Original Article

Glenohumeral kinematics after soft tissue interposition graft and glenoid reaming
A cadaveric study

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Abstract

Background: The management of young patients with glenohumeral arthritis is controversial. Resurfacing of the glenoid with biologic interposition and reaming of the glenoid have been suggested as potential treatment options. The goal of this study was to determine the change in glenohumeral contact pressures in interposition arthroplasty, as well as glenoid reaming in an arthritis model. We hypothesized that interposition with meniscal allograft will lead to the best normalization of contact pressure throughout the glenohumeral range of motion.

Materials and Methods: Eight fresh-frozen cadaveric shoulders were tested in static positions of humeral abduction with a compressive load. Glenohumeral contact area, contact pressure, and peak force were determined sequentially for (1) intact glenoid (2) glenoid with cartilage removed (arthritis model) (3) placement of lateral meniscus allograft (4) placement of Achilles allograft (5) arthritis model with reamed glenoid.

Results: The arthritis model demonstrated statistically higher peak pressures than intact glenoid and glenoid with interpositional allograft. Meniscal and Achilles allograft lowered mean contact pressure and increased contact area to a level equal to or more favorable than the control state. In contrast, the reamed glenoid did not show any statistical difference from the arthritis model for any of the recorded measures.

Conclusion: Glenohumeral contact pressure is significantly improved with interposition of allograft at time zero compared to an arthritic state. Our findings suggest that concentric reaming did not differ from the arthritic model when compared to normal. These findings favor the use of allograft for interposition as a potential treatment option in patients with glenoid wear.

Key words: Glenoid reaming, glenoid resurfacing, interpositional arthroplasty, lateral meniscus, shoulder arthritis, shoulder arthroplasty

MeSH terms: Glenohumeral joint, grafting, tissue, shoulder joint, grafts

Introduction

The management of young patients with glenohumeral arthritis is controversial and particularly challenging. It is now well established that advanced glenohumeral arthrosis can be seen in the young patient population as well as in the elderly population.[1] There can be chondral injury secondary to a traumatic event such as fracture or dislocation. There are also several potential iatrogenic causes of early glenohumeral arthritis. In particular, glenohumeral chondrolysis has recently been identified as a significant source of shoulder pain in young patients.[2-5] This subset of patients may have chondrolysis related to thermal injury from radiofrequency devices[6,7] or the use of indwelling intraarticular pain catheters.[8,9] Other iatrogenic causes of shoulder arthrosis can be mechanical in nature from implants,[10,11] or after capsulorrhaphy due to altered joint mechanics.[12]

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There have been various proposed treatments for glenohumeral arthritis but have shown mixed results.[13,14] Nonarthroplasty methods, such as arthroscopy with debridement and capsular release[15-17] and autologous chondrocyte implantation,[18-20] have shown some benefits in the short term, but there appears to be progression of osteoarthritis in most cases and poorer results with higher initial severity of arthritis. Prosthetic arthroplasty including humeral hemiarthroplasty and total shoulder arthroplasty has shown more predictable pain relief.[21] There has been some debate as to the appropriate management of the glenoid. Sperling *et al*.[22] reported progressive glenoid erosion in patients under 50 who underwent hemiarthroplasty as opposed to total shoulder arthroplasty. There was also a higher rate of revision in the hemiarthroplasty group.

Potential complications with erosion of the unresurfaced glenoid or loosening of a polyethylene component have driven the search for alternatives. Resurfacing of the glenoid with biologic interposition of soft tissue (lateral meniscus, Achilles, xenograft, and human dermal tissue) and isolated reaming of the glenoid to recreate concavity have been described as potential treatment options in this increasingly complex issue.[23,24] However, mixed clinical results have been reported with failure rates anywhere from 10% to 90%.[25,26] One factor which may explain this disparity in results may be the type of graft, preparation of the graft and the effect on glenohumeral biomechanics, or patient selection. Gilmer *et al*.[27] reported the results of "Ream-and-Run" arthroplasty for 176 consecutive cases. They found that the best results were in patients over 60 years of age, with good preoperative shoulder function, and no prior shoulder surgery.

The goal of this study was to determine the change in glenohumeral contact pressures in curved versus flat biologic interposition arthroplasty, as well as glenoid reaming in a glenoid arthritis model. We hypothesized that biologic interposition with meniscal allograft will lead to the best normalization of glenoid contact pressure throughout the glenohumeral range of motion.

