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The anterior deltoid's importance in reverse shoulder arthroplasty: a cadaveric biomechanical study

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Background: Frequently, patients who are candidates for reverse shoulder arthroplasty have had prior surgery that may compromise the anterior deltoid muscle. There have been conflicting reports on the necessity of the anterior deltoid thus it is unclear whether a dysfunctional anterior deltoid muscle is a contraindication to reverse shoulder arthroplasty. The purpose of this study was to determine the 3-dimensional (3D) moment arms for all 6 deltoid segments, and determine the biomechanical significance of the anterior deltoid before and after reverse shoulder arthroplasty.
Methods: Eight cadaveric shoulders were evaluated with a 6-axis force/torque sensor to assess the direction of rotation and 3D moment arms for all 6 segments of the deltoid both before and after placement of a reverse shoulder prosthesis. The 2 segments of anterior deltoid were unloaded sequentially to determine their functional role.
Results: The 3D moment arms of the deltoid were significantly altered by placement of the reverse shoulder prosthesis. The anterior and middle deltoid abduction moment arms significantly increased after placement of the reverse prosthesis ($P < .05$). Furthermore, the loss of the anterior deltoid resulted in a significant decrease in both abduction and flexion moments ($P < .05$).
Conclusion: The anterior deltoid is important biomechanically for balanced function after a reverse total shoulder arthroplasty. Losing 1 segment of the anterior deltoid may still allow abduction; however, losing both segments of the anterior deltoid may disrupt balanced abduction. Surgeons should be cautious about performing reverse shoulder arthroplasty in patients who do not have a functioning anterior deltoid muscle.
Level of Evidence: Basic Science Study, Biomechanics, Cadaver Model.

Keywords: Reverse total shoulder arthroplasty; shoulder reconstruction; deltoid; flexion; abduction; moment arms; cadaveric study

Reverse shoulder arthroplasty represents an increasingly useful tool for the treatment of rotator cuff arthropathy,[4,7,11,27] complex proximal humerus fractures,[18,29] and revision shoulder arthroplasty.[6,19,21] The reverse total shoulder prosthesis medializes the center of rotation of the glenohumeral joint and in doing so increases recruitment of deltoid muscles fibers.[5,8,10] This increases the moment arm and resultant mechanical torque about the shoulder due to the position of the glenoid component. A functional deltoid is critical to a successful outcome after a reverse total shoulder arthroplasty.

The anterior deltoid is seen as a vital structure to maintain during surgical exposures, and its disruption has been associated with functional weakness.[16,20,23] A recent case series of anterolateral deltoid muscle ruptures after

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reverse total shoulder arthroplasty in a patient population that had undergone a previous open rotator cuff repairs demonstrated the importance of the anterior deltoid to a successful clinical outcome. The patients in this series all had significant declines in their functional outcome after anterolateral deltoid rupture occured.[28] This report seems to support the concept that the anterior deltoid is vital for a successful outcome after reverse shoulder arthroplasty. However, Glanzmann et al reported a successful reverse shoulder arthroplasty after a previous deltoid muscle flap transfer,[9] suggesting that the entire deltoid may not be necessary for a successful outcome after this procedure. These diverging reports underscore the importance to clearly elucidate the role of the anterior deltoid before and after reverse shoulder arthroplasty.

The purpose of our study is to investigate the moment arms in all planes of movement of the glenohumeral joint (flexion, abduction, and rotation) in both the native shoulder and following reverse shoulder arthroplasty utilizing a laterally based glenosphere. Additionally, we sought to better elucidate the necessity of the anterior deltoid for function of the reverse shoulder arthroplasty.

