Quantitative and Computed Tomography Anatomic Analysis of Glenoid Fixation for Superior Capsule Reconstruction: A Cadaveric Study

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Purpose: To investigate glenoid fixation for superior capsule reconstruction (SCR) and evaluate anchor positions, intraosseous trajectories, and proximity to the suprascapular nerve (SSN) and glenoid fossa. The secondary purpose was to provide technical pearls and pitfalls for anchor insertion on the superior glenoid during SCR. **Methods:** Three beath pins were arthroscopically inserted into 12 (n = 12) nonpaired human cadaveric shoulders through Neviaser, anterior, and posterior portals to simulate anchor placement on the superior glenoid during SCR. Computed tomography scans were performed to evaluate anchor positioning and insertion trajectories. Specimens were then dissected to delineate the anatomic relations of the beath pins to the SSN and glenoid fossa. **Results:** The superior glenoid anchor position was a mean 15.0 ± 4.0 mm to the SSN and 6.5 ± 1.7 mm to the glenoid fossa. The posterior glenoid anchor position was a mean 11.8 ± 2.1 mm to the SSN and 2.9 ± 2.9 mm to the glenoid fossa. On average, the superior pin was placed at 12:30 ± 0:30 (left-sided glenoid clock face) and inserted at 19° ± 9° with respect to the sagittal plane of the glenoid, the anterior pin was placed at 11:00 ± 0:30 and inserted 40° ± 17° off the glenoid, and the posterior pin was placed at 3:00 ± 1:00 and inserted at 52° ± 12° off the glenoid. **Conclusions:** The results of the present cadaveric study showed that glenoid fixation was safe with respect to the SSN and delineated technical guidelines and trajectories for inserting 3 anchors into the glenoid. **Clinical Relevance:** This study shows that 3 anchors can be inserted into the glenoid without a risk of SSN damage and delineates technical guidelines for anchor insertion.

Superior capsule reconstruction (SCR) has recently been introduced as a treatment for massive, irreparable rotator cuff tears. This procedure has gained increasing popularity because clinical and biomechanical studies have shown that SCR is a reliable and effective treatment.[1,2] Further development of the surgical technique has involved modified fixation methods on the superior glenoid with the usage of 3 or more suture anchors.[3-5] Although the anatomy of the greater tuberosity and lateral fixation techniques have been studied extensively,[6,7] less is known regarding medial (glenoid) fixation techniques and exact anchor placement sites on the superior glenoid for SCR. Specifically, it remains unclear if several anchors can be placed without their intraosseous trajectories interfering, and if the superior glenoid provides sufficient bone stock to place larger salvage anchors.

Previous investigations have shown the anatomic relation between the course of the suprascapular nerve (SSN) and suture anchor placement on the glenoid rim for labral repair techniques and the Nevasier portal for acromioclavicular joint resection.[8-13] These studies have reported that inserting superior and posterior suture anchors introduces a potential risk of damaging the SSN. For SCR, anchor placement on the superior glenoid is further medial, and it therefore remains unclear if the suggested safe distance of 1 cm to the SSN[12] is invaded.

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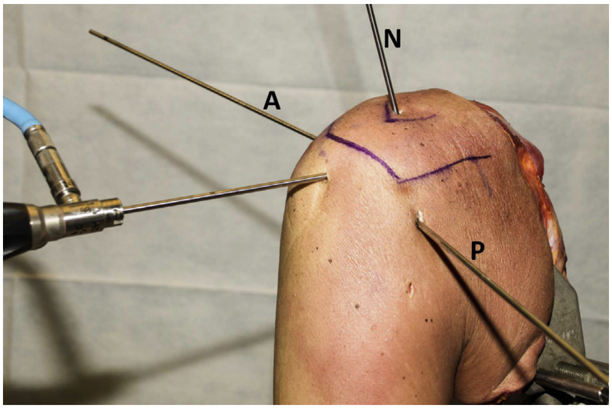

Fig 1. Photograph showing arthroscopic placement of 3 beath pins in the Neviaser, anterior, and posterior portals using a lateral viewing portal in a left shoulder specimen positioned in the beach chair position. (A, anterior; N, Neviaser; P, posterior.)

The primary purpose of this study was to investigate glenoid fixation for SCR and evaluate anchor positions, intraosseous trajectories, and proximity to the SSN and the glenoid fossa. The secondary purpose was to provide technical pearls and pitfalls for anchor insertion on the superior glenoid during SCR. The hypotheses of this study were that the superior glenoid would provide sufficient bone stock for insertion of 3 anchors and that glenoid fixation would not endanger the safe zone of 1.0 cm to the SSN.

