Effect of lateral meniscus allograft on shoulder articular contact areas and pressures

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The objective of this study was to determine the effect of a lateral meniscus allograft on the articular contact area and pressures across the glenohumeral joint under compressive loads of 220 N and 440 N. Eight fresh-frozen shoulders were used, and contact areas and pressures were determined with a Tekscan flexible tactile force sensor. Testing conditions included a normal glenohumeral joint and one interposed with a lateral meniscus allograft. Using the Tekscan sensing equipment, we evaluated the total force (in Newtons), contact area (in square millimeters), mean contact pressure (in kilograms per square centimeter), peak force (in Newtons), and peak contact pressure (in kilograms per square centimeter). The interposed lateral meniscus allograft group showed a statistically significant decrease in total force at both 220 N and 440 N, as well as a decrease in contact area for the 220-N testing condition. There were no statistically significant differences between the two groups in contact area at 440 N or in peak forces or peak contact areas for either 220-N or 440-N testing condition. Biomechanically biologic resurfacing with a lateral meniscus allograft of the glenohumeral joint is supported by decreased forces on the glenoid surface. (J Shoulder Elbow Surg 2007;16:367-372.)

Pain in the glenohumeral joint related to arthritis or osteochondral defects can be a disabling condition for both young and old patients but represent two distinct populations with confounding problems. A young patient can have an arthritic condition caused by primary arthritis, trauma, recurrent instability, or previous surgical intervention.[21,23,28,29] Orthopae-

dists have traditionally steered younger patients away from total shoulder arthroplasty because of their active lifestyles, leading to accelerated glenoid component wear and associated loss of glenoid bone stock. These patients have instead been offered conservative management, arthroscopic debridement or release (or both), hemiarthroplasty, hemiarthroplasty with soft-tissue interposition, or rarely, glenohumeral fusions.[5,7,9,15,25]

Performing a humeral head replacement alone in these patients can be beneficial.[6] However, the development and progression of glenoid arthrosis comprise the most common reason for reoperation and an unsatisfactory result after hemiarthroplasty.[20,26,36,37] Unfortunately, compared with total shoulder replacement, hemiarthroplasty performance is inferior with respect to pain relief, regaining motion, and return to function.[4,12,14,33] Another alternative is to offer the patient biologic resurfacing on the glenoid side in conjunction with a humeral head replacement[5] or, if he or she only has glenoid arthritis, biologic resurfacing alone. The older patient with severe arthritis is usually offered a total shoulder arthroplasty because of the decreased activity level, but there is still concern over the survivorship of the glenoid component.[24] Many surgeons elect to perform a hemiarthroplasty because of the difficulty of exposing the glenoid and implanting a glenoid prosthesis properly.[17,19] An even more perplexing patient is one who presents with pain after a previous arthroplasty procedure as a result of component or catastrophic failure. Revision arthroplasty is technically demanding and associated with inferior results.[2,3,18,27,38]

Other authors have critically evaluated the contact areas and pressures of an intact and pathologic glenohumeral joint.[10,16,34,35,41] Some of these studies have reported an increase in contact area and pressure as arm abduction approaches 120°, which begins to decrease beyond this elevation.[10,35,41] Under abnormal conditions, these contact areas are increased as a result of contractures, biconcentric loading conditions, and loss of soft-tissue restraints.[10,13] In the glenohumeral joint, in situ compressive properties of the glenoid labrum are similar to those of knee menisci and may have some similar functions.[8]

An allograft may be considered in a primary setting when the age, occupation, and activity level of the patient create concern regarding glenoid component longevity. The interpositional graft may serve two functions clinically. The first is to improve glenohumeral conformity, leading to decreased pain and improved function. The second is to act as a biologic resurfacing agent on the load-bearing surface. The clinical results in this patient population are currently the subject of investigation, and therefore, routine use of a lateral meniscus allograft as a biologic interposition awaits definitive clinical results.

This study was performed to understand better the function of a lateral meniscus allograft applied to the glenoid in a biomechanical setting. The hypothesis was that interposition of a lateral meniscus allograft between the humeral head and glenoid surface would result in a decrease in force transmission across the glenoid surface.

MATERIALS AND METHODS

Specimen preparation

Eight fresh-frozen human cadaveric shoulders that had no evidence of glenohumeral arthritis were used. The mean age of the specimens was 57 years (range, 40-70 years). The shoulders were stripped of all of their soft tissue except the labral complex. The humerus was then cut in cross section at a line approximately 5 cm distal to the greater tuberosity. The remaining proximal humerus was embedded in dental acrylic (Lang Dental, Wheeling, IL). The scapula was cut in a line approximately 3 cm medial and parallel to the glenoid joint surface, and the parallel cut end was then embedded in dental acrylic with the glenoid fossa exposed for loading. Throughout preparation and testing, the glenohumeral specimens were kept moist with normal saline solution. Each of the 8 glenohumeral specimens was used once for each testing condition.

Biomechanical testing

The embedded proximal humerus was fixed to the actuator of the materials testing system (Instron model 1321; Instron, Canton, MA) to be used as the loading plate. The humerus was positioned in 90° of scapular abduction and in neutral alignment, as described by Matsen et al.[22] This one static arm position was used for the testing conditions, because it allowed the compressive force applied to be perpendicular to the glenoid surface to centralize contact pressures and contact areas. The embedded glenoid was fixed to the table of the materials testing system (Figure 1). A flexible tactile force sensor, composed of a flat 56-mm square grid of piezoelectric sensing units, or sensels, with 62 sensels/cm^2 (I-Scan model 5051; Tekscan, South Boston, MA), was calibrated per the manufacturer's recommendations and then placed on the glenoid surface.

Loads of 220 N and 440 N were applied via the actuator through the humeral head to the glenoid surface. The force (in Newtons) at each sensel and contact area (in millimeters) data were acquired via the tactile force sensor
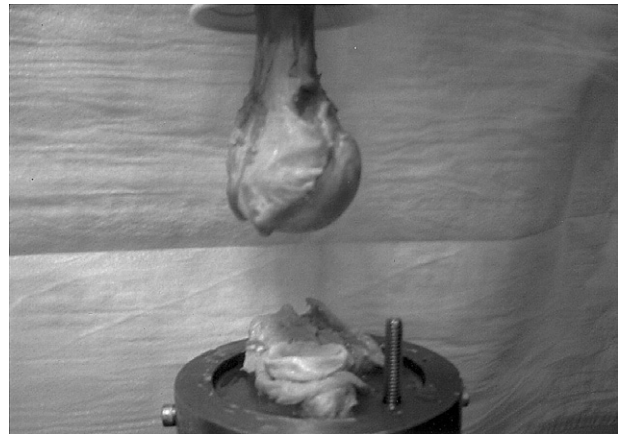

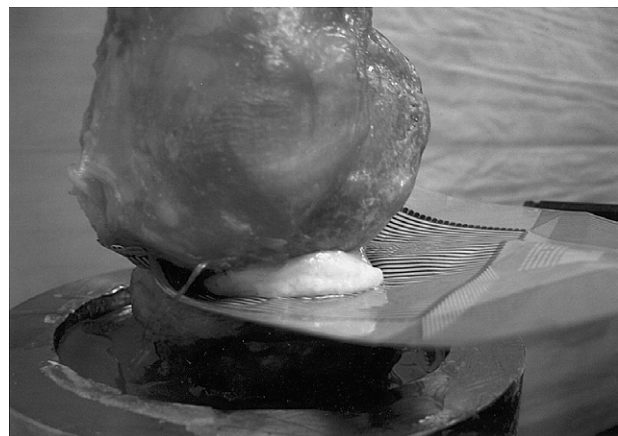**Figure 1** Biomechanical testing apparatus.

