Comparison of a Distal Tibial Allograft and Scapular Spinal Autograft for Posterior Shoulder Instability With Glenoid Bone Loss

Christopher Nacca,*† MD, Joseph A. Gil,† MD, Steven F. DeFroda,† MD, MEng, Rohit Badida,† MS, and Brett D. Owens,† MD

Investigation performed at the Warren Alpert Medical School, Brown University, Providence, Rhode Island, USA

Background: Posterior glenoid bone deficiency can occur with recurrent glenohumeral instability. Glenoid reconstruction with a distal tibial allograft (DTA) has been reported to successfully restore contact pressures that occur during posterior glenohumeral translation. However, there are concerns regarding the risk of allograft resorption, availability, and costs. Extracapsular reconstruction using a scapular spinal autograft (SSA) has been reported as an alternative technique secondary to its anatomic location relative to the posterior shoulder and preferable autograft properties. There are no known prior biomechanical studies evaluating the scapular spine as an effective extracapsular graft choice.

Purpose: To compare the efficacy of a DTA and SSA in restoring the stability of a glenoid with a large posterior bone defect compared with the intact native glenoid.

Study Design: Controlled laboratory study.

Methods: Ten cadaveric shoulders were tested. With the use of a custom KUKA robot, a 50-N compressive force was applied to the glenohumeral joint. The peak force required to translate the humeral head beyond the glenoid lip posteriorly as well as the lateral displacement that occurred during posterior translation were measured. Testing was performed in 5 conditions: (1) intact glenoid and labrum, (2) simulated reverse Bankart lesion, (3) 12-mm posterior glenoid defect, (4) glenoid defect reconstructed with a fresh DTA, and (5) glenoid defect reconstructed with an SSA.

Results: The mean glenoid width was 30 mm. The mean peak force and lateral displacement decreased significantly with a glenoid defect (0.99 ± 2.3 N and 0.06 ± 0.09 mm, respectively; $P < .0001$) compared with the intact glenoid (23.00 ± 9.7 N and 1.83 ± 0.70 mm, respectively; $P = .0001$). There was no significant difference between the peak force after reconstruction of the defect with a DTA (23.00 ± 7.4 N) and SSA (23.00 ± 7.7 N) when compared with the intact glenoid ($P = .9999$). There were no significant differences in the peak force between the 2 grafts ($P = .9999$). Additionally, both the DTA (1.04 ± 1.09 mm) and the SSA (1.02 ± 1.17 mm) demonstrated no differences in lateral displacement when compared with the intact glenoid ($P = .2336$ and .2043, respectively). There was no difference in lateral displacement that occurred between the DTA and SSA ($P = .9999$).

Conclusion: Reconstruction of a large posterior glenoid defect with either a DTA or an SSA can effectively restore glenohumeral stability.

Clinical Relevance: This study supports the use of a DTA or SSA in posterior glenoid defect reconstruction. Clinical studies are needed to determine the long-term effects of utilizing such grafts.

Keywords: instability; shoulder; bone graft; glenoid defect; posterior shoulder dislocation

Posterior glenoid bone deficiency is commonly cited as a contributor to recurrent posterior shoulder instability, although it is quite rare in comparison with other factors.[5,15,16] Causes for posterior glenoid deficiency include congenital dysplasia, traumatic events such as a dislocation, or attritional bone loss secondary to repetitive subluxation events that occur in at-risk populations, such as in offensive linemen in American football.[3,9,15]

Historical treatment for glenoid dysplasia or failed capsulorrhaphy included bone block augmentation procedures with iliac crest or acromial bone grafting.[6,13] In 1952, McLaughlin[10] recommended the combination of posterior bone block augmentation and capsular plication to address posterior instability. This procedure has described both the

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use of an iliac crest bone graft (ICBG) and scapular spinal autograft (SSA), with some authors preferring an SSA because of its ease of harvest via the posterior approach.[1,6]