Methods

Specimen Preparation

Twelve (n = 12) nonpaired, fresh-frozen, cadaveric shoulders (age range: 34-65 years; mean: 55 years; 7 male, 5 female; 9 right, 3 left) from donors with no history of shoulder injury, surgery, or abnormal pathology were studied. Specimens were thawed at room temperature for 24 hours before arthroscopic preparation. All specimens had intact supraspinatus and infraspinatus tendons. Each shoulder was placed in the beach chair position, and a single orthopaedic surgeon (J.C.K.) arthroscopically created defects of the supraspinatus and infraspinatus tendons, simulating massive posterosuperior rotator cuff tears.

Anchor Placement

One sports medicine fellowship-trained orthopaedic surgeon with clinical experience in SCR (P.J.M.) placed 3 beath pins on the superior glenoid through standard posterior, anterior, and Neviaser[12,14] arthroscopy portals, consistent with the SCR technique published by Katthagen et al.[5] (Fig 1). To carefully evaluate the trajectory and placement of anchors, 2.4-mm beath pins were marked with a permanent marker at 19.5 mm from the drill tip, and were drilled into the bone to this mark with arthroscopic guidance through a standard lateral viewing portal (Fig 1). This insertion depth was chosen to simulate the possibility of using larger anchors for SCR. Pin positioning was established to the best ability of the operating surgeon to simulate the technique performed in the operating room. Based on the senior author's (P.J.M.) experience and preferred technique,[4] the anterior portal was made immediately anterior to the acromioclavicular joint, the posterior portal was made adjacent to the posterior acromion, and the Neviaser portal was made as lateral as possible. The superior glenoid pin was first placed through the Neviaser portal, followed by the anterior and posterior pins through the anterior and posterior portals, respectively. To reproduce the native attachment of the superior capsule, the superior glenoid anchor position was established just medial to the superior labral attachment.[3]

Computed Tomography (CT) Imaging and Evaluation

After surgical placement of all pins, CT scans (Aquilion Premium; Toshiba America Medical Systems, Tustin, CA) were obtained for each specimen using a clinical CT scan protocol (0.5 mm slice thickness, 120 kVp voltage, 150 mA current, and 500 ms exposure). Each CT scan was then reconstructed to align the glenoid cavity in the sagittal plane. All reconstructions were oriented as left-sided shoulders to achieve higher comparability amongst our specimens. Therefore, clock face positioning of each anchor was determined in the sagittal plane using a left-sided glenoid clock face (Fig 2).[15] In the axial and sagittal views, the possibility of interference or collision between beath pins was noted. Anterior and posterior beath pin trajectories

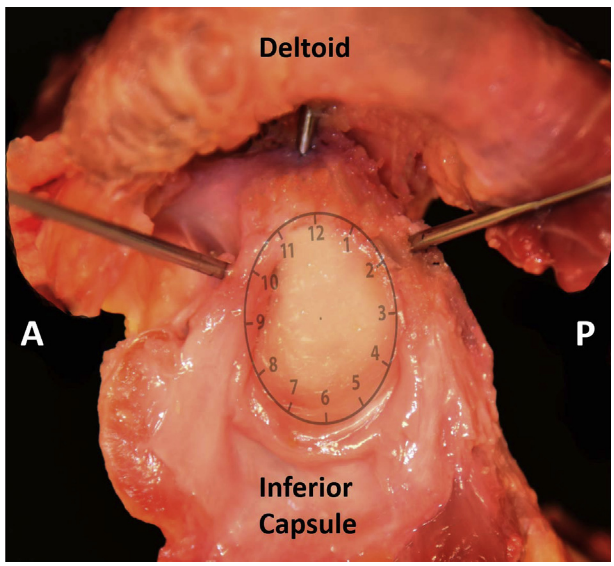

Fig 2. Image of a left shoulder with a clock face superimposed on the glenoid fossa showing the positioning of the anterior, superior, and posterior beath pins. (A, anterior; P, posterior.)

