part of the clinical evaluation of various ankle complaints from August 2017 through January 2018 were considered for study inclusion. MRI studies were considered for study inclusion if they were performed without contrast and showed no osteoarthritic changes to the ankle, defined as the presence of any osteophyte formation. The exclusion criteria included evidence of previous trauma altering the distal tibial anatomy, surgery, or post-traumatic changes to the distal tibia, particularly regarding the incisura, on imaging review. In addition, MRI scans were excluded if they were obtained out of plane with the tibia, defined as scans in which the gantry was set to a plane that was not perpendicular to the distal tibia. Patients were also excluded if they lacked any anthropometric parameters evaluated, including height and weight.

Imaging studies that met the provisional inclusion criteria proceeded to undergo chart review to confirm lack of prior surgery. On chart review, studies were included in the study group if they lacked prior surgery around the ankle and if demographic and morphometric variables, including age, sex, height, weight, and BMI, were available for data analysis. Morphometric variables were retrospectively identified from chart review, recorded as part of clinical care.

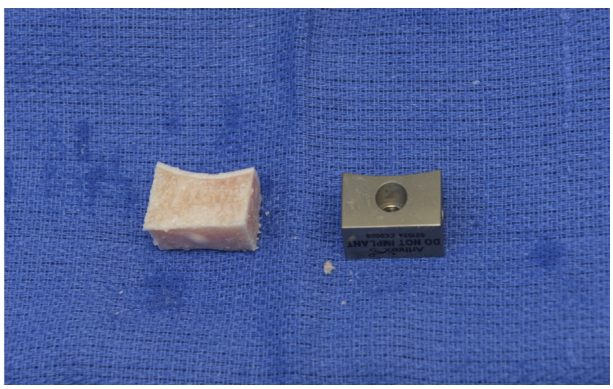

Fig 2. Clinical photograph of a 10×22–mm harvested distal tibial allograft next to an operative sizing guide.

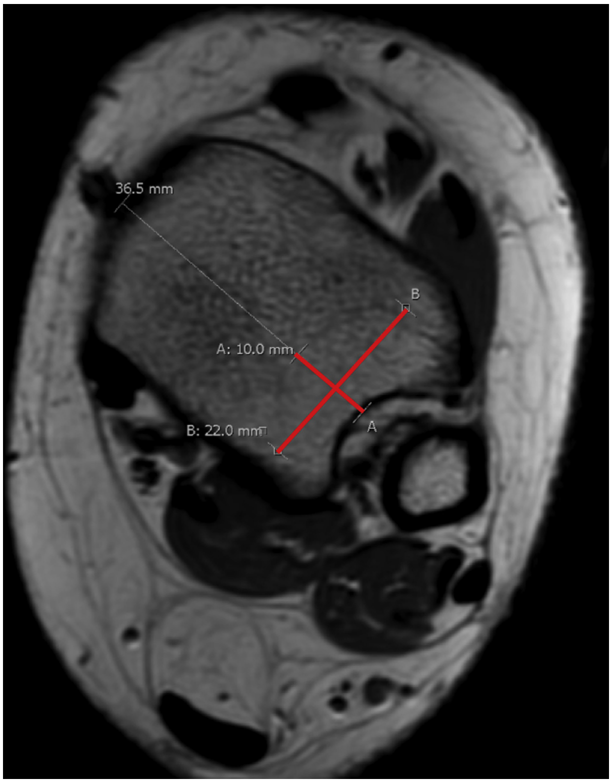

Fig 3. Axial magnetic resonance image showing the graft dimensions in red of a 10 × 22—mm graft, as measured on the distal tibia, from the deepest portion of the lateral tibial concavity. The maximum medial-to-lateral diameter at that level is also measured.

All routine ankle MRI examinations were performed without contrast on either a GE 1.5-T Optima MR450w system or a GE 3.0-T Discovery MR750 system (General Electric Healthcare, Chicago, IL). The routine ankle MRI protocol included the following sequences: axial T1, axial proton density with fat saturation, sagittal T1, sagittal T2 with fat saturation, and coronal T2 with fat saturation. All images were acquired using an Invivo 8-channel HD ankle coil (Philips, Best, Amsterdam, The Netherlands). Axial images were acquired with a 1-mm slice thickness; coronal images, a 4-mm slice thickness; and sagittal images, a 3-mm slice thickness.