Long-term outcomes for bone block procedures have demonstrated poor results.[11] Meuffels et al[11] reported that patients who underwent posterior glenoid reconstruction with a bone block were at a high risk for developing glenohumeral osteoarthritis. More recently, glenoid augmentation procedures utilizing a distal tibial allograft (DTA) have been effectively utilized for posterior glenoid reconstruction.[7,12] Theoretical advantages of glenoid reconstruction with a DTA include the restoration of joint congruity and restoration of the articular cartilage interface.[5] Short-term clinical outcomes appear to be promising; however, there is a lack of information on how these patients fare at long-term follow-up.[5,7,12]

In a biomechanical cadaveric study, Frank et al[5] demonstrated that reconstruction of a glenoid defect with both an ICBG and a DTA yielded similar contact mechanics with respect to the intact glenoid. To our knowledge, no prior studies exist evaluating the use of scapular spinal grafting as an intra-articular graft choice alternative. Theoretical advantages of using an SSA are its anatomic accessibility and autograft properties.

The objectives of this study were to (1) evaluate the ability to restore the stability of a large posterior glenoid defect with both a DTA and an SSA and (2) compare the biomechanical properties of a DTA versus SSA. We hypothesized that both grafts would be effective in the restoration of glenohumeral contact pressures and glenohumeral translation.

METHODS

Preparation of Shoulder Specimens

Ten fresh-frozen cadaveric shoulders (10 male donors) were used in this study. Our institution purchased human cadaveric specimens from MedCure. The identity of the specimens was blinded. Institutional review board permission is not required for basic science research.

The mean age of the specimens at the time of death was 58 years (range, 55-63 years). We excluded specimens with moderate to severe osteoarthritis present on pretesting computed tomography (CT) or during specimen preparation. We also excluded any specimens over the age of 65 years. The shoulders were thawed overnight at room temperature before testing. The skin, subcutaneous tissue, and posterior rotator cuff tendons were removed, leaving the anterior structures intact, including the biceps tendon. These soft tissue structures were sacrificed to allow for improved visualization and appropriate access to the posterior glenoid. Posterior capsulotomy was performed to gain access to the posterior glenoid and labrum. A posterior approach and capsulotomy were utilized to improve access and to mirror a posterior instability state in which the capsule and ligaments are typically redundant and loose, providing minimal restraint to posterior translation. The medial margin of the scapula was osteotomized along a line parallel to the glenoid surface. The humeral shaft was osteotomized 10 cm distal to the most superior portion of the humeral head.

Both the scapula and humerus were potted in a 2-part urethane compound (300Q; Smooth-On) utilizing custom fixtures. Before potting, the exposed bony ends were transfixed with 2 cortical screws to increase rotational stability at the bone-potting interface. The glenoid surface was potted parallel to the horizontal plane, while the humerus was potted in 30° of abduction and 30° of flexion with respect to the glenoid. This positioning was chosen to simulate a load-and-shift test in which the majority of stability is provided by the glenohumeral articulation rather than capsuloligamentous and tendinous structures. After potting, all specimens underwent CT before mounting. Pretest CT volume images were used to measure the depth of the glenoid, which was defined as the distance from the most posterior reference point on the rim to the deepest portion of the glenoid.

Testing Apparatus

All testing was performed with a 6-axis industrial robot (KR 6 R700; KUKA) that was integrated with simVITRO LabVIEW-based control software (Cleveland Clinic). The robot was equipped with a multiaxis load cell (SI-580 N; ATI) at the end effector for the measurement of forces and torques in all 3 Cartesian directions. This interface provided a flexible musculoskeletal simulator to control and report joint kinetics and kinematics. The specimen was then mounted to the robot with the glenoid parallel to the base and the humerus attached to the robot end effector. After mounting, the spatial relationships between the robot, load cell, and specimen were established using a 6 degrees of freedom digitizing probe (Optotrak; NDI). The glenoid coordinate system was generated via the digitization of bone-based anatomic landmarks determined within a specimen-specific CT image.