Materials and Methods

Specimen preparation

Eight fresh-frozen human cadaveric shoulders were used for testing (7 male, 1 female, average age 51 years, range: 45–58 years). The shoulders were dissected free of all soft tissues except the glenoid labrum to expose the glenohumeral joint, leaving the scapula intact. The scapula was cut 3–4 cm medial and parallel to the joint line. The cut end of the scapula was then potted in dental acrylic (Isocryl, Lang Dental, Wheeling, IL.). The humeral shaft was cut transversely and potted in acrylic cement within a polyvinyl chloride pipe. Care was taken to frequently moisten the cartilaginous and labral surfaces with normal saline.

The humeral shaft was placed into a custom jig and mounted on an MTS electro-mechanical testing machine (Insight 5, MTS Systems Corp, Eden Prairie, MN), which served as the compressive loading device. The angle on the jig was adjustable to give anywhere from 0° to 90° of abduction in relation to the glenoid and then fixed for testing. The glenoid was mounted onto the MTS parallel to the floor [Figure 1a].

The exposed length of humeral shaft outside the polymethyl methacrylate (PMMA) potting was 5 cm to minimize bending moments and to clear the mounting jig during abduction. The rotation of the humeral shaft was standardized by placing the lesser tuberosity directly anterior [Figure 1b].[28]

A dynamic pressure-sensitive pad (I-Scan 5051, Tekscan Inc., Boston, MA), which is 0.1 mm thick, contains a 56 mm × 56 mm matrix, and has a density of 62 sensels per cm^2 was precalibrated on the MTS according to manufacturer's recommendations. The calibration consisted of a two-point method, which included 20% and 80% of the maximum test load (440N) applied across the glenohumeral joint. During testing, the pressure sensor served to measure the glenohumeral articular contact pressures. The pressure pad was placed between the humerus and glenoid and marked at the 12, 3, 6, and 9 o'clock positions so that the pad could be placed in identical position during each sequential trial.

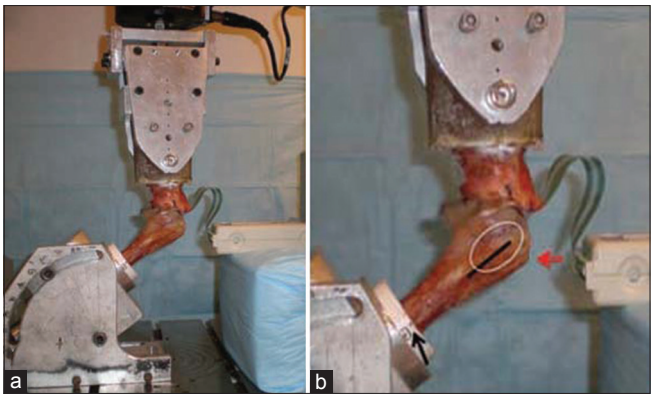

Figure 1: (a) Global view of the relationship of the humerus, glenoid, and mounting brackets in the MTS device. (b) A close up view of the orientation of the humerus to the MTS device. The black line bisects the lesser tuberosity (outlined by the white ellipse) and aligns with the center of the MTS clamp (highlighted by the black arrow). Red arrow denotes the greater tuberosity

The MTS machine was used to apply a compressive load of 440N, and the glenohumeral contact area, contact pressure, and peak force were determined with the Tekscan sensor [Figure 2]. A load of 440N was chosen as an approximate load across the glenohumeral joint during activities of daily living.[29,30] The testing protocol involved sequentially testing several conditions for all specimens at 30° then 60° of humeral abduction (based on previous work[29-31]) including: (1) Intact glenoid, (2) glenoid with cartilage removed (arthritis model), (3) placement of interpositional lateral meniscus allograft, (4) placement of interpositional Achilles allograft, and (5) arthritis model with concentrically reamed glenoid. The sensor was marked at the 12, 3, 6, and 9 o'clock positions with ink. Corresponding marks were made on the outside of the glenoid rim to ensure reproducibility of sensor placement. The sensor was placed between the humeral head and the glenoid and each testing condition was tested 3 times and the average value was taken. Previous work has shown a decrease in sensor sensitivity after 95 tests to 440N. Sensors were used for a maximum of two specimens.[31] Between tests, the cartilage surfaces were dipped in saline and it was allowed to rest for at least 5 min before applying the repeated load.

After initial contact pressure testing in the intact state, the glenohumeral arthritis model was generated. All the cartilage from the glenoid surface was removed down to subchondral bone and smoothed down to a flat surface using a curette. The labrum was removed sharply from the rim of the glenoid. After the creation and testing of the flat arthritic glenoid model, the glenoid was prepared for the use of a lateral meniscal allograft and Achilles allograft as soft tissue interposition arthroplasty options. Bone tunnels were created on the glenoid neck at the 2, 4, 8, and 10 o'clock positions to maintain the position of the graft. The two horns of a lateral meniscus were sutured together to form a ring, secured with the sutured end at 12 o'clock on the glenoid face, and positioned centrally along the face of the glenoid[32] [Figure 3]. After testing the lateral meniscal interposition, the meniscus was removed and an Achilles allograft was placed on the glenoid. The Achilles was prepared as a flat interposition graft, sized to the glenoid, and harvested from the thin, fan shaped proximal portion of the allograft. The grafts harvested were 2 mm thick and neither doubled nor folded. The Achilles allograft was sutured in place using the same bone tunnels to maintain tension and prevent movement during testing.