After identification of eligible images, the maximum medial-lateral (ML) diameter and anteroposterior (AP) depth of the tibia were measured at the level of the physeal scar because this corresponds to the maximum depth of bone used for glenoid augmentation (Fig 1). All measurements were made by a senior orthopaedic resident (M.S.G.) after initial training with the lead author, a fellowship-trained shoulder surgeon (S.A.P.). Measurements were taken with the imaging at maximal size on a viewing screen to allow for the greatest measurement accuracy. Because the standard articular graft dimensions for reconstruction are typically 10 × 22 mm, these dimensions were used to assess feasibility (Fig 2). A 10-mm line was drawn from anterior to posterior from the deepest portion of the incisura, and the maximum ML diameter at that level was measured and recorded (Fig 3). This was used to determine whether the tibiae would be able to be acceptable for use as a graft for anterior glenoid augmentation, recorded as a dichotomous variable. Finally, the ROC was measured for each distal tibia in the sagittal plane, which corresponds to the ROC of the glenoid in the coronal plane (Fig 4). This was achieved by using a best-fit circle to the articular surface of the distal tibia. The radius of this circle was measured.

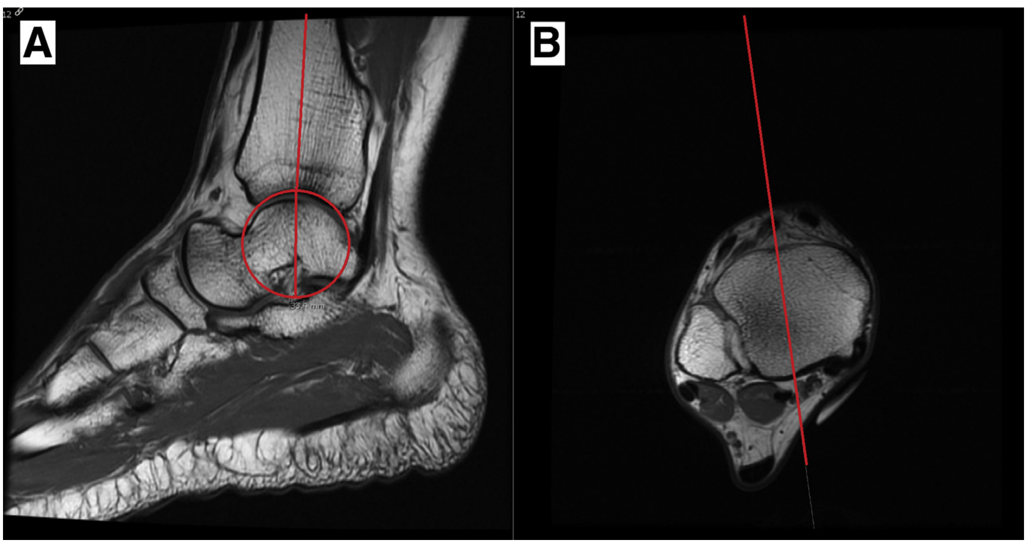

Fig 4. Magnetic resonance images of a right distal tibial showing the midpoint of the axial image (B) chosen as a reference point to measure the radius of curvature on the sagittal image (A) by placing a best-fit circle along the curvature of the distal tibia. The midpoint (vertical) line is created on the tibia to center the best-fit circle; then, the diameter of the circle is measured to obtain the radius of curvature.

Table 1. Basic Demographic Information and MRI Measurements

Variable	Data
Age, yr	38.2 ± 12.7 (18-75)
Height, in	67.8 ± 3.8 (58-75)
Weight, lb	196.1 ± 42.2 (100-334)
BMI	29.8 ± 5.4 (20.2-46.9)
ROC, mm	22.8 ± 3.3 (17.2-43.2)
AP tibial dimension, mm	36.4 ± 3.3 (29.8-45.7)
ML tibial dimension, mm	40.5 ± 3.7 (32.3-48.4)

NOTE. Data are presented as mean ± standard deviation (range).
AP, anteroposterior; BMI, body mass index; ML, medial-lateral; MRI, magnetic resonance imaging; ROC, radius of curvature.

The distal tibial morphology was classified according to the classification reported by Parada et al.,[11] which references the ability to retain the lateral cortex of the distal tibia for potentially improved graft fixation. This 3-part classification consists of type A grafts, deemed ideal for DTA augmentation, having a flat cortical margin at the incisura; type B grafts, deemed acceptable, having a slight concavity measuring less than 5 mm in depth; and type C grafts, deemed unacceptable for DTA augmentation, having a concavity greater than 5 mm in depth.

