Anterior Glenoid Reconstruction With Distal Tibial Allograft

Biomechanical Impact of Fixation and Presence of a Retained Lateral Cortex

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Background: Glenoid reconstruction with distal tibial allograft (DTA) is a known surgical option for treating recurrent glenohumeral instability with anterior glenoid bone loss; however, biomechanical analysis has yet to determine how graft variability and fixation options alter the torque of screw insertion and load to failure.

Hypothesis: It was hypothesized that retention of the lateral cortex of the DTA graft and the presence of a washer with the screw will significantly increase the maximum screw placement torque as well as the load to failure.

Study Design: Controlled laboratory study.

Methods: Whole, fresh distal tibias were used to harvest 28 DTA grafts, half of which had the lateral cortex removed and half of which had the lateral cortex intact. The grafts were secured to polyurethane solid foam blocks with a 2-mm epoxy laminate to simulate a glenoid with an intact posterior glenoid cortex. Grafts underwent fixation with 4.0-mm cannulated drills, and screws and washers were used for half of each group of grafts while screws alone were used for the other half, creating 4 equal groups of 7 samples each. A digital torque-measuring screwdriver recorded peak torque for screw insertion. Constructs were then tested in compression with a uniaxial materials testing system and loaded in displacement control at 100 mm/min until at least 3 mm of displacement occurred. Ultimate load was defined as the load sustained at clinical failure.

Results: The use of a washer significantly improved the ultimate torque that could be applied to the screws (+cortex and +washer = 12.42 N·m [SE, 0.82]; –cortex and +washer = 10.54 N·m [SE, 0.59]) ($P < .0001$), whereas the presence of the native bone cortex did not have a significant effect (+cortex and –washer = 7.83 N·m [SE, 0.40]; –cortex and –washer = 8.03 N·m [SE, 0.56]) ($P = .181$).

Conclusion: In a hybrid construct of fresh cadaveric DTA grafts secured to a foam block glenoid model, the addition of washers was more effective than the retention of the lateral distal tibial cortex for both load to failure and peak torque during screw insertion.

Clinical Relevance: This biomechanical study is relevant to the surgeon when choosing a graft and selecting fixation options during glenoid reconstruction with a DTA graft.

Keywords: biomechanical; distal tibia; glenoid reconstruction; shoulder instability

Reconstruction of the anterior glenoid with distal tibial allograft (DTA) is a known surgical option for recurrent instability of the glenohumeral joint in the setting of anterior glenoid bone loss.[4,5,12,13,16] This surgery can be performed as a primary procedure[5] or in a revision setting.[11,14] This procedure uses the articular surface of the distal tibia to recreate the lost bone and cartilage of the anterior glenoid. The presence of articular cartilage and the similarity of the radius of curvature of the articular surface of the distal tibia to the glenoid makes the DTA graft an attractive alternative to other bony reconstruction procedures.[9,10] The graft is typically arranged with the medial cancellous portion of the distal tibia placed into compression against the glenoid, with the lateral cortex of the

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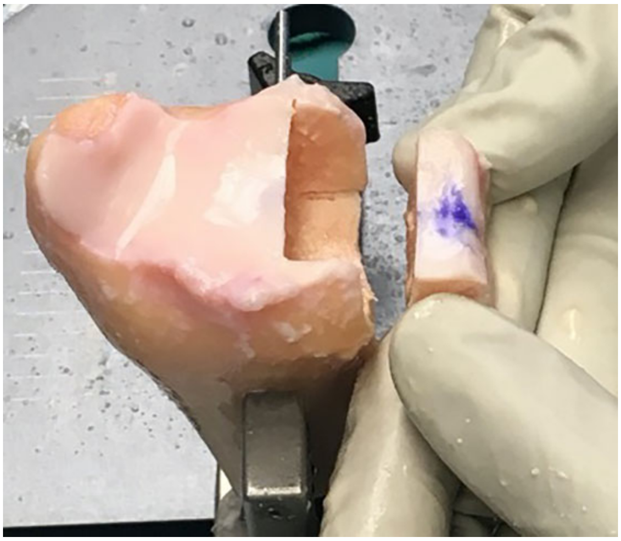

Figure 1. Photograph of a distal tibial graft harvested while secured on a graft preparation station; a blue surgical marker has been used to mark the center of the graft.

tibia used to secure fixation (Figures 1 and 2). The lateral aspect of the distal tibia at the articular surface has known anatomic deviations that vary from a straight border to a concave surface.[9,10] A straight, or nearly straight, lateral border has been found in up to 85% of tibias in imaging studies that used magnetic resonance imaging (MRI).[10] The presence of a straight lateral border allows the surgeon to retain the lateral cortex of the tibia to place screws against during the reconstruction, whereas a concave border requires the cortex to be removed to create a straight border, rendering the graft completely cancellous.