Table 1. Location and Trajectories of Simulated Superior, Anterior, and Posterior Anchors

	Clock Face Positioning, Left-Sided Clock		Trajectories, °	
Beath Pin	Mean ± Standard Deviation	Median (Range)	Mean ± Standard Deviation	Median (Range)
Superior	12:30 ± 0:30	12:45 (11:30-1:00)	19 ± 9	17 (5-35)
Anterior	11:00 ± 0:30	11:00 (10:00-12:00)	40 ± 17	37.5 (17-63)
Posterior	3:00 ± 1:00	3:00 (1:30-4:00)	52 ± 12	56 (26-65)

were determined in the axial view with respect to the plane of the glenoid fossa. The superior beath pin trajectory was determined in the coronal view with respect to the glenoid fossa. In addition, glenoid length and width were measured, and the distance between hours of the clock face in the plane of the beath pins was calculated to determine if there was adequate bone stock to insert a fourth anchor during SCR.

Anatomy Dissection and Measurements

Each specimen was dissected to expose the rotator cuff muscles. The humerus was disarticulated and the acromion was removed with an oscillating saw to expose the glenoid fossa and to facilitate anatomic measurements. Subsequently, the remaining supraspinatus muscle belly was carefully dissected and retracted from the supraspinatus fossa to expose the underlying SSN. In a similar fashion, the infraspinatus and teres minor muscles were carefully retracted from the infraspinatus fossa. An electronic digital caliper with a manufacturer reported accuracy of 0.02 mm (Fowler, Newton, MA) was used to measure the shortest distance from each beath pin on the superior and posterior glenoid to the SSN and to the glenoid fossa.

Statistical Analysis

Anatomic measurements for each specimen were collected by 2 independent investigators and analyzed for inter-rater reliability (J.M.S. and J.C.K.). Inter-rater reliability was assessed by calculating intraclass correlation coefficients (ICC) for each measurement.[16] The Landis and Koch classification system was used to classify the strength of agreement amongst the data: <0.00 = poor, 0.00 to 0.20 = slight, 0.21 to 0.40 = fair, 0.41 to 0.60 = moderate, 0.61 to 0.80 = substantial, and 0.81 to 1.00 = almost perfect.[17] Clock face positions were rounded to the nearest quarter of an hour (15 minutes). All data were expressed by means and standard deviations calculated from the collected measurements.

Table 2. Glenoid Measurements and Distance Calculations

	Mean ± SD, mm	Median (Range), mm
Distance between hours	10.9 ± 1.6	10.8 (8.5-14.1)
Glenoid length	35.8 ± 4.8	34.2 (31-44.3)
Glenoid width	27.6 ± 3.8	25.9 (24-33.4)

SD, standard deviation.

Results

Glenoid Fixation Locations and Trajectories

CT analysis showed that the superior beath pin was placed at a mean 12:30 ± 0:30 (left-sided clock), the anterior fixation pin was placed at a mean 11:00 ± 0:30, and the posterior pin was placed at a mean 3:00 ± 1:00 (Table 1). On gross examination of each specimen, all beath pins were fully situated within the bone, and on radiographic CT analysis, none of the pins came in direct contact with one another distally. However, in 6 of 12 (50%) specimens, the anterior and superior pins were in close proximity (approximately 1-3 mm). The exact distance between the pins was, however, somewhat difficult to accurately assess because of the metal artifact generated by the CT scan. Trajectory analysis revealed that the superior pin was placed at a mean medial angulation of 19° ± 9° (defined with respect to the sagittal plane of the glenoid fossa), and the anterior and posterior pins were inserted into the glenoid with mean medial angulations of 40° ± 17° and 52° ± 12°, respectively (Table 1). Glenoid length and width measurements and distance between hours' calculations are presented in Table 2.

Anatomy Measurements

Inter-rater reliability for anatomic measurements was excellent for all measurements ($ICC_{Sup/SSN} = 0.947$, $ICC_{Sup/Joint} = 0.875$, $ICC_{Post/SSN} = 0.889$, $ICC_{Post/Joint} = 0.924$). The superior glenoid anchor position was a mean 15.0 ± 4.0 mm to the SSN and 6.5 ± 1.7 mm to the glenoid fossa (Table 3 and Fig 3). The posterior glenoid anchor position was a mean 11.8 ± 2.1 mm to the SSN and 2.9 ± 2.9 mm to the glenoid fossa (Table 3 and Fig 4). The distance between the posterior anchor

Table 3. Proximity of the Superior and Posterior Anchor Positions to the Suprascapular Nerve and to the Glenoid Fossa

Measurement	Mean ± SD, mm	Median (Range), mm
Superior pin to SSN	15.0 ± 4.0	14.3 (7.5-21.4)
Superior pin to GF	6.5 ± 1.7	6.1 (4.5-10.2)
Superior GF to SSN	21.5 ± 3.6	21.2 (16.2-27.4)
Posterior pin to SSN	11.8 ± 2.1	12.5 (6.8-14.2)
Posterior pin to GF	2.9 ± 2.9	2.0 (0.0-9.0)
Posterior GF to SSN	14.7 ± 2.6	14.2 (11.6-19.9)

GF, glenoid fossa; SD, standard deviation; SSN, suprascapular nerve.