A 50-N compressive force was constantly applied to the humerus to keep the humeral head compressed in the glenoid fossa; 50 N was chosen, as it was effective in a previous biomechanical instability study.[17] The initial reference position was determined to be the center of the glenoid as based on CT data. This reference position was confirmed

*Address correspondence to Christopher Nacca, MD, Warren Alpert Medical School, Brown University, 222 Richmond Street, Providence, RI 02903, USA (email: c.nacca11@gmail.com).

†Warren Alpert Medical School, Brown University, Providence, Rhode Island, USA.

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Ethical approval was not sought for the present study.

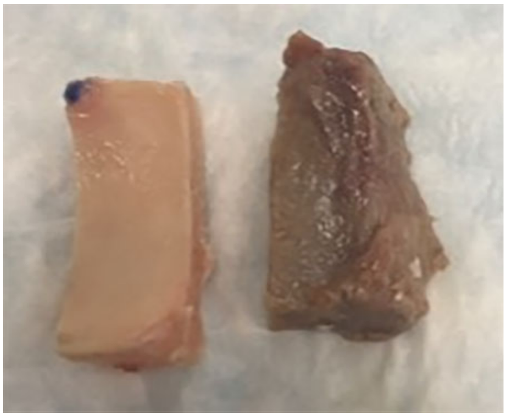

Figure 1. Examples of a harvested distal tibial allograft (left) and scapular spinal autograft (right).

when both the x- and y-axis forces recorded were minimized (~0 N) before translation. Starting from the initial reference position, the humeral head was translated in the posterior direction for 10 mm at a rate of 1.0 mm/s. This 10-mm displacement protocol was utilized for the entire cohort, as the glenoid widths were all measured as 30 ± 1 mm. These parameters were utilized in prior studies that examined the effect of anterior glenoid bone defects on anterior shoulder instability.[8,17] The specimens were hydrated with normal saline before mounting and before each test to minimize cartilage desiccation. The peak force that occurred during humeral head translation as well as lateral displacement (z-axis) of the center of the humeral head were recorded. Three trials were performed for each condition, and the mean value was used for data analysis.

Creation of Bone Defect

After testing in the intact state, osteotomy simulating a 12-mm posterior bone defect was then performed. A large (12 mm) defect was created to allow for adequate graft fixation. This lessened the concern for a potential confounding factor of graft fixation failure with fixation of smaller grafts. Measurements were made based on pretest CT volume images. Osteotomy lines were drawn in the superior-inferior direction of the y-axis with respect to the glenoid center, which was used as the reference point. Osteotomy was initially performed with a sagittal saw and then completed with an osteotome.

Graft Preparation

A fresh DTA (Figure 1) was prepared in accordance with the methods described by Provencher et al.[14] For each glenoid, a DTA of the same laterality was used (right DTA for right glenoid). Next, a graft with the same dimensions (width and length) as the glenoid defect was carefully cut from the lateral one-third of the distal tibia (Figure 2). The graft thickness was variable but large enough for adequate fixation. An SSA was harvested from each tested shoulder

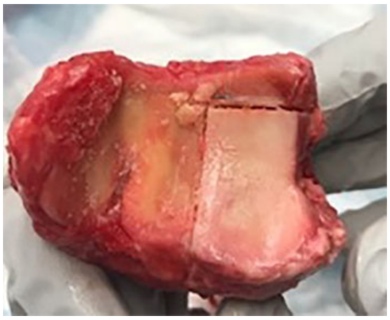

Figure 2. Harvesting technique of a distal tibial allograft from the lateral portion of the tibial plafond as adopted from Provencher et al.[14]

Figure 3. Harvesting technique of a scapular spinal autograft from the midportion of the spine as described by Arciero and Mazzocca.[1]