Statistical Analysis

Statistical analysis was performed using the SPSS statistical package (version 24; IBM, Armonk, NY). Significance was set at $P < .05$. Descriptive statistics were calculated. Pearson correlation coefficients were calculated to identify relations between morphometric parameters and tibial measurements. Univariate analyses comprising the independent Student *t* test and χ^2 procedures were used to compare recorded patient demographic variables against acceptable morphology for glenoid augmentation, defined as type A or B grafts.[11]

Results

A total of 176 ankle MRI studies were identified over the study period, of which 33 were excluded for gantry issues with the MRI scans (out of plane), 1 was excluded for a metal artifact owing to prior surgery, and 1 was excluded for a lack of height and weight data, leaving a total of 141 imaging studies (73 men and 68 women; mean age, 38.2 ± 12.7 years) for inclusion. Basic demographic information including height, weight, and BMI, as well as measurements of the ROC and tibial dimensions, is summarized in Table 1 and presented separately by patient sex in Table 2.

Distal tibial incisura morphology showed 17 patients (12.1%) with type A (ideal) morphology, 104 (73.8%) with type B (acceptable), and 20 (14.2%) with type C (unacceptable), leaving a total of 85.8% of patients with ideal or acceptable morphology for glenoid augmentation (Fig 5). All 141 analyzed studies showed the ability to account for the dimensions of a standard DTA bone block, as used for glenoid augmentation. Patient age showed a significant effect of distal tibial morphology, with younger patients being significantly more likely to have an ideal or acceptable morphology (type A or B) (36.9 ± 11.6 years for type A or B vs 46.2 ± 16.0 years for type C, $P = .02$; Table 3). No significant differences in ideal or acceptable morphology were found according to sex (83.6% for men vs 88.2% for women, $P = .427$).

Male subjects were significantly taller than female subjects (70.2 in [95% CI, 69.6-70.8 in] vs 65.2 in [95% CI, 64.4-65.9 in]; $P < .001$). Male subjects were also significantly heavier than female subjects (211.9 lb [95% CI, 203.5-220.4 lb] vs 179.1 lb [95% CI, 169.0-189.2 lb]; $P < .001$). No significant difference in BMI was found between sexes (30.2 for men [95% CI, 29.2-31.3] vs 29.3 for women [95% CI, 27.8-30.9]; $P = .34$). Men had greater ML dimensions (42.8 mm; 95% CI, 42.1-43.4 mm) than women (38.0 mm; 95% CI, 37.3-38.7 mm). Men also had significantly larger AP dimensions (38.2 mm; 95% CI, 37.5-38.9 mm) than their female counterparts (34.6 mm; 95% CI, 34.0-35.2 mm; $P < .001$).

Comparing the tibial dimensions with height, weight, and BMI, we found significant moderately positive linear correlations between AP dimensions and height ($r = 0.58$, $P < .001$) and between AP dimensions and weight ($r = 0.38$, $P < .001$). Moderately positive linear correlations were also seen between ML dimensions and height ($r = 0.71$, $P < .001$), along with ML dimensions and weight ($r = 0.47$, $P < .001$; Table 4). No significant linear correlation was found between BMI and ML dimensions ($r = 0.14$, $P = .11$). Moderately positive linear correlations were found between ROC and height ($r = 0.51$, $P < .001$), as well as between ROC and weight ($r = 0.29$, $P < .001$), but no significant correlation was present for BMI ($r = 0.05$, $P = .53$). Patient age was not related to either the AP or ML distal tibial dimensions or ROC.

Table 2. Basic Demographic Information and MRI Measurements for Women (n = 68) and Men (n = 73)

Variable	Women	Men
Age, yr	39.3 ± 14.4 (18-75)	37.2 ± 10.8 (19-67)
Height, in	65.2 ± 3.1 (58-71)	70.2 ± 2.5 (63.5-75)
Weight, lb	179.1 ± 41.7 (100-273)	211.9 ± 36.3 (143-334)
BMI	29.3 ± 6.2 (20.2-46.9)	30.2 ± 4.6 (21.1-45.6)
ROC, mm	21.1 ± 2.0 (17.2-26.8)	24.4 ± 3.4 (18.8-43.2)
AP tibial dimension, mm	34.6 ± 2.53 (29.8-39.9)	38.2 ± 3.0 (31.9-45.7)
ML tibial dimension, mm	38.0 ± 3.0 (32.3-45.3)	42.8 ± 2.8 (36.4-48.4)

NOTE. Data are presented as mean ± standard deviation (range).
AP, anteroposterior; BMI, body mass index; ML, medial-lateral; MRI, magnetic resonance imaging; ROC, radius of curvature.

