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The effect of humeral version on teres minor muscle moment arm, length, and impingement in reverse shoulder arthroplasty during activities of daily living

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Background: External rotation can be compromised after reverse total shoulder arthroplasty (RTSA). A functional teres minor (TM) is relatively common in patients with posterosuperior tears of the rotator cuff, and its function should be enhanced for better postoperative results. The aim of this study was to investigate how the version of humeral fixation can affect the TM rotational moment arm and muscle length as well as impingement after RTSA.
Methods: A 3-dimensional shoulder model was used to describe RTSA. Four humeral fixation versions were tested: +20°, 0°, −20°, and −40° (+, anteverted; −, retroverted). TM rotational moment arm and length as well as impingement-free range of motion were calculated for a set of 3 simple clinical motions: (1) scapula plane abduction (0°-150°); (2) internal/external rotation with the arm in adduction; and (3) internal/external rotation with the arm in abduction. Six common activities of daily living were also evaluated.
Results: An anteverted fixation maximized TM moment arms, but it also resulted in very short muscle length (compared with normal) and increased inferior impingement. In contrast, 40° humeral retroversion resulted in the longest TM muscle length, but it also showed the smallest moment arms and increased anterior impingement in some of the activities of daily living.
Conclusions: Even if TM external rotation moment arm is higher in RTSA than in a normal shoulder, the decreased length could impair its force generation. The 0° and 20° retroversion was the optimum compromise between sufficient TM length and moment arm with minimum impingement.
Level of evidence: Basic Science, Computer Modeling.

Keywords: Reverse shoulder arthroplasty; teres minor; humeral version; external rotation; moment arm; muscle length

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Reverse total shoulder arthroplasty (RTSA) is gaining popularity in the treatment of rotator cuff arthropathy.[21] Clinical data have shown that RTSA can relieve pain and improve arm function by restoring flexion and abduction.[4,8] However, several studies have also shown that external rotation can be compromised after RTSA.[5,19,20] This loss of external rotation may limit the patient's ability to perform common activities of daily living (ADLs) that require combined abduction and external rotation, such as eating or combing hair. Thus, the outcome of RTSA is influenced by the integrity of the external rotators, specifically the teres minor (TM).[21]

According to Grammont[9] and Boileau,[5] a potential solution to improve active external rotation is to increase humeral retroversion to improve the mechanical advantage of the TM, when it is present. However, no studies have focused on the ability of the TM to externally rotate the shoulder after RTSA. Biomechanical studies have investigated the effect of the humeral version (HV) on impingement-free range of motion (ROM),[11,14,15] and their results vary.

The purpose of this study was to evaluate TM rotational moment arms and muscle lengths after RTSA. Furthermore, we aimed to determine how changes in HV affected these variables and how they compared with a normal shoulder. Testing conditions consisted of standardized, arbitrary motions of the shoulder as well as more complex motions that were designed to simulate ADLs. Our hypothesis was that the muscle length of the TM and moment arm would be reduced after RTSA compared with the normal, native shoulder. We also hypothesized that these deficits could at least be partially corrected by increasing the retroversion of the humeral component of the prosthesis. This is clinically important because maximizing the function of the TM will improve the external rotation strength needed to perform ADLs.

Methods

Biomechanical computer model

A 3-dimensional (3D) biomechanical model, the Newcastle Shoulder Model,[6] was used for this investigation. The model represents a normal shoulder and includes 6 rigid segments (thorax, clavicle, scapula, humerus, radius, and ulna). The skeletal geometry of the segments derived from the reconstruction of the Visible Human data set.[22] The model includes 31 muscles and 3 ligaments of the upper extremity that are divided into 90 lines of action representing the anatomic muscle division into fascicles.[1,16] These lines of action are modeled as elastic strings that wrap around standard shapes (e.g., cylinders and spheres) corresponding to the bone geometry (Fig. 1). Specialized software (SIMM; MusculoGraphics Inc, Santa Rosa, CA, USA) was used for the model visualization and muscle wrapping. The model that also includes the sternoclavicular, acromioclavicular, and glenohumeral joints can simulate the 3D scapula and clavicle kinematics and can compute the length and moment arm of any muscle over a predefined motion by the tendon-excursion method.[1,2]

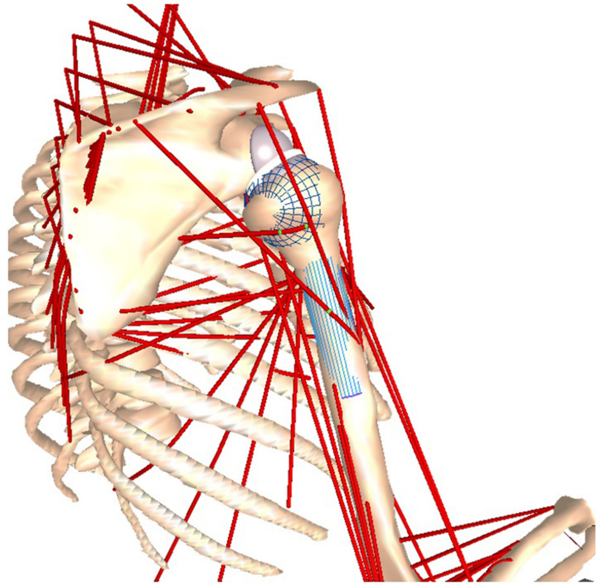

Figure 1 The Newcastle Shoulder Model representing an RTSA. The only active rotator cuff muscle in the model is the TM, which wraps around the humeral head.

For the current study, an adapted version of the Newcastle Shoulder Model that resembles the geometry of a commercially available reverse shoulder prosthesis (Delta III; DePuy Synthes, Lyon, France; Fig. 1) was also used as it was described by Kontaxis and Johnson.[18] The RTSA model was created by simulating a virtual surgery on the original Newcastle Shoulder Model by using all the appropriate surgical tools and following the standard surgical guidelines as they are described by the manufacturer. All the rotator cuff muscles were excluded from the RTSA model with the exception of the TM.

The shoulder model also uses a contact detection algorithm that can evaluate implant to bone or bone to bone impingement. There are a few studies to show how HV affects impingement in RTSA. In the current investigation, impingement was evaluated to understand how the change in HV can affect both TM function (moment arm and muscle length) and impingement.

Model setup and kinematic inputs

To understand how RTSA and humeral fixation can affect the biomechanical properties of the TM, its rotational moment arm and length were calculated and compared for different versions of the humeral component. Those values were also compared with normal anatomy to investigate how the RTSA geometry can affect the biomechanical properties of TM. The version angle was defined with the help of the epicondylar axis as shown in Figure 2. To simulate a retroverted fixation, the stem was implanted with a clockwise rotation, and vice versa. The different version setups that were tested in the study were +20° HV, 0° HV, −20° HV, and −40° HV (+, anteverted; −, retroverted).

The TM rotational moment arm and length data were computed for a set of kinematic profiles: