Factors affecting fixation of the glenoid component of a reverse total shoulder prosthesis

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The semiconstrained design of the reverse arthroplasty allows loads from the humerus to challenge the fixation of the glenoid component to the scapula. We examined some of the factors affecting the quality of glenoid screw fixation, including the density of the material into which the screws are placed, the purchase of individual screws, and the direction of loading in relation to screw placement. Loads were applied by the humeral component to glenoid components with different conditions of fixation. The load to failure for each set of conditions was measured and compared statistically. Load to failure was less when the glenoid component was fixed to material of lesser density. Each screw contributed to the quality of fixation; the screw nearest the point of load application made the largest contribution. Load to failure was less when the load was colinear with a line through the nonlocking holes in the base plate compared to colinear with a line through the locking holes. In performing a reverse total shoulder, surgeons should emphasize secure intraosseous placement of the fixation screws in the best quality bone available. The placement of the inferior screw appears to be the most critical. (J Shoulder Elbow Surg 2008;17:323-327.)

Reverse total shoulder prostheses are now often used when the shoulder is seriously compromised by various combinations of irreparable cuff deficiency, arthropathy, failed prior reconstructions, severe bone loss or deformity, and instability.5,8-10,13,14,16-19,27,28,30,31 With these semiconstrained prostheses, loads applied to the humerus are transferred directly to the fixation of the glenoid component. As a result, failure of glenoid component fixation (Figure 1) is one of the most common complications of the reverse total shoulder.4,9,11,14,18,19,27,30 While previous reports have concerned the anatomy of scapular bone and its relevance to glenoid component fixation,2,3,7,12,20-24,26,29 few have considered optimization of screw fixation of the glenoid component.1,19 A review of articles regarding reverse total shoulder prostheses, especially those showing glenoid component fixation failure, reveals a wide variability in the placement of glenoid fixation screws in the limited bone available in the scapula.4,9,11,14,18,19,27,30 No study has been published regarding the effect of screw placement on the load to failure of glenoid fixation of the most commonly used type of reverse total shoulder arthroplasty, one with a glenoid hemisphere applied to the surface of glenoid bone using 4 screws, the superior and inferior of which are fixed-angle locking screws.

To understand better factors affecting the security of screw fixation of the glenoid component, we have tested the hypotheses that (1) the load to failure of fixation of the glenoid component is significantly affected by the density of the material into which the fixation screws are placed; (2) the load to failure of glenoid component fixation is significantly reduced if any of the 4 screws fails to achieve purchase in the material; and (3) the fixation is strongest when the 2 locking screws are in line with the applied load.

MATERIAL AND METHODS

We tested a commonly used and commercially available reverse total shoulder prosthesis, in which a glenoid hemisphere is applied directly to the glenoid bone with 4 equally spaced screws (Delta, DePuy, Warsaw, IN) (Figure 2). Two of the fixation screws, opposite each other, lock into the base plate of the prosthesis, and 2 of the screws, also opposite each other, are nonlocking. We selected the 36 mm glenosphere, the standard metaglene, a standard humeral component with a 3 mm polyethylene cup, and 36 mm long locking and nonlocking screws. Consistent with previous publications in The Journal,19 such as Harman et al, we used commercially prepared blocks of rigid, unicellular polyurethane foams (Last-A-Foam FR-3700, General Plastics, Tacoma, WA) to ensure uniformity of the material into which the fixation screws of the metaglene were inserted. In contrast with the study of Harman et al, which used foam resembling cortical bone of “excellent” quality,19...
we used foam with densities within the range reported for normal human, cancellous bone (medium density = 0.24 g/cm\(^3\)) and osteopenic cancellous bone (low density = 0.16 g/cm\(^3\)).\(^6\) A new block of foam was used for each test.

**Testing protocol**

The security of each glenoid component fixation was challenged by loads applied through a reverse total shoulder humeral component potted with the stem in 50° of abduction relative to the glenoid, so that the inferior lip of the humeral cup would not contact the material to which the glenoid component was fixed (Figure 2). Loading was either in a direction colinear with a line connecting the locking holes in the base plate (colinear locking) or colinear with a line connecting the 2 nonlocking holes (colinear nonlocking). Because failure of glenoid component fixation can be catastrophic, as is evident from Figure 1 and articles by Werner et al\(^4\) and Bohsali et al,\(^30\) we chose to study load to failure rather than studying component motion on cyclical loading, as did Harman et al.\(^19\) For each screw configuration, the glenoid was preloaded to 200 N, and then the humeral component was advanced at 30 mm/s using a materials testing machine (MTS Systems, Eden Prairie, MN). The 30 mm/s displacement rate was selected after preliminary trials indicated that this rate was sufficiently slow to allow for recording of load and sufficiently fast to avoid apparent plastic deformation of the foam. The failure load was recorded by the MTS and the mode of failure documented using a video recorder.

To test the 1st hypothesis, we compared the colinear locking load to failure for glenoid prostheses fixed to medium and low-density material. To test the 2nd hypothesis, we compared the colinear locking load to failure in low-density material; all screws were inserted to the load to failure when each 1 of the 4 screws was omitted. To test the 3rd hypothesis, we compared the colinear locking load to failure to the colinear nonlocking load to failure in low-density material. Five separate trials were carried out for each configuration and the loads to failure averaged for each screw configuration. Each specimen was tested to failure. No specimen was tested more than once.

**Statistical analysis**

Testing of each hypothesis required comparison of data of 2 groups of independent tests. There were no repeated measures. Significance was defined as \(P < .05\), using the unpaired, two-tailed \(t\) test assuming unequal variance.

**RESULTS**

**Failure mode**

In each case, the failure was sudden and complete with abrupt separation of the glenoid component from the material to which it was fixed. All failures occurred by pullout of the screw closest to the point of load application. There were no cases of screw breakage.