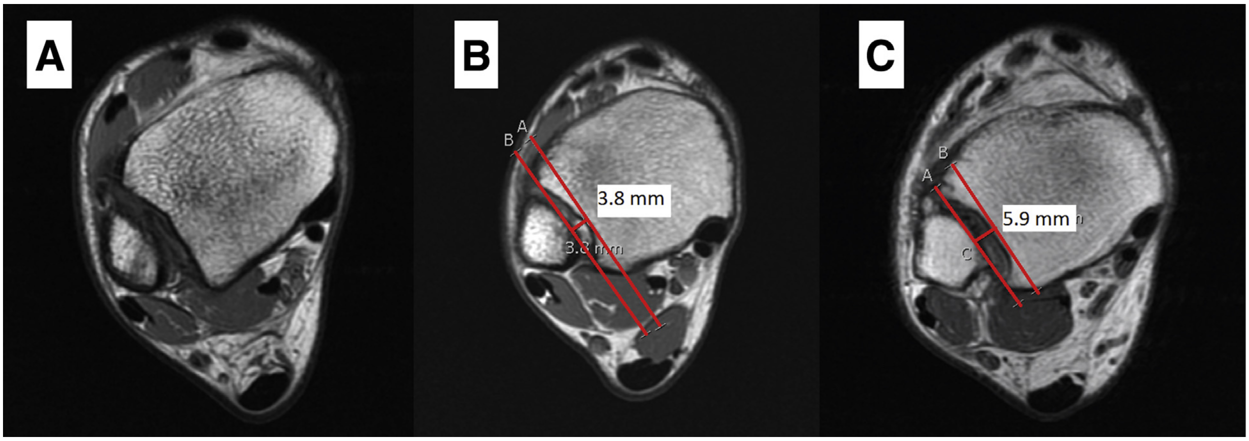

Fig 5. Three magnetic resonance images of 3 different right distal tibiae showing a type A tibia with a nearly flat lateral border (A), a type B tibia with a concavity of less than 5 mm (measured at 3.8 mm between the red lines shown) (B), and a type C tibia with a concavity greater than 5 mm (measured at 5.9 mm between the red lines shown) (C).

Discussion

This study showed that all potential donors with a height of 67 ± 5 inches are suitable candidates for a standard DTA of 10 × 22 mm for reconstruction of a 25% to 30% glenoid defect. The dimensions of the distal tibia are significantly affected by patient sex and height, with men and taller patients exhibiting larger physical dimensions. Age and weight do not display a significant association with distal tibial morphology. Glenoid reconstruction with DTA has rapidly gained acceptance as an alternative to the Latarjet procedure for recurrent glenohumeral instability with glenoid bone loss.[12-14] In our opinion, the increasing popularity of the DTA creates concern regarding the l potential graft available, given that a fresh, never-frozen graft is used for this procedure to maximize the viability of the articular cartilage. Historically, obtaining fresh osteochondral grafts to treat chondral injuries in the knee has caused long delays in being able to perform surgery, especially when size matching is warranted. Furthermore, DTAs can be used in the shoulder to reconstruct both anterior and posterior glenoid defects, thus increasing the demand on these grafts.[5-7] This study reveals that further characterization of the suitable characteristics of potential donors using easily measured variables such as height and sex will assist in identifying appropriate DTAs to allow surgeons to effectively match the graft with the patient and his or her glenoid defect. This may also allow for streamlining of the graft procurement and matching process and potentially reduce delays in treatment.

In a previous study, distal tibial morphology was defined based on the characteristics of the lateral tibial cortex alone.[11] In that analysis of ankle MRI scans, grafts with a completely flat lateral border were termed “type A,” grafts with a depth of concavity of less than 5 mm were termed “type B,” and grafts with significant concavity with a depth greater than 5 mm were termed “type C” and deemed unacceptable because the entire lateral cortex needed to be removed to create a flat lateral border. That study found 14.1% type A, 71.8% type B, and 14.1% type C grafts, for an overall graft acceptability rate (types A and B) of 85.9%. Although our study examined many other factors, we found very similar results, with 12.1% type A, 73.8% type B, and 14.2% type C grafts, for an overall graft acceptability rate based on contour alone (types A and B) of 85.8%.