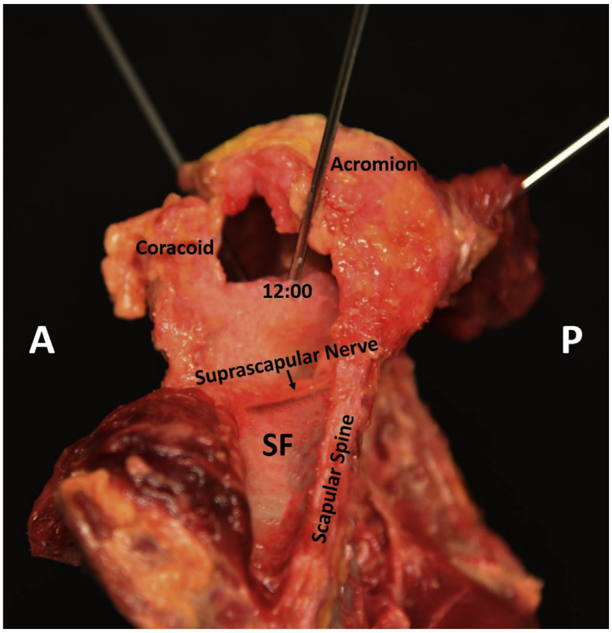

Fig 3. Photograph of a dissected right shoulder showing the proximity of the suprascapular nerve to the superior glenoid anchor position (12:00) from a superomedial perspective. (A, anterior; P, posterior; SF, supraspinatus fossa.)

position and the SSN was less than 10 mm in 2 specimens (9.2 and 6.8 mm). In these 2 instances, the pin to glenoid fossa distances were 3.2 and 7.4 mm, respectively. The mean distances between the glenoid rim and the SSN were 21.5 ± 3.6 mm and 14.7 ± 2.6 mm for the superior and posterior positions, respectively (Table 3).

Discussion

The most important finding of this study was that anchor fixation for SCR on the superior glenoid is safe with regard to the SSN; the mean distances of the superior and posterior anchors to the SSN were 15.0 ± 4.0 mm and 11.8 ± 2.1 mm, respectively. Furthermore, the presented study delineates safe technical guidelines for inserting 3 anchors on the superior glenoid. Inserting the anterior and posterior anchors 1.5 hours from the superior anchor at approximately 45° off the sagittal plane of the glenoid reduces the risk of interference with the superior anchor, which is oriented approximately 20° off the sagittal plane (Fig 5). Because of the decreased medial inclination angle of the superior anchor through the Nevasier portal compared with larger insertion angles anteriorly and posteriorly, it introduces the greatest risk of glenohumeral joint perforation. However, because there is a larger safety boundary (with respect to the SSN), the authors recommend placing the superior anchor 5 to 10 mm away from the glenoid rim to minimize this risk. Finally, this study has determined that in cases where an anchor must be replaced (due to mechanical failure or poor bone quality), there is sufficient bone stock to place larger anchors to improve fixation.

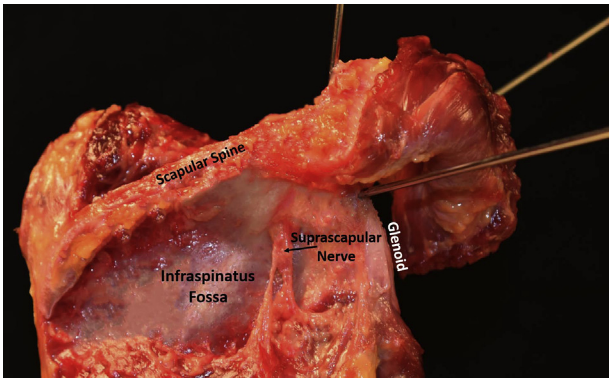

Fig 4. Photograph of a dissected right shoulder showing the proximity of the suprascapular nerve to the posterior glenoid anchor position from a posterior perspective.