The objective of this study was to compare the maximum torque of screw placement as well as the biomechanical load to define failure of DTA grafts divided into 4 groups: with and without the retention of the lateral cortex and with and without the presence of a washer used with the screw. Our hypothesis was that the retention of the lateral cortex and the presence of a washer with the screw would significantly increase the maximum screw placement torque as well as the load to failure.

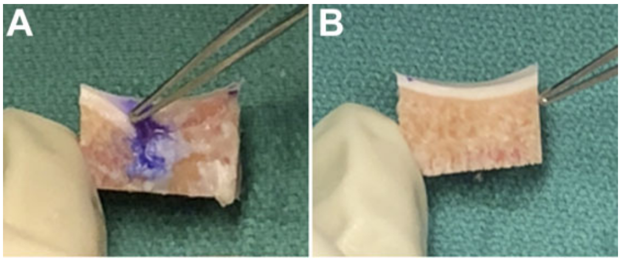

Figure 2. Photograph of (A) the cortical side and (B) the cancellous side of the distal tibial allograft.

METHODS

Samples and Preparation

Whole, fresh distal tibias were obtained from a tissue bank, and 28 DTA grafts were harvested in a standardized fashion using a graft harvest station to ensure reproducibility.[3] The grafts were donated by an orthopaedic allograft supply company (JRF Ortho). Unfortunately, the age and sex of the donors were not available, although previous studies have shown that the suitability of grafts is independent of these factors.[9,10] The DTA grafts were then secured to a polyurethane solid foam block with a density of 20 pounds per cubic foot and with a 2-mm epoxy laminate on 1 side (Sawbones; Pacific Research Laboratories). This model was used to recreate the scenario typical of anterior glenoid bone loss with a cancellous anterior glenoid and an intact posterior glenoid cortex. Standardized DTA grafts were created that were 7×22 mm. Half of the distal tibias had the lateral cortex removed to create a completely cancellous lateral surface (Figure 3).

Screw Fixation

In each case, the graft was prepared with standardized fixation using a 4.0-mm cannulated drill over guidewires to create pilot holes through the graft. This size drill correlated with the size needed for the graft positioner, which is larger than the outer diameter of the screw. This created the gliding hole for the lag-by-technique design. A graft

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Ethical approval was not sought for the present study.

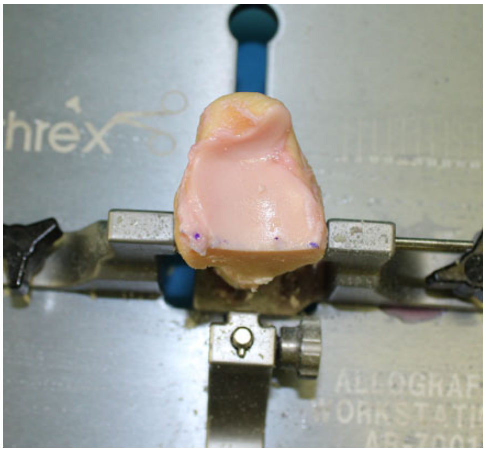

Figure 3. Photograph of a distal tibia secured on a graft preparation station. The lateral cortex has been removed, so the lateral border of the graft will be completely cancellous.

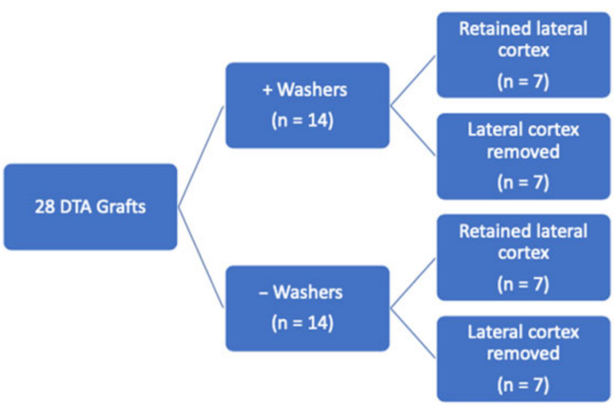

Figure 4. Grouping of study samples according to the fixation of grafts. DTA, distal tibial allograft.

positioner was then used to place the DTA graft against the polyurethane block so that the articular surface of the graft was flush against the top surface of the block. The graft was provisionally secured to the block with guidewires, and then the foam block was overdrilled with a 2.7-mm cannulated drill, correlating with the inner diameter of the screw or thread hole, creating a lag-by-technique insertion fashion.

All samples were secured with 2 titanium 3.75-mm cannulated, fully threaded screws. All screws were 42 mm in length to ensure that they completely penetrated the far cortex of the polyurethane block, represented by the epoxy laminate. Half of each group of samples (lateral cortex intact and lateral cortex removed) underwent fixation with screws and washers, and half underwent fixation with screws alone. This created 4 equal groups of 7 samples each (Figure 4). We were limited by the total number of tibial grafts available. Screws, washers, fixation instrumentation, and graft preparation station were supplied by a medical device manufacturer (Arthrex).

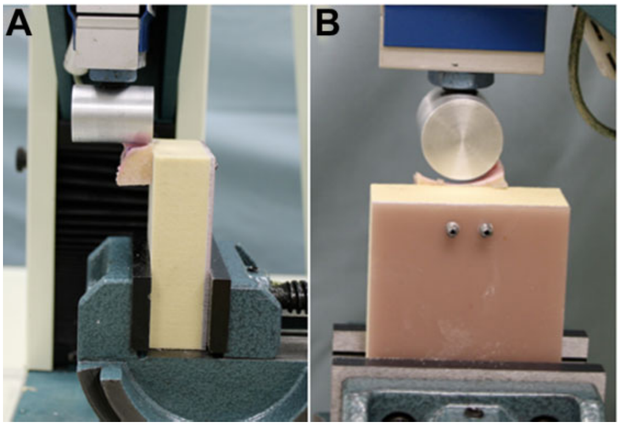

Figure 5. (A, B) Photographs of the distal tibial graft secured to a foam block with screw fixation, secured in a vice, and loaded with a custom apparatus to provide compression against the graft. The epoxy laminate in (B) simulates the posterior cortical surface of the glenoid.

Biomechanical Testing

Screws were advanced with a digital torque-measuring screwdriver (DID-4A; Imada), and peak torque was recorded for each screw during insertion. All screws were inserted by the first author (S.A.P.), an experienced surgeon who has performed more than 100 glenoid reconstruction procedures with either Latarjet or DTA. Although not standardized, an attempt was made to secure each graft with the level of compression consistent with what would be performed in an actual operation. Peak torques of the 2 screws were averaged to obtain mean peak torque for each construct. Constructs were then held in a vice and tested in compression utilizing a uniaxial materials testing system (Tinius Olsen H5KS). Samples were held with a custom-fabricated adaptor and loaded in displacement control at a rate of 100 mm/min until at least 3 mm of displacement occurred (Figure 5), which was defined as clinical failure. This amount of displacement was chosen to represent the minimum that would lead to a clinically inferior result. Load and displacement were recorded continually throughout the test, and ultimate load was defined as the load sustained at clinical failure.

Statistical Analysis

Two-factor analysis of variance with interaction (factor 1, cortex presence; factor 2, washer presence) was used to compare groups to determine the effects of each variable of interest on peak torque and ultimate load. A value of $P < .05$ was considered to be statistically significant.

RESULTS

The peak torque of both screws was averaged, and groups were compared to determine whether the presence of the washer or the presence of the cortex was the defining feature in the biomechanical performance of the constructs.