Glenoid reaming

Next, the Achilles was removed and the glenoid was reamed with a concentric glenoid reamer according to the protocol of Matsen *et al*.[23] The humeral head was measured using standard sizing guides (Tornier N.V., The Netherlands.). A 6 mm pilot hole was drilled into the glenoid slightly above the superior-inferior midpoint of the articular surface. An appropriate glenoid reamer (DePuy "Ream and Run" Glenoid reamers, Warsaw, IN), 2 mm greater than the humeral head diameter, was selected to recreate glenoid concentricity. The pilot hole was used to center the reamer on the face of the glenoid. The goal of reaming was to ensure a single spherical glenoid cavity devoid of any residual articular cartilage and to create a concave surface representative of the "ream and run" technique. Of note, the reamers used did leave a raised rim of bone around the pilot hole, which was smoothed down with a burr to prevent artifact loading on the Tekscan maps.

Statistical analysis

Data obtained from the pressure maps were then analyzed with descriptive statistics (SAS), and repeated measures ANOVA calculation was performed to compare the mean values for contact area, contact pressure and peak force across testing conditions. Three trials were performed for each testing state and the mean of the three values was

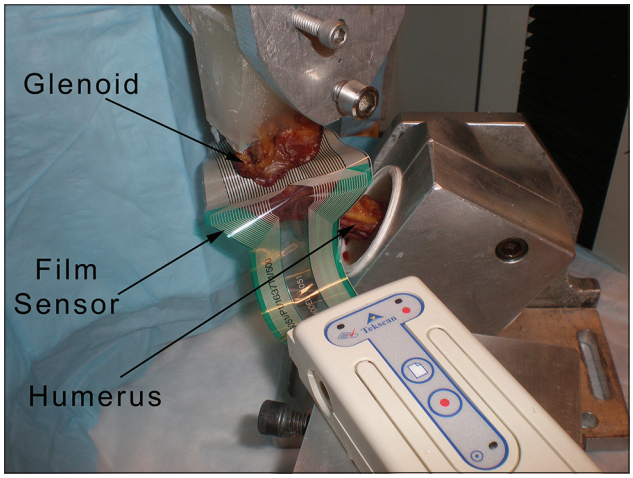

Figure 2: Testing apparatus showing the relationship of the glenoid, sensor, and humerus

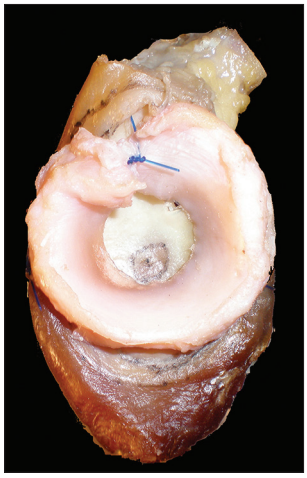

Figure 3: Representative example of a testing sample with lateral meniscus sutured to glenoid

used for the statistical analysis. For comparison between the testing conditions, *post hoc* comparisons were made, adjusted for multiple comparisons, following a significant global test. In addition, each condition was compared with a regression analysis followed by ANOVA and *post hoc* testing. Statistical significance was set at $P < 0.05$.

Results

Contact pressure, contact area, peak pressure, and peak force are depicted in Table 1. Representative pressure maps for each of the 5 testing states are shown in Figure 4. Areas of lower pressure are represented by blue colors and areas of high pressure are represented by red colors. The change in pressure distribution is evident for each of the different testing states. Results were measured in the intact state at 30° and 60° of humeral abduction.

Contact pressure at 30°

In the intact state, contact pressure was measured at 4.85 kg/cm^2 (3.9–6.3 kg/cm^2, standard deviation [SD]: 0.78). The next phase of testing was performed after preparing the glenoid surface into the arthritic model. The labrum and cartilage were removed down to the subchondral bone using a combination of sharp dissection and curettes. Care was taken to make sure there was a smooth glenoid surface that would not artificially affect the Tekscan measurements [Table 1].

Arthritis contact pressure was measured at 7.08 kg/cm^2 (5.1–9.4 kg/cm^2, SD: 1.47).