Figure 2 Lateral meniscus interposition centered on glenoid with Tekscan sensor.

over a period of 5 seconds. The mean force (in Newtons), contact area (in square millimeters), mean contact pressure (in kilograms per square centimeter) over the entire surface, peak force of the most loaded sensel (in Newtons), and peak contact area (in kilograms per square centimeter) were then calculated by the data acquisition software provided by the sensor manufacturer.

The second testing condition included the interposition of a lateral meniscus allograft. The two ends of a lateral meniscus were sutured together to form a ring. It was fastened superiorly with the two sutured ends at 12 o'clock on the glenoid face and positioned centrally along the face of the glenoid, and a slight compressive load was applied to prevent movement (Figure 2). There was no noticeable movement of the meniscus during any of the testing conditions. The loading regimen of 220 N and 440 N was then applied a second time, and the same resultant data were collected again over a period of 5 seconds. Mean force, contact area, mean contact pressure, peak force, and peak contact pressure data at the glenoid surface under a lateral meniscus interposition were then compared between the normal condition and the meniscus-ring implant condition
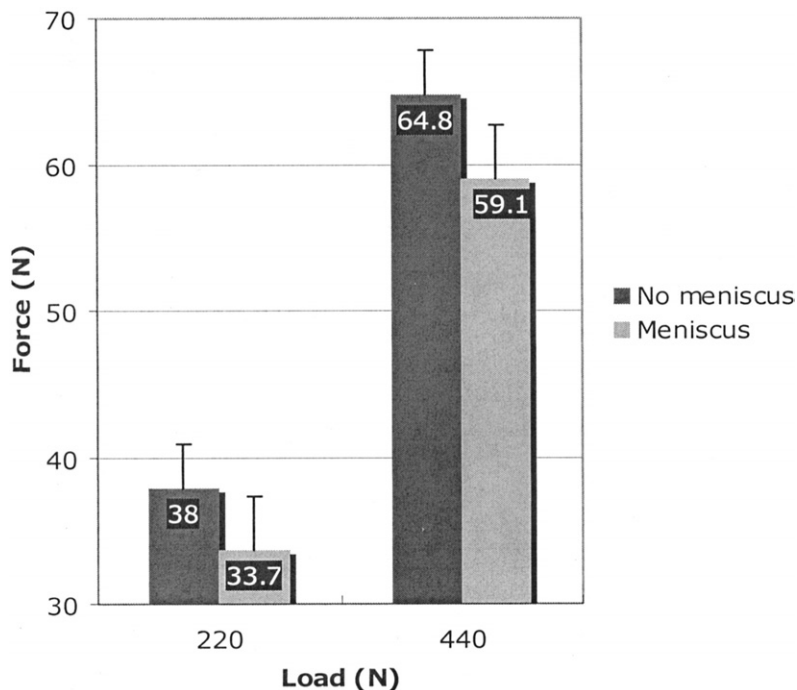
Figure 3 Force decreased under both loading conditions with interposition of lateral meniscus allograft. *Dark gray bars*, No meniscus; *light gray bars*, meniscus.

by use of a Student *t* test. One lateral meniscus allograft was used for all testing conditions. It was kept moist in normal saline solution between trials and positioning of the glenohumeral specimens and showed no signs of degradation throughout testing.

RESULTS

The mean force for both loading conditions was decreased in the lateral meniscus interposition group and was statistically significant (Figure 3). For the 220-N loading condition, the mean force of the normal glenohumeral articulation was 38.03 N (SD, 3.74 N) and that of the lateral meniscus group was 33.71 N (SD, 4.57 N), for a statistically significant decrease in mean force of 11% ($P < .05$). For the 440-N loading condition, the mean force of the normal glenohumeral articulation was 64.77 N (SD, 5.95 N) and that of the lateral meniscus group was 59.11 N (SD, 7.10 N), for a statistically significant decrease in mean force of 9% ($P < .05$).