Arthroscopic shoulder surgery has historically carried a risk of iatrogenic SSN injury, especially when working at the medial aspect of the joint, near the glenoid rim, such as during labral repair.[18] The results of the present study show that, on average, the superior and posterior

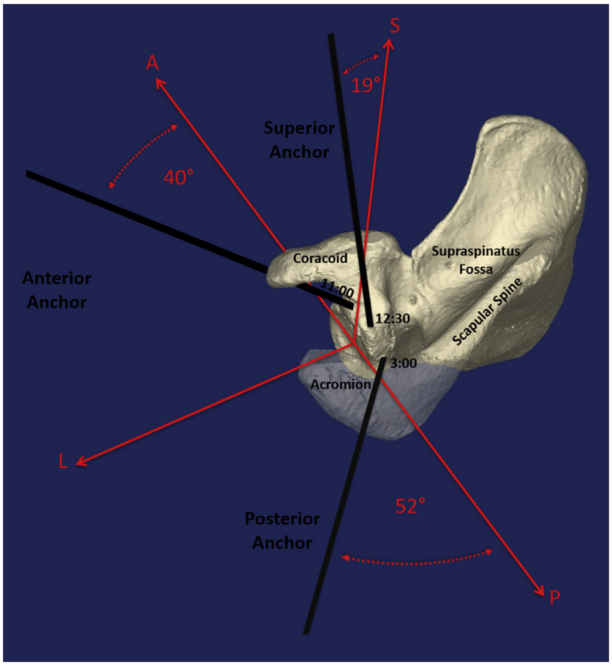

Fig 5. Model of a left scapula from a posterosuperolateral perspective showing the insertion trajectories and placements of anterior, superior, and posterior anchors. The anterior anchor was directed 40° off the sagittal plane of the glenoid and placed at the 11:00 position. The superior anchor was directed 19° off the sagittal plane and placed at the 12:30 position. The posterior anchor was directed 52° off the sagittal plane and placed at the 3:00 position. (A, anterior; L, lateral; P, posterior; S, superior.)

anchor positions avoid the SSN by a mean 15.0 ± 4.0 mm and 11.8 ± 2.1 mm, respectively. In an anatomic investigation on 500 cadaveric scapulae by Gumina et al.,[19] the shortest distance between the supraglenoid tubercle and the SSN was determined to be 2.1 cm and between the posterior glenoid rim and the SSN 1.1 cm. They suggested that these measurements could be used as boundaries during preoperative planning for arthroscopic surgery to avoid iatrogenic injury. The average superior and posterosuperior distances from the glenoid rim to the SSN in this study were 21.5 mm and 14.7 mm, respectively, in accordance with the findings by Gumina et al.[19] Previously, a posterosuperior distance of 10 mm from the SSN has been defined as "safe."[12] In the present study, although there were 2 instances of posterior beath pins placed within the safe distance of 10 mm to the SSN, the mean pin distance to the posterior glenoid rim was 2.9 ± 2.9 mm, which was well within the 1.1 cm boundary as described by Gumina et al.[19] Similarly, the superior beath pins were inserted well within the boundary of 2.1 cm at a mean distance of 6.5 ± 1.7 mm from the superior glenoid rim. These results confirm that there is a smaller safety window for the posterior anchor and should therefore be inserted flush with the glenoid rim to decrease proximity to the SSN.

Multiple studies have evaluated the risk of SSN injury and glenoid vault penetration during superior labrum anterior and posterior tear repair and have shown that inserting posterior anchors through an anterior portal carries a considerable risk.[9-11,20] In this study, the posterior beath pin was placed through the posterior portal to direct its trajectory toward the coracoid base, as opposed to using an anterior portal, which would alter the trajectory toward the SSN. Portal placement often varies among surgeons and can depend on individual anatomy. Based on the senior author's (P.J.M.) experience and preferred technique,[4] the anterior portal was made just anterior to the acromioclavicular joint, the posterior portal was made adjacent to the posterior acromion, and the Neviaser portal was made as lateral as possible. The authors recommend that SCR glenoid anchor fixation should be performed through the aforementioned portals to decrease the risk of glenoid perforation.