The next phase of testing was performed with an Achilles allograft. All glenoid specimens were tested with an Achilles allograft that was an average of 2 mm thick. A 4 mm thick graft was used in 4 specimens as a separate testing condition. The results are included, but the sample size is too small for statistical significance. Achilles contact pressure was measured at 4.66 kg/cm^2 (3.6–5.5 kg/cm^2, SD: 0.59). For the thick Achilles, contact pressure was 4.08 kg/cm^2 (3.6–5 kg/cm^2, SD: 0.57). The Achilles was removed and a lateral meniscus was sutured to the glenoid surface using bone tunnels. Contact pressure for the meniscus was 4.13 kg/cm^2 (3.3–4.5 kg/cm^2, SD: 0.37). The meniscus was removed and the glenoid was reamed in the method described above. Contact pressure was similar to the

Table 1: Measurements for various testing states

	Contact pressure (kg/cm^2)		Contact area (mm^2)		Peak pressure (kg/cm^2)		Peak force (N)	
	30 Deg.	60 Deg.	30 Deg.	60 Deg.	30 Deg.	60 Deg.	30 Deg.	60 Deg.
Intact	4.85	4.76	525	545	14.24	13.99	9.01	8.83
Arthritis	7.08	7.38	279	279	18.61	19.24	11.78	12.18
Achilles	4.66	4.55	525	537	17.46	17.21	11.06	10.90
Meniscus	4.13	4.23	727	709	12.98	13.19	8.23	8.35
Reamed	6.09	6.33	372	367	18.39	18.23	11.64	11.54

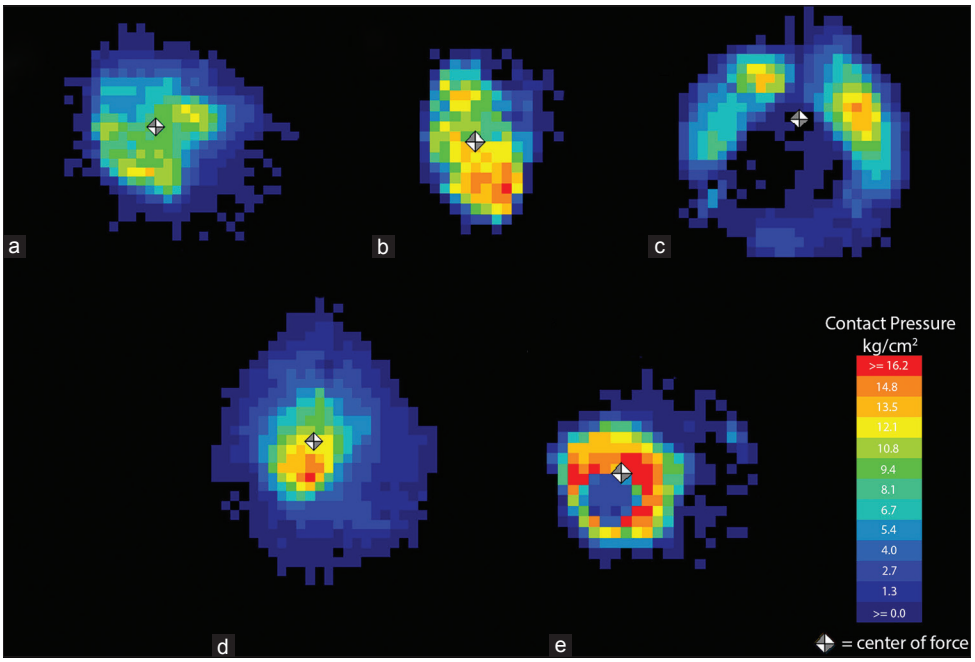

Figure 4: Contact pressure maps of (a) intact glenoid, (b) arthritic model; (c) lateral meniscus allograft; (d) achilles allograft; (e) reamed glenoid

arthritic state and measured 6.09 kg/cm^2 (4.8–6.8 kg/cm^2, SD: 0.67). All subsequent conditions were tested in a similar fashion.

Contact pressure at 60°

At 60° of humeral abduction, contact pressure was measured at 4.76 kg/cm^2 (4.1–5.3 kg/cm^2, SD: 0.46) for the normal state. Arthritic contact pressure increased to 7.38 kg/cm^2 (4.5–11.2 kg/cm^2, SD: 2.01). Achilles contact pressure was measured at 4.55 kg/cm^2 (3.8–5.5 kg/cm^2, SD: 0.51). Thick Achilles contact pressure was 4.05 kg/cm^2 (3.5–5 kg/cm^2, SD: 0.58). After removal of the Achilles and placement of the meniscus, contact pressure was measured at 4.23 kg/cm^2 (3.6–4.6 kg/cm^2, SD: 0.34). Reaming produced similar results to the 30° group with contact pressure measured at 6.33 kg/cm^2 (4.6–8.2 kg/cm^2, SD: 1.12).