The contact areas recorded by the Tekscan sensors were statistically significantly decreased in the lateral meniscus group only for the 220-N loading condition ($P < .05$). For this loading condition, the contact area of the normal glenohumeral articulation was 494.88 mm^2 (SD, 120.40 mm^2) and that of the lateral meniscus group was 391.63 mm^2 (SD, 80.04 mm^2), for a statistically significant decrease in contact area of 20% ($P < .05$). For the 440-N loading condition, the

contact area of the normal glenohumeral articulation was 520.38 mm^2 (SD, 119.47 mm^2) and that of the lateral meniscus group was 466.25 mm^2 (SD, 78.64 mm^2), but this was not statistically significant ($P = .07$). Of interest, with both loading conditions, there was sparing of contact in the central portion of the glenoid and more peripheral loading in the lateral meniscus group (Figure 4).

There were no statistically significant differences under either loading condition in the comparison of the testing conditions for the other testing parameters. The mean contact pressure was slightly higher in the lateral meniscus group compared with the normal glenohumeral articulation, but the difference was not statistically significant ($P = .15$). For both loading conditions, peak force and peak contact pressure were lower for the lateral meniscus group, but the differences were not statistically significant (Table I).

DISCUSSION

Injury to the labrum and glenoid rim not only affects the stability of the shoulder but also increases the contact pressures across the glenohumeral joint.[16] Similarly, arthritic surfaces are rendered less clinically relevant when unloading occurs across the joint.[1,31] This study evaluated pressure changes on the face of the native glenoid that occur under the influence of compressive loads in the normal state and when a
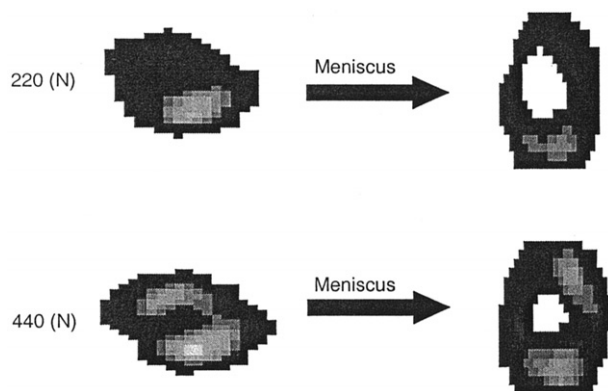
Figure 4 Tekscan pressure force (in Newtons) and contact area (in square millimeters) under both loading conditions are decreased with interposition of lateral meniscus allograft. The central sparing of the glenoid and peripheral loading pattern in the lateral meniscus group should also be noted.

Table I Results of mean contact pressure, peak force, and peak contact pressure

Testing condition	Mean contact pressure (kg/cm²) (SD)	Peak force (N) (SD)	Peak contact pressure (kg/cm²) (SD)
220-N load			
No meniscus	0.82 (0.15)	1.73 (0.33)	2.73 (0.54)
Meniscus	0.89 (0.09)	1.52 (0.29)	2.40 (0.46)
P value	.15	.07	.08
440-N load			
No meniscus	1.31 (0.20)	2.42 (0.28)	3.83 (0.44)
Meniscus	1.31 (0.12)	2.35 (0.34)	3.71 (0.53)
P value	.91	.57	.57

lateral meniscus is placed, acting as an interpositional graft. Using Tekscan pressure-sensing technology, we were able to evaluate the contact area, mean contact pressure, and peak pressure distributed on the glenoid face before and after placement of a lateral meniscus allograft. DeMarco et al[11] have proved the accuracy and reproducibility of this technology for orthopaedic applications. Traditionally, Fuji film (Fuji Photo Film, New York, NY, USA) has been used to determine contact pressures across joints in other research endeavors.[10,30,32,41] We believe, as do other investigators, that the Tekscan technology allows for a more in-depth, accurate, and reproducible data collection.[11,16,42]

This study demonstrated the effect of placing a lateral meniscus allograft between the humeral head and glenoid and applying compressive loads of 220 N and 440 N. When compared with the normal glenohumeral articulation, mean force in the lateral meniscus allograft group decreased by 11% during the 220-N testing condition and by 9% during the