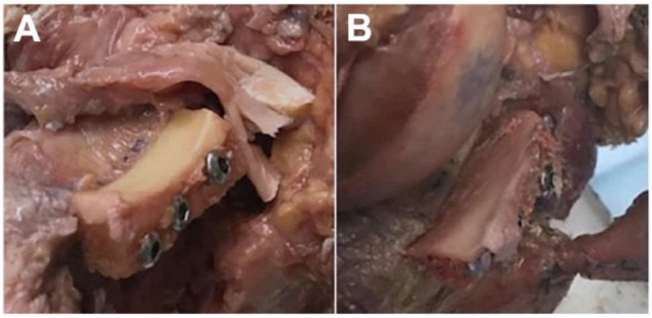

Figure 4. Reconstruction of the glenoid defect with a (A) distal tibial allograft and (B) scapular spinal autograft.

by a technique adopted from Arciero and Mazzocca.[1] This entailed measuring out approximately 2.5 to 3 cm in length and 1.5 cm in width from the midportion of the scapula, which was already exposed in the initial shoulder preparation (Figure 3). Using a sagittal saw, this block was harvested and shaped in a similar fashion to the DTA to match the glenoid defect (Figure 1).

Grafts were appropriately contoured so that they were flush with the glenoid articular surface. Provisional fixation was achieved with pointed reduction forceps and two 1.6-mm Kirschner wires. Definitive fixation was achieved with three 3.5-mm fully threaded screws drilled in a lagging fashion to achieve compression (Figure 4).

Test Conditions

The humerus was positioned in 30° of abduction, flexion, and neutral rotation relative to the scapula. Testing was performed under 5 conditions: (1) intact glenoid and labrum, (2) simulated reverse Bankart lesion, (3) 12-mm posterior glenoid defect, (4) glenoid defect reconstructed with a fresh DTA, and (5) glenoid defect reconstructed with an SSA. A reverse Bankart lesion was created by elevating the capsulolabral attachment periosteally from the 6-o'clock to 11-o'clock position in the right glenoid.

Statistical Analysis

One-way repeated-measures analysis of variance was used to compare the change in peak force and lateral displacement across the simulated conditions. When a significant effect was observed, it was further analyzed separately with the Dunnett test. The intact glenoid was used as the baseline condition and compared with the glenoid defect and bone grafting conditions. The level of significance was set at $P < .05$. All statistical analyses were performed with GraphPad Prism (7.0c; GraphPad Software).

RESULTS

Stability

The mean peak force that occurred with posterior translation decreased significantly with a glenoid defect (0.99 ± 2.3 N) in comparison with the intact glenoid (23.00 ± 9.7 N) and a reverse Bankart lesion (19.70 ± 9.1 N) ($P < .0001$). There was a significant increase in peak translational force after reconstruction with both the DTA (23.00 ± 7.4 N) and the SSA (23.00 ± 7.7 N) in comparison with the glenoid defect ($P < .0001$). There was no significant difference between the peak force with the DTA and SSA when compared with the intact glenoid and reverse Bankart lesion ($P = .9999$ and .9743, respectively). There were no significant differences in the peak force between the 2 grafts ($P = .9999$) (Figure 5).

Lateral Humeral Displacement

Similar to peak force, lateral displacement decreased significantly with the glenoid defect (0.06 ± 0.09 mm) in comparison with the intact glenoid (1.83 ± 0.70 mm) and reverse Bankart lesion (1.68 ± 0.73 mm) ($P = .0001$ and .004, respectively). There was a significant increase in lateral displacement after reconstruction with both the DTA (1.04 ± 1.09 mm) and the SSA (1.02 ± 1.17 mm) in comparison with the glenoid defect ($P = .042$ and .0479, respectively). There was no significant difference in lateral displacement with the DTA and SSA when compared with the intact glenoid ($P = .2336$ and .2043, respectively) and reverse Bankart lesion ($P = .3860$ and .3705, respectively). There was no significant difference in lateral displacement between the 2 grafts ($P = .9999$) (Figure 6).