Contact area at 30° and 60°

Contact area in the intact state at 30° measured 524.75 mm^2 (347–695 mm^2, SD: 122.4). At 60°, the contact area was measured at 544.88 mm^2 (435–700 mm^2, SD: 93.22). After preparing the glenoid, contact area in the arthritis state at 30° measured 279.38 mm^2 (155–508 mm^2, SD: 102.42) and 278.88 mm^2 (142–461 mm^2, SD: 102.69) at 60°. Contact area after placement of the thin Achilles at 30° measured 524.88 mm^2 (374–700 mm^2, SD: 94.73). At 60°, the contact area was measured at 537 mm^2 (405–661 mm^2, SD: 72.19). When a thicker Achilles was trialed, it increased to 742.75 mm^2 (545–853 mm^2, SD: 123.74) and 717.25 mm^2 (556–850 mm^2, SD: 114.12) at 30° and 60°, respectively. Contact area with the lateral meniscus at 30° measured 727 mm^2 (610–918 mm^2, SD: 108.09) and 709.13 mm^2 (561–856 mm^2, SD: 107.28) at 60°. Contact area in the reamed glenoid at 30° measured 372 mm^2 (284–531 mm^2, SD: 72.6). At 60°, the contact area was measured at 367.38 mm^2 (252–550 mm^2, SD: 84.06).

Peak force at 30° and 60°

Peak force in the intact state at 30° measured 9.01N (7.7N–11.3N, SD: 1.12). At 60° of humeral abduction, peak force measured 8.83N (7.3N–11.1N, SD: 1.28). In the arthritis state at 30°, it increased to 11.78N (10N–13.4N, SD: 1.18) and 12.18N (10.8N–13.4N, SD: 0.94) at 60°. Placing the thin Achilles improved the peak force to 11.06N (9.5N–13.4N, SD: 1.19) at 30° and 10.9N (8.9N–12.6N, SD: 1.14) at 60°. Using the thick Achilles allografts, it was further decreased to 5.8N (4.5N–6.8N, SD: 0.91) and 6.43N (5.2N–7.2N, SD: 0.74) at 30° and 60°, respectively. The lateral meniscus demonstrated 8.23N (6.6N–9.7N, SD: 1.04) at 30° and 8.35N (6.9N–9.8N, SD: 0.92) at 60°. Peak force after reaming increased to 11.64N (9.7N–13.2N, SD: 1.15) at 30° and 11.54N (10N–13.2N, SD: 0.96) at 60°.

Discussion

When comparing the different glenoid configurations to each other, certain trends were evident [Figure 4]. The arthritic glenoid was statistically different to the normal glenoid group resulting in significant increase in peak force and contact pressure, with a decrease in the contact area. This was observed for both the 30° and 60° groups. There was also point saturation of the sensor during several trials in the arthritis model. The maximum saturation level was used for these points in our calculations. This change in characteristics is likely due to the removal of the glenoid labrum and glenoid cartilage. The resulting increase in contact pressure and decrease in contact area would be an expected result in the setting of glenohumeral arthritis.

Both the lateral meniscus and the Achilles group resulted in significant improvement in comparison to the arthritis model and showed no statistical difference when compared to the normal intact group. The increase in contact area and decrease in contact pressure with the lateral meniscus is corroborated by the work of Creighton *et al*., who used a similar model to study the effects of lateral meniscal allograft of glenohumeral joint loads.[30] In the limited sample size using the thick Achilles, there was a trend toward further improved contact pressures over the thin Achilles group. In contrast, the concentric reaming group resulted in no improvement in contact area or pressure when compared to the arthritis model.

Glenohumeral contact pressure is significantly less with biologic interposition of lateral meniscal allograft or Achilles allograft at time zero compared to an arthritic state. The biologic interposition of lateral meniscal allograft restored mean contact pressure for all specimens and all conditions to a normalized mean of 11% less than intact state ($P < 0.05$), i.e. there is less contact pressure with interposition that with the intact normal state. This is compared to 4% less than intact for the Achilles allograft ($P < 0.05$) [Figure 5]. Contact area also significantly increased in the lateral meniscus group, but was similar to the intact state for the Achilles. This is presumed to be secondary to the curved meniscus allograft, being more congruent with the humeral head as opposed to the Achilles allograft. The arthritis model caused a loss of concavity and an overall flatter contour to the glenoid. This led to more point loads on the Tekscan map with a decrease in the contact area. These areas of point loading allowed more of the force from the testing apparatus to be transmitted across the joint over a smaller contact area. These saturations were at "high points" of the glenoid that may represent remaining cartilage or a locally flatter or convex contour.