440-N testing condition. Both of these findings were statistically significant ($P < .05$). During the 220-N testing condition, the application of the lateral meniscus led to a 20% reduction in contact area, which was also statistically significant ($P < .05$). Of interest was the relative central glenoid sparing of both testing conditions with interposition of the lateral meniscus allograft. This could be of importance in dealing with central cartilage lesions or central cavitary bone defects requiring bone grafting, taking contact pressure away from these at-risk areas. This finding is similar to central decreases in contact forces across the tibiofemoral joint with an intact meniscus or immediately after meniscus transplantation.[40] However, in the knee that is meniscus-deficient, contact area is reduced, and this significantly increases the load-per-unit area.[39] Our study shows that this appears to be paradoxical in the shoulder, but one must remember that this study examined one point and position in time, which is not how the meniscus functions exactly in the knee. As a load is applied through the knee, the meniscus is forced to the periphery, like a seed squeezed between 2 fingers. The resultant radial displacement is resisted by the hoop stresses inherent in the native meniscus, which converts the axial load into tensile strain.[39] Meniscus use in the shoulder could be functioning strictly as a shock absorber.

Two distinct patient populations may benefit from the use of lateral meniscus allograft interposition to the glenoid. The first is a younger patient who has a large glenoid chondral lesion, glenohumeral chondrolysis, or an early arthritic condition. If the patient requires placement with a hemiarthroplasty, the addition of a lateral meniscus allograft may decrease the progression of glenoid arthritis by the central sparing effect of the interposed meniscus. In chondrolysis, interposition with a lateral meniscus allograft may decrease contact pressures across an already damaged glenoid surface to allow for pain relief and better function. The second population is an older patient who has arthritis with excessive glenoid wear that precludes implantation of a glenoid prosthesis or a patient who has pain as a result of glenoid prosthesis loosening. In both of these cases, the deficient glenoid bone stock requires bone grafting, and there is an inability to place or replace a glenoid prosthesis. Incorporating a lateral meniscus interpositional allograft on top of the bone graft may act as a barrier to the bone graft and possibly allow for earlier graft incorporation by decreasing the contact pressures across the glenohumeral joint. These grafts should be used with caution, however, because the long-term viability of the graft, as well as its success, is not known.

There are several limitations of this biomechanical model. The main limitation is that it is a static model, similar to one used in previous studies.[10,16,41] As a

result of the static testing conditions, the humerus is centralized within the glenoid because of the natural concavity of the glenoid-labral complex, minimizing pressures. As Greis et al.[16] stated, this may represent the best-case scenario across the joint. This, however, makes the finding of central sparing of the lateral meniscus allograft even more impressive. The meniscus was only anchored in one position on the glenoid surface because of the physical limitations of Tekscan sensels. If they are sutured and disrupted, as would be required in fixing the meniscus allograft to the glenoid periphery, the data collection would have been compromised. Without the ability to stabilize the Tekscan device to the glenoid, we could not test multiple arm positions. Another limitation is that only one lateral meniscus allograft was used for all testing conditions. It was kept moist in normal saline solution between trials and positioning of the glenohumeral specimens and showed no signs of degradation throughout testing. If there were a significant difference in dimensions of the meniscus allograft or size mismatch of the glenoid-meniscus interface, these factors would obviously alter loading characteristics.

This study examined the effect of the interposition of a lateral meniscus allograft on compressive loading mechanics on the glenoid surface. Despite the shortcomings of the model, we believe this information is helpful in understanding how applying a lateral meniscus allograft to the glenoid face may be beneficial in a clinical setting. A lateral meniscus allograft applied to the glenoid face appears to decrease contact pressures by around 10% and centrally spares glenoid contact. Specific areas of future research include developing a dynamic model, evaluating the humeral contact and loading characteristics, and determining the best mode of fixation of the allograft to the glenoid periphery. Obviously, more research is warranted on this surgical procedure, particularly with regard to its indications and sizing of the lateral meniscus graft to the glenoid, in addition to prospectively performed outcome studies.

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