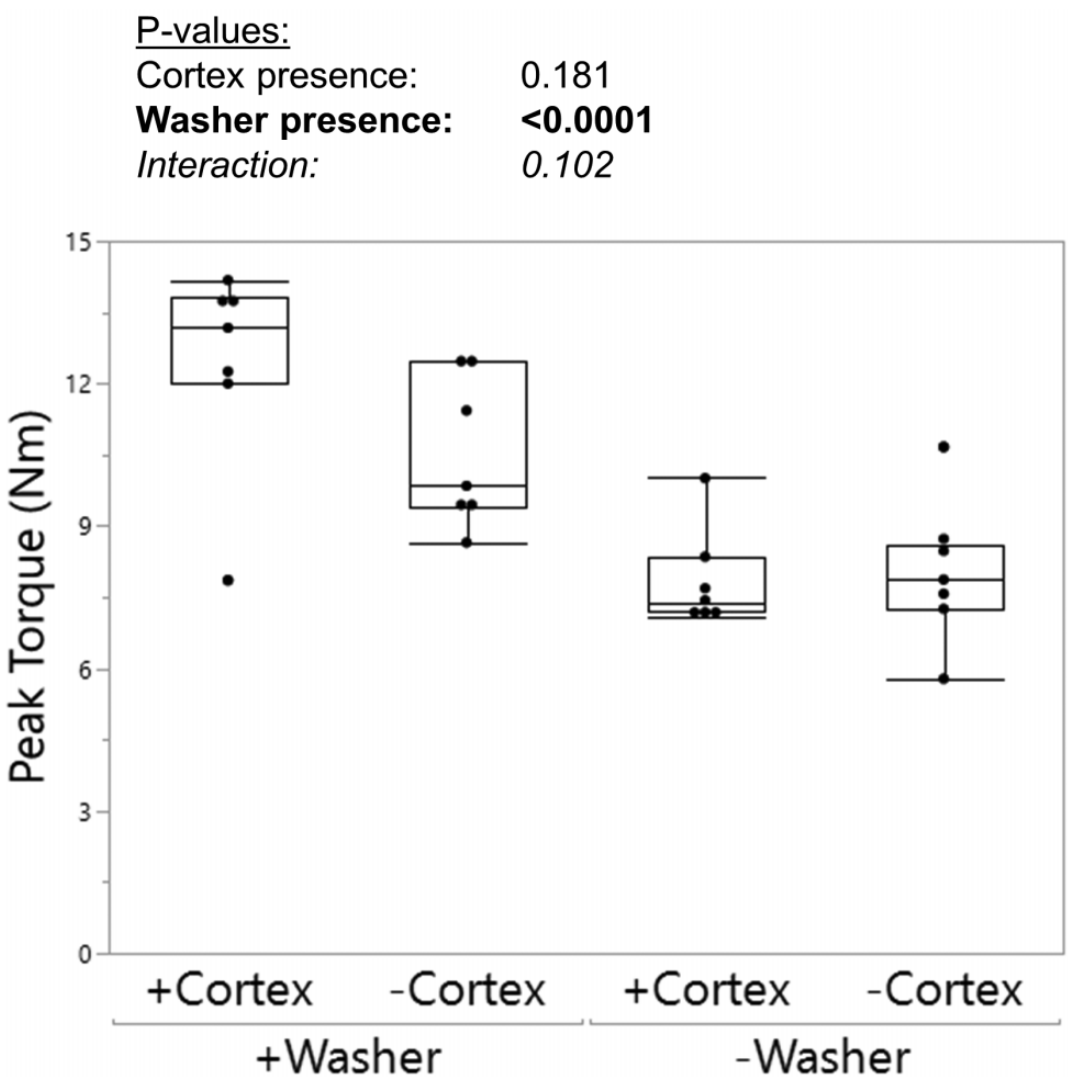

Figure 6. Graph depicting the results of peak insertion torque of screws in the 4 study groups.

This study showed that the use of a washer significantly improved the ultimate torque that could be applied to the screws ($P < .0001$), whereas the presence of the native bone cortex did not have a significant effect ($P = .181$) (Figure 6). There was not a significant interaction between the effects of the cortex and washer ($P = .102$), meaning that there was not a synergistic effect of a cortical shell or washer on the biomechanical performance of the constructs (ie, the biomechanical benefit from the use of a washer did not require that an intact bone cortex be present). Peak torque between the groups was as follows: +cortex and +washer = 12.42 N·m (SE, 0.82); +cortex and –washer = 7.83 N·m (SE, 0.40); –cortex and +washer = 10.54 N·m (SE, 0.59); and –cortex and –washer = 8.03 N·m (SE, 0.56).