The results of the study suggest that both Achilles and lateral meniscal allograft result in significant improvement in contact force and area of glenohumeral loading, though lateral meniscal allograft results in better improvement when compared to Achilles graft. Specifically looking at the contact pressure mapping, [Figure 4] use of the curved allograft (meniscus) in the arthritic glenoid resulted in decreased contact pressure in the central area of the glenoid compared to the flat allograft (Achilles).

The reamed glenoid showed no statistical difference for any outcome measurement in comparison to the arthritis model. We did note an area of high pressure and point loading of the sensor at the periphery of the pilot hole. The glenoid reamer would leave a small ridge at the edge of the pilot hole [Figures 6 and 7]. During testing, we attempted to smooth this defect to the surrounding bone using a high speed burr. In addition, the pilot hole is 6 mm in diameter, which translates to a 28 mm loss in the contact area. Grossly, the reaming appeared to restore some concavity and concentricity to the glenoid.

Glenohumeral contact pressure is optimally restored with biologic interposition of lateral meniscal allograft or Achilles allograft. Our findings suggest that concentric reaming of the glenoid did not play a significant role in evenly distributing glenohumeral contact pressure compared to the unreamed glenoid; however, as discussed in the limitations, may be reflective of the arthritic model studied.

There are some limitations in this biomechanical study as to how it would translate to a clinical setting. The surgeon-induced, *in vitro* arthritis model we used does not replicate the arthritic state *in vivo*; however, it is the most consistent cadaveric model. Glenohumeral arthritis is variable and can present with biconcave glenoid wear and a retroverted glenoid. The labral tissue can be calcified, hypertrophic, or even possibly absent. The "Ream and Run" technique preserves the labrum, which would most likely give more favorable contact pressures to that model. This technique may also be most beneficial in the eccentrically worn glenoid, which was not studied in the current model. The arthritic model in this study assumed was made as a "worst case scenario" with all cartilage and labrum removed. There is a possibility that a biconcave glenoid may have a less favorable initial contact pressure as well. In addition, the shoulder is a dynamic joint. This study tests only compressive forces across the joint and does not take into account cyclic and shear loading. When these interventions are undertaken *in vivo*, the behavior of the joint with activities of daily living should be considered. It is further noted that this is a time equals zero *in vitro* assessment and we cannot account for any fibrocartilage regrowth, which may occur in the clinical setting and further influence glenohumeral biomechanics. Finally, despite the repeat measures study design, the small sample size should be noted.

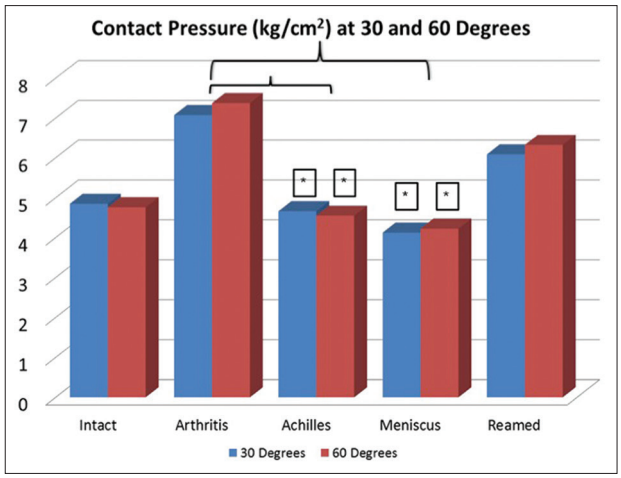

Figure 5: Bar diagram showing contact pressure through all of the testing states. *Denotes statistically significant differences ($P < 0.05$)

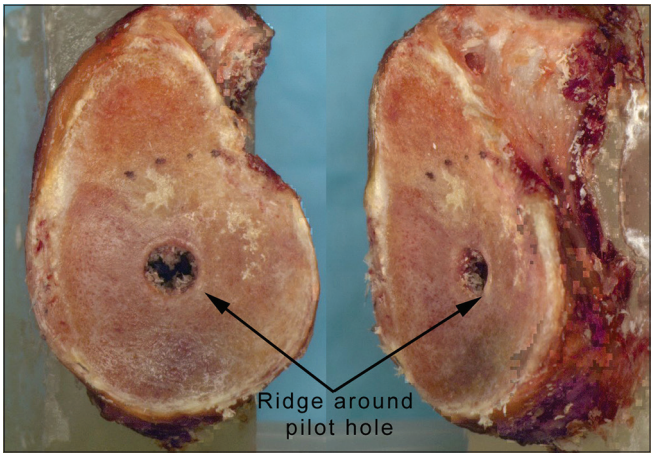

Figure 6: Reamed glenoid en face and oblique view showing ridge around 6 mm pilot hole