**Effect of material density**

Colinear locking load to failure for glenoid component fixation to material of a low density, resembling osteoporotic cancellous bone, was 2153 ± 115 N, 23% less than the value for fixation to material of a medium density resembling normal cancellous bone, 2811 ± 75 N (\(P < .005\)).

**Effect of lack of individual screw purchase**

For low-density material, the colinear locking load to failure with 2 locking and 2 nonlocking screws was 2153 ± 115 N. When any one of the screws was omitted, the load to failure was significantly reduced. When the locking screw opposite the point of load application was absent, the load to failure was reduced 16% to 1817 ± 41 N (\(P < .01\)). When either one of the nonlocking screws was absent, the load to failure was reduced 28% to 1554 ± 103 N (\(P < .0005\)). When the locking screw nearest the point of load application was absent, the load to failure was reduced 35% to 1391 ± 75 N (\(P < .0001\)).

**Effect of load direction in relation to the locking and nonlocking screws**

For low-density material, the colinear locking load to failure with 2 locking and 2 nonlocking screws was 2153 ± 115 N. For low-density material, the colinear nonlocking load to failure was 1832 ± 35 N, 15% less (\(P < .01\)).
DISCUSSION

The unique feature of reverse total shoulder arthroplasties is that they substitute intrinsic, prosthetic, and glenohumeral stability when the normal stability from the rotator cuff, capsule, coracoacromial arch, and glenoid concavity is lacking. This stability is achieved by a hemispherical glenosphere secured to a metaglene, which is fixed to the glenoid by screws and a peg designed for bone ingrowth. The articular concavity is on the humeral side and oriented so that the force applied by the deltoid compresses the convexity of the glenosphere into the concavity of the humeral component. The design does not allow for translation but, rather, only rotation around the center of rotation of the glenosphere. The value of this intrinsic stability is that it provides a fixed center of rotation, about which the deltoid muscle can move the shoulder. The risk of this intrinsic stability is that loads applied to the humerus are transferred directly to the fixation of the glenoid component to the glenoid bone. While the peg of glenoid prosthesis has a hydroxypatite coating to encourage biological fixation, the importance of bone ingrowth into this peg is uncertain. In any event, initial fixation depends solely on mechanical fitting and screw fixation. In commonly used reverse total shoulder arthroplasties, the metaglene has 4 holes for screw fixation. The superior and inferior screws are intended to be locking screws at a fixed angle of 16° with the central peg of the metaglene.

The normal scapula is quite narrow at its axillary border and body, and is somewhat curved so that the fixed angle inferior and superior screws can miss secure engagement in bone, unless precise alignment is achieved at surgery. When a locking screw is used, it tightens securely in the metaglene, whether or not it is in bone, so that the surgeon may be unaware that the bone has not been fully engaged by the screw. When the scapular anatomy is distorted, as is often the case in rotator cuff tear arthropathy or in revision shoulder arthroplasty where reverse total shoulder arthroplasties are often used, achieving secure purchase with each screw may be even more difficult. Inferior scapular bone resorption, or notching, associated with the reverse total shoulder prosthesis may jeopardize the security of the inferior screw. Lastly, intraoperative or postoperative plain radiographs may not reveal the true screw positions in the limited bone of the scapula. These uncertainties prompted us to explore the importance in glenoid fixation of the quality of bone into which the screws are inserted, of achieving purchase with each of the 4 screws, and of the direction of loading with respect to the locking and non-locking screws. The long-term importance of the quality of screw fixation into scapular bone was recently emphasized by Guery et al and Bohsali et al, who recognized the problem of delayed glenoid loosening of the reverse total shoulder arthroplasty.

Our study indicates that the surgeon should strive to place each of the glenoid fixation screws in the best quality bone possible. Examples of insertion of glenoid fixation screws in areas of less dense scapular bone can be seen in the reports by Werner et al and Nyffeler et al. The most important screw is the
bone can result in the inferior screw missing the axillary border of the scapula. 

Lastly, it has been recommended that the glenoid component be positioned as inferiorly as possible. This inferior positioning increases the risk that the inferior screw will pass below the axillary border of the scapula (Figure 3). The implication of these observations is that surgical exposure of the axillary border may provide the best assurance of optimal screw placement. This requires careful protection of the axillary nerve and possible dissection of the origin of the long head of the triceps.

This study has several limitations. First, our investigative method did not use human scapular bone. The use of individual cadaveric scapulas would have introduced substantial individual variability in bony anatomy and quality, as emphasized by previous investigators. Such variability among specimens may have obscured the effect of screw configuration. Instead, we followed the precedent of previous literature, using simulated bone material to examine the effectiveness of locking and nonlocking screw fixation.

Second, this investigation does not attempt to simulate the wide variety of clinical loading situations in which a reverse total shoulder prosthesis might be used. Third, this study did not include every possible screw configuration or a wide range of loading protocols. Lastly, other designs of reverse shoulder prostheses with different screw configurations were not tested.

In conclusion, this study demonstrates that screw position and purchase are important factors in the quality of fixation obtained with the glenoid component of the reverse total shoulder prosthesis. The most important appears to be the inferior screw, as this screw is positioned to resist the tensile loads applied to it by humeral loading applied to the inferior aspect of the glenoid prosthesis. The strongest configuration tested had locking screws located both nearest and opposite the point of humeral loading. Optimizing screw fixation is of even greater importance when screws are inserted into material of poor quality.

It is evident from the illustrations in published studies regarding reverse total shoulder prostheses that the surgeons performing these procedures do not uniformly control screw position. Our study supports careful surgical exposure and technique of screw placement to achieve optimal glenoid component fixation.

REFERENCES