Similarly, the use of a washer significantly improved the load each construct was capable of sustaining at 3 mm of displacement (ie, ultimate load; $P = .009$), whereas the presence of the native bone cortex did not have a significant effect ($P = .600$) (Figure 7). No significant interactions were detected between the effects of the cortex and washer ($P = .196$). Load at 3 mm of displacement between the groups was as follows: +cortex and +washer = 942.14 N (SE, 60.39); +cortex and –washer = 701.14 N (SE, 42.44); –cortex and +washer = 895.86 N (SE, 73.99); and –cortex and –washer = 809.00 (SE, 49.88).

All but 2 samples failed by bending of the screws. The other 2 samples (+cortex and –washer, –cortex and +washer) failed by fracture through the graft. The small number of failures other than by screw bending did not allow for a statistical analysis of failure by group.

DISCUSSION

This study found that, in a hybrid model of cadaveric DTA fixation to a polyurethane block modeling glenoid bone loss, the addition of washers was more effective than the retention of the lateral distal tibial cortex for both load to failure and peak torque during screw insertion.

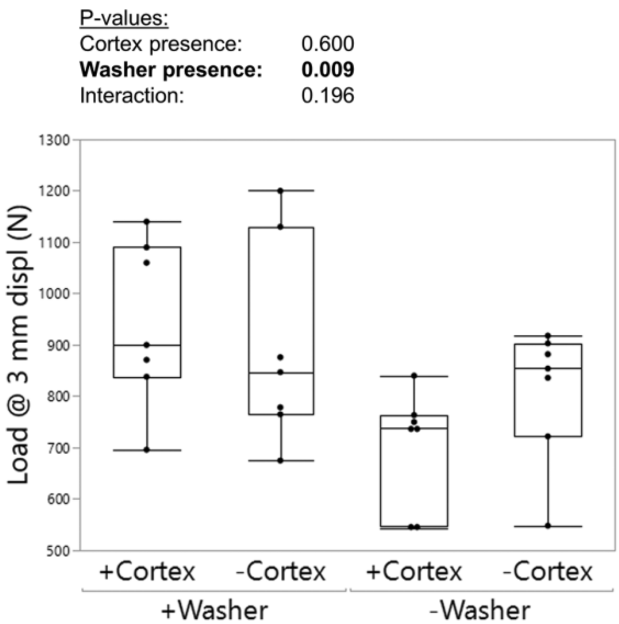

Figure 7. Graph depicting the results of load at ultimate failure in the 4 study groups.

Reconstruction of the glenoid with DTA has been shown to be a reliable procedure, with results that are comparable with a coracoid transfer (Latarjet) procedure.[5] Frank et al[5] demonstrated, in their series of 100 patients (50 DTA, 50 Latarjet), that patients who underwent DTA had no significant differences in any postoperative scores, complications, reoperations, or instability. This was despite the fact that DTA patients in this series had a greater percentage of glenoid bone loss than the Latarjet patients. Their study highlighted the impressive results of reconstruction with an allograft compared with autograft, long thought to be the gold standard in any bone grafting situation.

Increased DTA graft use has brought about increased understanding of the variability of the geometry of the lateral cortex of the distal tibia. As the lateral cortex is where the fibula articulates, the cortex has been found to have 3 distinct variations. Parada et al[10] reported type A tibias to have a flat contour and be an ideal graft. Type B tibias had a slight concavity of less than 5 mm of central depth and were determined to be acceptable grafts with the ability to retain most of the lateral cortex for fixation. Type C grafts were felt to be unacceptable for use, as they had a deep concavity with a central depth of more than 5 mm, necessitating complete removal of the cortex for hardware fixation.[10] They found that almost 86% of distal tibias in an MRI study were either type A or B, leaving 14% of tibias deemed to be unacceptable (type C). A further analysis found that neither age, height, weight, sex, nor body mass index affected the ability to allow harvest of a standard-size DTA graft.[9] This report means that presumably any distal tibia would be a suitable donor if it were not for the deep concavity of the lateral cortex encountered in 1 of every 7 DTA grafts.