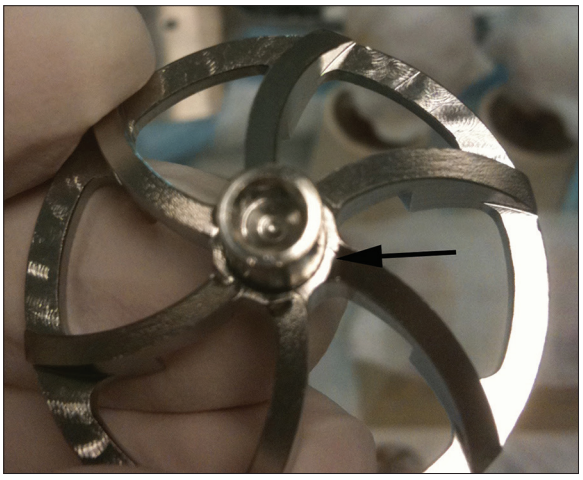

Figure 7: Glenoid reamer showing space between cutting flutes and centering post

The 60° condition was always tested second in our protocol. In addition, the meniscus was tested after the Achilles. This may introduce a component of soft tissue creep into the experimental conditions. In addition, these are time zero biomechanical measurements, which do not account for the biological activity of the glenoid surface itself. This would potentially play a role in how the biological interposition would heal to the surface of the glenoid and how the glenoid surface would adapt after being reamed. The other consideration is the meniscus or a thicker graft acting as a "bumper" to improve the stability of the glenohumeral joint, which was not measured in this study. The reaming technique used for the glenoid did produce some high spots at the periphery of the pilot hole, which were evident with the Tekscan measurements. Grossly, the ream and run technique appeared to increase glenoid concavity and concentricity, and there was a trend toward that in our data as well. Using a different technique or reamer for glenoid reaming that neither needs such a large pilot hole nor creates a ridge around the pilot hole may produce more consistent Tekscan results.

Conclusion

The findings in this study suggest the use of concave allograft for biologic interpositional arthroplasty, which is a potential treatment option in patients with glenoid wear. Use of a meniscal graft leads to normalization of glenohumeral contact forces through recreation of glenohumeral concentricity resulting in an increase in contact area and decrease in contact pressure. In addition, it may be possible to achieve similar biomechanical results with an Achilles allograft. Our limited testing with a thick Achilles allograft may suggest that a thicker graft can better normalize glenohumeral contact pressures. We were unable to show a significant difference between arthritis and the ream and run model. This may be because of the type of arthritis model used, specifically removing all cartilage and labrum. Future studies with a different model of arthritis and an intact labrum will be necessary to make the distinction between the arthritis model and the ream and run technique.

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Nil.

Conflicts of interest
There are no conflict of interest.