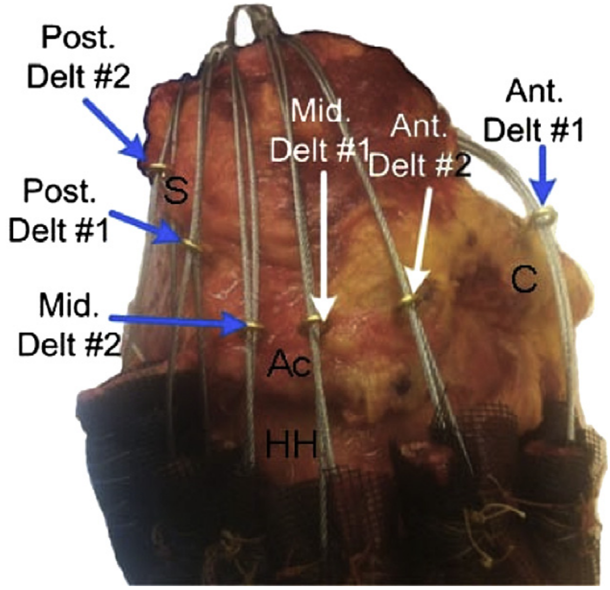

Figure 1 Six portions of deltoid labeled. *C*, the clavicle; *Ac*, the acromion; *HH*, humeral head; *S,* scapular spine.

Materials and methods

Specimen preparation

Eight fresh-frozen cadaveric right shoulders, 6 male and 2 female, with ages ranging between 46 and 68 years were obtained. The specimens were stored at -20°C and thawed for 24 hours before testing. Specimens were excluded from use if they were found to have prior surgery or deltoid muscle compromise.

The skin, subcutaneous, and adipose tissues were removed around exposing the underlying muscles. The planes dividing the anterior (clavicular head), middle (acromial head), and posterior (posterior scapular spine head) deltoid were defined. Each segment was measured and divided evenly into 2 portions, making 6 total portions of the deltoid that was then sharply removed from the scapular spine, acromion, and clavicle. The anterior most portion of the anterior deltoid was labeled anterior deltoid #1, the next portion anterior deltoid #2, etc. (Fig. 1).

Nylon mesh was sewn into each of the deltoid segments as well as the latissimus dorsi and pectoralis major with 0 Vicryl suture (Ethicon, Somerville, NJ, USA). A stainless steel cable of 1.6 mm in diameter was sutured to the Nylon mesh. The origin of each deltoid muscle segment was noted, and an eyelet was placed at the site to guide excursion of the muscle. The cables were threaded through the eyelets prior to mounting the specimen on the experimental apparatus. The clavicle was pinned to the acromion in its anatomic position.

Experimental apparatus

The scapula was firmly mounted to a customized metal plate with plates, and screws. The plate was placed with the glenoid vertical, and the center of rotation of the humeral head in line with a 6-axis force/torque (F/T) sensor (JR3, Inc., Woodland, CA, USA). Metal struts extended from the sensor to a platform where the humerus was fixed inside a metal cylinder with screws, which, in turn, was clamped to the apparatus (Fig. 2). The position of the humerus relative to the 6-axis F/T sensor center was noted with a digitizer (Immersion, San Jose, CA, USA) both before (the anatomical or native specimen) and after surgery (the prosthetic specimen) to minimize the error due to the possible offset between the center of rotation and the 6-axis F/T sensor. A 3D Flock of Bird motion sensor (Ascension Technology, Burlington, VT, USA) provided the 6 degree-of-freedom positions and angles of the humerus during the experiment.

The cables sewn into the muscles were then passed through eyelets at the measured midpoint of each muscle portion's insertion and onto pulleys that were connected to free hanging weights. The weight applied to the each portion of deltoid was approximately 10% of the maximum force, which can be generated by each portion, estimated by published physiological cross sectional areas of the deltoid.[2,13,15,26] A precision linear motor (LinMot, Spreitenbach, Switzerland) was attached to a selected cable to generate individual dynamic force, up to 60 N, with constant low velocity to each of the deltoid segments to determine their 3D mechanical actions. The pectoralis major and latissimus dorsi were each loaded with 10 N of weight statically throughout the experiment.

Experimental protocol

After mounting the scapula and humerus onto the apparatus, the humerus was placed at 0° of abduction and neutral rotation with respect to the epicondylar axis. Its position relative to the 6-axis force sensor was digitized. Weight was added to the cables, and the linear motor sequentially cycled through each segment (starting with anterior deltoid #1, ending with posterior deltoid #2) of the deltoid within pre-defined maximum pulling force limit (the 10% of maximum pulling force of each portion of deltoid) while the free weight remained on the other portions providing a physiologic static load to the joint. The 3D moment arm was