Anecdotally, the first author and senior author (S.A.P. and M.T.P.) have had to implant type C grafts and felt that there was a need for cortical augmentation such as washers to avoid screwhead penetration into the softer cancellous bone of the graft when advancing the screws. This was noted to be in stark contrast to the standard fixation of a DTA graft that retained the lateral tibial cortex, which seemed to provide more robust compression with advancing of screws compared with that in a Latarjet procedure, where surgeons typically opt for the "2-finger tight" technique.[2] This finding was the impetus of the current study to objectively measure not only how the retention of the lateral cortex and presence of washers affected the load to failure, but also how these variables affected the maximum torque when advancing screws.

The effect of cortical augmentation as well as screw design has been studied previously in a foam block model simulating the Latarjet procedure. Rabinowitz et al[15] examined a Latarjet model with fixation consisting of either 3.5-mm partially threaded titanium cannulated screws with "top hats," 3.75-mm fully threaded titanium cannulated screws with a 2-hole wedged profile plate, 3.75-mm fully threaded titanium cannulated screws without a 2-hole wedged profile plate, or 4.0-mm partially threaded stainless steel cannulated screws. They found that the cortically augmented fixation methods (top hat and wedged plate) demonstrated a higher maximum insertion torque, maximum contact pressure, and effective pressure distribution between the surfaces of their coracoid and glenoid models when utilizing polyurethane blocks. Their study did not examine the potential use of washers as a cortical augment.

Frank et al[6] also evaluated a foam block model to compare fixation of single screws, double screws, and the effect of washers and miniplates. They also examined the effect of screw insertion angle on their outcomes. They concluded that the miniplate yielded the highest ultimate failure load at a 0° insertion angle and found that the construct with 2 screws and washers statistically outperformed 2 screws without washers, regardless of the screw diameter. As they utilized a bone block model for their testing, all blocks had a specimen uniformity; however, none had epoxy laminate to simulate the intact posterior cortex of the glenoid. Techniques for screw fixation of either a DTA or a Latarjet call for the cortical purchase of the screws through the posterior glenoid.[2,16,18]

There have been many debates about the size and characteristics of screws used for fixation during bony glenoid reconstruction procedures. Unplanned second surgery for hardware removal is one of the most common complications of Latarjet procedures making the choice of screw type an even more valid debate.[2,7] As the DTA literature continues to grow, guidelines for screw type and characteristics are largely extrapolated from the existing Latarjet literature. The first author and senior author have both revised failed Latarjet procedures for broken and bent solid screws as well as cannulated screws, demonstrating that if bony union does not occur, even a solid screw can fail.

Biomechanical properties certainly favor the strength of solid screws over cannulated screws; however, cadaveric studies have shown that cannulated screws had biomechanical equivalence in strength and stiffness between 4.0-mm solid screws and 3.5-mm cannulated screws in the Latarjet procedure.[1,8,17] Certainly, the screw characteristics are pertinent only until bony union of the graft to the glenoid occurs. Once bony union has been achieved, the mechanical properties of the screw are no longer applicable, as the bony union is supporting the construct.

Limitations

This study has several limitations, beginning with the use of a biomechanical foam block instead of a cadaveric specimen for testing purposes. This alternative was chosen in an attempt to mimic a uniform bone density for all specimens. The use of the foam block also provides a perfectly flat border for compression of the DTA graft, which is often not the case clinically during an actual procedure when there are imperfections along the anterior glenoid. Obviously, cadaveric DTA grafts were still used in this study because we wished to evaluate the grafts for specific failure types. These cadavers could have had significant differences regarding bone density that may have affected our outcomes. Regarding the biomechanical loading of the grafts, the actual clinical loading of a DTA is almost never the exact scenario that we tested, which was that only the graft was loaded, in a straight line of force, with no load going through the "glenoid" model. We chose this testing setup as it provided a worst-case scenario and therefore would eliminate the foam block glenoid model from sharing any of the load on the DTA graft. Last, this hybrid model of fresh, cadaveric grafts secured to a uniform foam block is not an exact substitute for the surgery in a living patient, and further work is needed to see if these results correlate with an in vivo environment.

CONCLUSION

The results demonstrate that, in a hybrid construct of fresh cadaveric DTA grafts secured to a foam block glenoid model, the addition of washers was more effective than the retention of the lateral distal tibial cortex for both load to failure and peak torque during screw insertion.

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