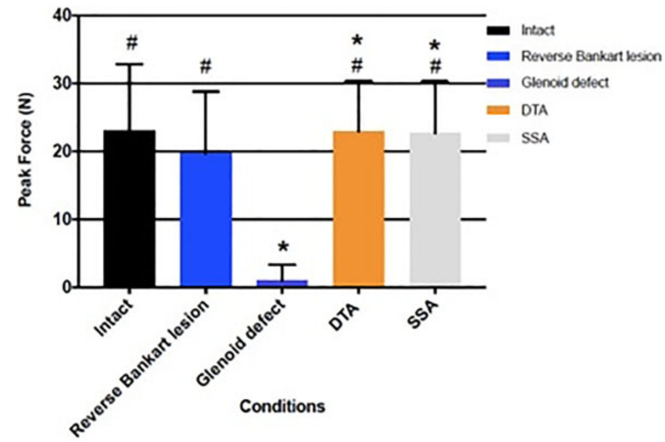

Figure 5. Peak force decreased with the creation of a reverse Bankart lesion and glenoid defect (blue bars). *In shoulders with bone grafting utilizing a distal tibial allograft (orange bar) and scapular spinal autograft (gray bar), peak force increased significantly when compared with the glenoid osseous defect ($P < .05$). #Comparison of grafted specimens with an intact glenoid and grafted specimens with a reverse Bankart lesion did not reveal a difference in peak force ($P > .2$ and $P > .3$, respectively). DTA, distal tibial allograft; SSA, scapular spinal autograft.

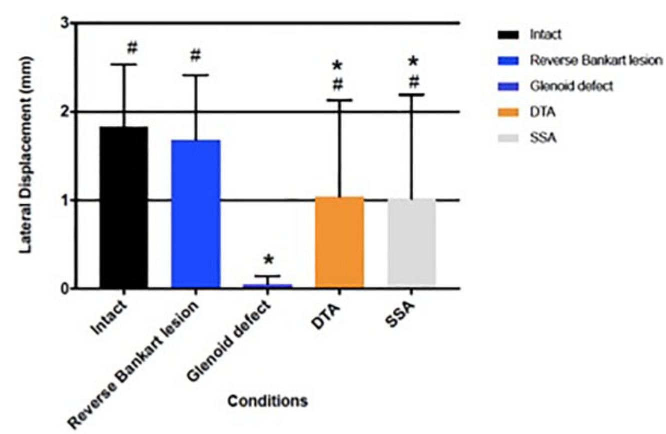

Figure 6. Lateral displacement decreased with the creation of a reverse Bankart lesion and glenoid defect (blue bars). *In shoulders with bone grafting utilizing a distal tibial allograft (orange bar) and scapular spinal autograft (gray bar), lateral displacement increased significantly when compared with the glenoid osseous defect ($P < .05$). #Comparison of grafted specimens with an intact glenoid and grafted specimens with a reverse Bankart lesion did not reveal a significant difference in lateral displacement ($P = .9999$). DTA, distal tibial allograft; SSA, scapular spinal autograft.

DISCUSSION

The purpose of this study was to compare the efficacy of a DTA and an SSA in restoring the stability of a glenoid with a large posterior bone defect in comparison with the intact native glenoid. Our results indicate that intra-articular glenoid reconstruction utilizing a DTA or an SSA can both effectively restore stability. We did not detect a difference in stability between these 2 graft options ($P = .9999$).

The only other biomechanical study that examined the biomechanical properties of posterior glenoid reconstruction with a bone block was performed by Frank et al.[5] They grafted posteroinferior glenoid defects with both a DTA and an ICBG. A compressive load of 440 N was applied to the humerus in several positions, and glenohumeral contact pressures, areas, and joint peak forces were recorded by a dynamic pressure-sensitive pad placed between the articular surfaces. The authors found no significant differences in contact pressures between the grafted specimens and the intact glenoids. Also, they found no significant difference in peak forces between the 2 bone block options. A limitation of their study was that no testing condition examined the force of translation, which is the primary clinical issue in patients with substantial bone loss. In our study, we translated the humerus posteriorly in a controlled manner to closely resemble physiological motion.