Table 3. Comparison of Patient Demographic Characteristics Between Type A or B DTAs (n = 121) and Type C DTAs (n = 20)

	Type	Mean (SD)	Range	Difference	*t*	*P* Value	95% CI of Difference
Age, yr	A or B	36.9 (11.6)	18-75	9.3	2.5	.02*	1.58-17.08
	C	46.2 (16.04)	27-72				
Height, in	A or B	67.8 (3.7)	58-75	0.20	0.22	.83	−1.60 to 1.99
	C	68.0 (3.9)	59-73				
Weight, lb	A or B	196.7 (42.3)	100-334	4.14	−0.41	.69	−24.3 to 16.05
	C	192.5 (42.5)	115-265				
BMI	A or B	29.9 (5.5)	20.2-46.9	0.82	−0.62	.53	−3.41 to 1.78
	C	29.1 (4.9)	22.8-38.0				

BMI, body mass index; CI, confidence interval; DTA, distal tibial allograft; SD, standard deviation.
*$P < .05$.

Table 4. Pearson Correlation Coefficients and Associated 95% CIs Comparing AP and ML Measurements With Patient Height, Weight, and BMI

	Pearson Correlation Coefficient (95% CI)		
	AP Dimension	ML Dimension	ROC
Height, in	0.58* (0.46-0.68)	0.71* (0.62-0.78)	0.51* (0.37-0.62)
Weight, lb	0.38* (0.23-0.51)	0.47* (0.33-0.59)	0.29* (0.13-0.44)
BMI	0.12 (−0.04 to 0.28)	0.14 (−0.03 to 0.29)	0.05 (−0.11 to 0.22)

NOTE. Regarding BMI, the data showed $P = .14$ for AP dimension, $P = .11$ for ML dimension, and $P = .53$ for ROC.
AP, anteroposterior; BMI, body mass index; CI, confidence interval; ML, medial-lateral; ROC, radius of curvature.
*$P < .0001$.

There can be significant variations in the percentage of glenoid bone loss with shoulder instability. These can be attributable to numerous factors, including but not limited to the number of instability events, presence of underlying laxity of the glenohumeral joint, presence of an engaging humeral lesion, and chronicity of the instability. Despite this, guidelines for the dimensions of a "routine" DTA have been established.[15] This is a result of the finding that bony glenoid reconstruction is largely performed in cases of significant (>20%) bone loss[16-18] and, in a typical glenoid, 25% to 30% bone loss represents 8 to 9 mm of bone.[7] It has also been described that 10 mm of glenoid bone loss represents greater than one-third of the glenoid surface area.[19] Therefore, graft dimensions of 10 × 22 mm were chosen as the measurements for this study because defects greater than 30% to 40% are rare.

For reconstruction with an osteoarticular graft, not just the dimensions of the underlying bony structure but also the relative congruity, or degree of mismatch of the articular surface of the tibial plafond and native glenoid, should be determined. The normal ROC of the glenoid in the coronal plane does vary depending on the degree of degenerative wear and measurement methods. Prior feasibility studies evaluating the suitability of the DTA have confirmed excellent restoration of native glenoid morphology, resulting in broader contact areas and lower contact areas in a 30% bone loss model in comparison with the Latarjet procedure.[8]

The osseous ROC has been found to be greater than the cartilaginous ROC in cadaveric samples.[20] Several different studies have established an ROC range of 26.3 to 29 mm, depending on measurements with the cartilage or osseous reference.[9,10,20,21] Our measurement of the ROC of the distal tibia, at 22.8 mm, was similar to that found in similar studies (23.0-24.7 mm) seeking to validate the suitability of this graft option.[9,10] Certainly, this shows the similarity of the contour of the articular surface of a DTA compared with the native glenoid, which Provencher et al.[7] previously reported.

Limitations

Although this was a large, retrospective radiographic review, certain limitations must be acknowledged. This was only an imaging review study, which is inferior to direct measurements with cadaveric specimens. Moreover, as only a certain time frame of MRI scans was analyzed, greater variability may have been found within a larger sample size. This may also limit the presence of selection or sampling bias. Furthermore, as previously discussed, a graft size corresponding to a routine graft for cases of glenoid bone loss was chosen. There are certainly cases of excessive bone loss that may require larger graft dimensions than those used in this study; however, these cases are very rare in our collective experience. Overall, this study sought to define relations between donor demographic characteristics and the resultant dimensions of a graft harvested from the distal tibial articular surface. Although some relations were discovered (AP dimensions with height, weight, and BMI, as well as ML dimensions with height, weight, and BMI), many patient demographic factors were not at all correlated with graft dimensions. It is possible there are certain links or causal relations that could have been identified if other patient factors had been explored.

Conclusions

After MRI analysis, all potential donors permitted harvest of a standard-sized DTA irrespective of sex or common anthropometric measures, and 85.8% showed distal tibial morphology acceptable for glenoid augmentation. AP and ML graft dimensions and ROC correlated significantly with height and weight.

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