References

1. Chong PY, Srikumaran U, Kuye IO, Warner JJ. Glenohumeral arthritis in the young patient. J Shoulder Elbow Surg 2011;20 2 Suppl:S30-40.
2. Greis PE, Legrand A, Burks RT. Bilateral shoulder chondrolysis following arthroscopy. A report of two cases. J Bone Joint Surg Am 2008;90:1338-44.
3. Hansen BP, Beck CL, Beck EP, Townsley RW. Postarthroscopic glenohumeral chondrolysis. Am J Sports Med 2007;35:1628-34.
4. Ryu JH, Savoie FH 3rd. Postarthroscopic glenohumeral chondrolysis of the shoulder. Sports Med Arthrosc 2010;18:181-7.
5. Yeh PC, Kharrazi FD. Postarthroscopic glenohumeral chondrolysis. J Am Acad Orthop Surg 2012;20:102-12.
6. Good CR, Shindle MK, Kelly BT, Wanich T, Warren RF. Glenohumeral chondrolysis after shoulder arthroscopy with thermal capsulorrhaphy. Arthroscopy 2007;23:797.e1-5.
7. Ciccone WJ 2nd, Weinstein DM, Elias JJ. Glenohumeral chondrolysis following thermal capsulorrhaphy. Orthopedics 2007;30:158-60.
8. Bailie DS, Ellenbecker TS. Severe chondrolysis after shoulder arthroscopy: A case series. J Shoulder Elbow Surg 2009;18:742-7.
9. Chu CR, Izzo NJ, Coyle CH, Papas NE, Logar A. The *in vitro* effects of bupivacaine on articular chondrocytes. J Bone Joint Surg Br 2008;90:814-20.
10. O'Driscoll SW, Evans DC. Long term results of staple capsulorrhaphy for anterior instability of the shoulder. J Bone Joint Surg Am 1993;75:249-58.
11. Zuckerman JD, Matsen FA 3rd. Complications about the glenohumeral joint related to the use of screws and staples. J Bone Joint Surg Am 1984;66:175-80.
12. Parsons IM 4th, Buoncristiani AM, Donion S, Campbell B, Smith KL, Matsen FA 3rd. The effect of total shoulder arthroplasty on self-assessed deficits in shoulder function in patients with capsulorrhaphy arthropathy. J Shoulder Elbow Surg 2007;16 3 Suppl: S19-26.
13. Burkhead WZ Jr, Krishnan SG, Lin KC. Biologic resurfacing of the arthritic glenohumeral joint: Historical review and current applications. J Shoulder Elbow Surg 2007;16 5 Suppl: S248-53.
14. Burkhead WZ Jr, Hutton KS. Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. J Shoulder Elbow Surg 1995;4:263-70.
15. Richards DP, Burkhart SS. Arthroscopic debridement and capsular release for glenohumeral osteoarthritis. Arthroscopy 2007;23:1019-22.
16. Kerr BJ, McCarty EC. Outcome of arthroscopic débridement is worse for patients with glenohumeral arthritis of both sides of the joint. Clin Orthop Relat Res 2008;466:634-8.
17. Cameron BD, Galatz LM, Ramsey ML, Williams GR, Iannotti JP. Non-prosthetic management of grade IV osteochondral lesions of the glenohumeral joint. J Shoulder Elbow Surg 2002;11:25-32.
18. Scheibel M, Bartl C, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of full-thickness articular cartilage defects of the shoulder. J Bone Joint Surg Br 2004;86:991-7.
19. Romeo AA, Cole BJ, Mazzocca AD, Fox JA, Freeman KB, Joy E. Autologous chondrocyte repair of an articular defect in the humeral head. Arthroscopy 2002;18:925-9.
20. Kircher J, Patzer T, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of full-thickness cartilage defects of the shoulder: Results at nine years. J Bone Joint Surg Br 2009;91:499-503.
21. Gartsman GM, Roddey TS, Hammerman SM. Shoulder arthroplasty with or without resurfacing of the glenoid in patients who have osteoarthritis. J Bone Joint Surg Am 2000;82:26-34.

22. Sperling JW, Cofield RH, Rowland CM. Minimum fifteen-year followup of Neer hemiarthroplasty and total shoulder arthroplasty in patients aged fifty years or younger. J Shoulder Elbow Surg 2004;13:604-13.
23. Matsen FA 3rd, Bicknell RT, Lippitt SB. Shoulder arthroplasty: The socket perspective. J Shoulder Elbow Surg 2007;16 5 Suppl: S241-7.
24. Ball CM, Galatz LM, Yamaguchi K. Meniscal allograft interposition arthroplasty for the arthritic shoulder: Description of a new surgical technique. Tech Shoulder Elbow Surg 2001;2:247-54.
25. Krishnan SG, Nowinski RJ, Harrison D, Burkhead WZ. Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis. Two to fifteen-year outcomes. J Bone Joint Surg Am 2007;89:727-34.
26. Krishnan SG, Reineck JR, Nowinski RJ, Harrison D, Burkhead WZ. Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis. Surgical technique. J Bone Joint Surg Am 2008;90 Suppl 2(Pt 1):9-19.
27. Gilmer BB, Comstock BA, Jette JL, Warme WJ, Jackins SE, Matsen FA. The prognosis for improvement in comfort and function after the ream-and-run arthroplasty for glenohumeral arthritis: An analysis of 176 consecutive cases. J Bone Joint Surg Am 2012;94:e102.
28. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65.
29. Greis PE, Scuderi MG, Mohr A, Bachus KN, Burks RT. Glenohumeral articular contact areas and pressures following labral and osseous injury to the anteroinferior quadrant of the glenoid. J Shoulder Elbow Surg 2002;11:442-51.
30. Creighton RA, Cole BJ, Nicholson GP, Romeo AA, Lorenz EP. Effect of lateral meniscus allograft on shoulder articular contact areas and pressures. J Shoulder Elbow Surg 2007;16:367-72.
31. Ghodadra N, Gupta A, Romeo AA, Bach BR Jr, Verma N, Shewman E, *et al.* Normalization of glenohumeral articular contact pressures after Latarjet or iliac crest bone-grafting. J Bone Joint Surg Am 2010;92:1478-89.
32. Nicholson GP, Goldstein JL, Romeo AA, Cole BJ, Hayden JK, Twigg SL, *et al.* Lateral meniscus allograft biologic glenoid arthroplasty in total shoulder arthroplasty for young shoulders with degenerative joint disease. J Shoulder Elbow Surg 2007;16 5 Suppl:S261-6.