Lateral humeral displacement is thought of as a representation of the total depth of the glenoid socket. Our results demonstrated no significant difference in displacement between the grafted and intact specimens. These data support the effectiveness of articular reconstruction of the glenoid with the 2 types of bone grafts that we tested. Although we significantly increased displacement in our grafted specimens in comparison with the glenoid defect specimens, we were unable to completely restore displacement with respect to the intact specimens. We explain this finding secondary to failure to accurately match the articular curve of the natural posterior glenoid with the grafts. Although we did not measure the radius of curvature, subjectively it was evident that the grafts that we tested had a reduced radius of curvature relative to the native glenoid. Grafts were able to extend the articular surface, as demonstrated by the restoration of force. However, with a reduced radius of curvature, the recorded lateral displacement or height that the humeral head achieved during testing was smaller in comparison with the native glenoid. This is in contrast to previous studies in which the distal tibial graft was reported to have almost identical anatomic properties to the native glenoid.[2,5]

Secondary to the negative long-term consequences of nonanatomic reconstruction of the glenoid with an extra-articular ICBG, there has been increased focus on articular reconstructive procedures.[7] Although long-term outcome data are lacking, the limited available studies demonstrate excellent short-term function.[7,12] The use of an acromion or SSA in an extracapsular bone block fashion is not a new concept, having been described as early as 1989 by Fronek et al.[6] It is important to note that Fronek et al[6] utilized scapular spinal grafting as a bone block rather than as an extension of the articular surface that we describe here. The advantages of using an SSA include its accessibility, autograft properties, and avoidance of donor site morbidity, such as with an ICBG. However, in comparison with a DTA, the major drawback is the lack of articular cartilage. To allow an appropriate comparison with a DTA, we reconstructed the glenoid using an SSA in an intra-articular manner. To our knowledge, this is the first study to test an SSA fixed with the intra-articular technique that we describe here. Although we found no biomechanical advantage of using a DTA in comparison with an SSA, it is unclear if the lack of articular cartilage or if it was used in an extracapsular manner would ultimately lead to poor outcomes. Recently, in a study by Frank et al,[4] the authors found no difference in outcomes between DTA and Latarjet reconstruction in patients with anterior instability with $>15\%$ anterior bone loss when observed for at least 2 years.

The present study has several limitations. First, we grafted large defects (12 mm), which may not be as clinically relevant as smaller defects. However, we believe that it is reasonable to conclude that similar results would be achieved in posterior glenoid bone block reconstruction of smaller posterior glenoid defects that are not amenable to isolated soft tissue repair. Second, posterior instability is thought to occur in a relatively flexed and internally rotated position of the humerus. We tested shoulders in a relatively neutral manner, simulating a load-and-shift test. We did this because we aimed to isolate the stability conferred by the glenoid and labrum. Third, posterior rotator cuff tendons and soft tissue were sacrificed to improve visualization. This may alter the overall force required to translate the humerus. Additionally, the bone and soft tissue quality of cadaveric shoulders may not represent the tissues found in younger patients who typically present with posterior shoulder instability. Last, testing with cadaveric specimens did not allow us to account for the additional stability gained or lost once the graft healed to the glenoid.

CONCLUSION

Reconstruction of a large posterior glenoid defect with either a DTA or an SSA can effectively restore glenohumeral stability at time zero. While the use of a DTA had been previously proven to be effective from a biomechanical standpoint,[5] an SSA had not been previously tested biomechanically. An SSA may be advantageous with regard to graft incorporation and ease of harvest during the posterior approach to the shoulder; however, the lack of articular cartilage on this graft may be a limitation. Future studies should focus on the clinical outcomes of these 2 graft options in the management of posterior glenoid bone loss.

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