CT analysis revealed near collision between the anterior and superior anchors in 50% of cases. However, this result is conservative based on the use of a simulated insertion length of 19.5 mm and may only apply to situations in which the usage of a larger salvage anchor may be necessary. Otherwise, 3.5 × 15.8 mm anchors are standard[4] and, all else equal, would be even less likely to collide. Nonetheless, collision may lead to inadequate bone purchase and potential mechanical failure. Although this phenomenon has not been well documented in the literature, it remains a concern, especially in patients with glenoids of smaller circumference. Anchor collision may be avoided by placing the anterior anchor at an angle that is further medial and away from the superior anchor.

Heightened awareness of suture anchor failure at the greater tuberosity during rotator cuff repair[21] led to improved surgical techniques with superior biomechanical constructs.[6,7] However, suture anchor failure at the superior glenoid during SCR has been less well documented. Intraoperatively, if there appears to be insufficient bone purchase or the need to replace an anchor during SCR, a larger diameter "salvage" anchor can be used on the glenoid to improve fixation. The results of this study show that 3 anchors of typical[4] length (3.5 × 15.8 mm) can be inserted into the superior glenoid without issue. Furthermore, the results of the present study suggest that larger anchors with dimensions of 3.5 × 19.5 mm can be used in cases where one or more anchors require replacement due to inadequate fixation or in the situation when larger anchors are preferred. Moreover, on the basis of the calculated average of 10.9 mm of distance between hours, the authors recommend careful preoperative evaluation and planning for optimal anchor positioning if 3 larger (4.75 mm) or 4 smaller anchors are to be placed on the superior glenoid during SCR.

The results of the present study show that anchors had a tendency to be placed slightly further posterior than previously described in technique papers,[2-5] with the superior and posterior anchors placed on average at 12:30 and 3:00, respectively (anterior anchor at 11:00). Although this has not been biomechanically compared with the anchor positions of 10:00, 12:00, and 2:00, the positions determined by this article seem to be appropriate to reconstruct the native anatomy of the superior capsule.[22] Further investigation may be necessary to determine optimal anchor placement in the glenoid, with respect to biomechanical superiority.

Pouliart et al.[22] performed a cadaveric study on 110 human shoulders and reported 4 different configurations of the superior capsule complex, with 90% of specimens having a posterior capsular extension. They showed that both the anterior and posterior limbs of the superior capsule, which varied from 6 to 26 mm wide, were important in rotational stability and that the superior capsule complex functions in a similar fashion to the inferior glenohumeral ligament complex. When performing SCR, it is essential to be aware of this seemingly underappreciated complex anatomy and the extended posterior limb of the superior capsule.

Limitations

The authors acknowledge several limitations of this study. First, 2.4-mm beath pins were used as surrogates for anchor placement. Although we currently use primarily 3.0- or 3.5-mm anchors for glenoid fixation during SCR, larger anchors may be used clinically. Larger anchors will naturally increase the proximity to the SSN, particularly for the posterior anchor. Furthermore, it is important to note that, although a larger anchor may not penetrate the glenoid fossa, it may "bubble" or crack the articular surface due to an insufficient bone bridge. The results of this study are limited to the portals used for placement of each anchor. For instance, the posterior anchor may be placed through a posterior portal (as performed and recommended in this study) or through superior, posterolateral, or even anterior portals. For the purpose of this study, the beath pins were placed arthroscopically through portals to simulate the surgical procedure and therefore precision and accuracy were dependent on the surgical expertise of the senior surgeon (P.J.M.). The placement was also certainly influenced by individual anatomy of each of the cadaveric specimens. The senior surgeon (P.J.M.) made judgments based on his experience as to the best position and angle for insertion, similar to what would be done in an actual surgical procedure. Although repeated intraspecimen beath pin placements could conceivably have been done to better measure the reproducibility, precision, and accuracy, the creation of multiple drill holes in the glenoid would have precluded secure fixation of the beath pins in the bone and thus prevented such an analysis. When performing SCR, the surgeon must take individual anatomy into account and placement of the anchors from different portals leads to different trajectories with different risks for SSN injury. Furthermore, in practice, it is not even known if the function of the SSN is important, as in most cases in which an SCR is being performed, the supraspinatus and infraspinatus are deficient. A functional SSN may not be important in such instances. Finally, as another means to make the cadaveric model more clinically relevant and to decrease sampling error, both male and female specimens were used. The glenoid length and width data in this study, moreover, are similar to previously reported measurements in anatomic studies[19,23,24] and thus diminish the effect of sampling error.

Conclusions

The results of the present cadaveric study showed that glenoid fixation was safe with respect to the SSN and delineated technical guidelines and trajectories for inserting 3 anchors into the glenoid.

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