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ORIGINAL ARTICLE

Subscapularis tendon loading during activities of daily living

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Background: The purpose of this study was to determine the relative amount of load that is transmitted through the superior portion of the subscapularis during activities of daily living as compared with the load that is transmitted through the middle and inferior portions in a normal shoulder and in a shoulder with a supraspinatus tear.
Methods: By use of the Newcastle shoulder model, the subscapularis was modeled with 3 lines of action encircling the humeral head. The load was measured in the entire subscapularis, and the percentage of this load in each of the 3 tendinous bands was calculated. Subsequently, a supraspinatus tear was simulated, and the forces generated by the subscapularis and glenohumeral joint contact forces were measured.
Results: The maximum force produced by the entire subscapularis muscle for the various activities ranged from 3 to 43 N. Load sharing between the 3 subscapularis bands showed that the superior band bore the largest percentage of the total load of the muscle (95% ± 2%). The load in the subscapularis, particularly in the superior band, increased significantly when a supraspinatus tear was simulated ($P < .0001$).
Conclusion: The superior band of the subscapularis tendon bears the highest percentage of load compared with the middle or inferior band. The load in the subscapularis increased significantly in the presence of a simulated supraspinatus tear. Because a disproportionate amount of force is transmitted through the superior subscapularis, more clinical research is warranted to determine whether tears in this region should be routinely repaired.
Level of evidence: Basic Science Study; Computer Modeling

Keywords: Subscapularis tendon; rotator cuff tendons; anterosuperior rotator cuff tears; rotator cuff biomechanics; glenohumeral joint contact forces; shoulder biomechanics

The subscapularis is the largest and most powerful of the rotator cuff muscles but historically has received less attention in the literature.[22] The subscapularis functions to internally rotate the shoulder and dynamically stabilize the humeral head.[29] In addition, the subscapularis participates in force coupling as an antagonist to the superior pull of the deltoid. Depending on the position of the shoulder, the subscapularis can assist in flexion, abduction, and adduction.[10] Previously, subscapularis tears were described as rare injuries,[4] but recent studies have identified a higher prevalence of subscapularis injuries than originally thought.[23,33] The treatment of isolated subscapularis tears, as well as those associated with a larger anterosuperior cuff tear, remains an area of debate in orthopedics.

The subscapularis muscle originates on the anterior surface of the scapula. The superior two-thirds of the muscle converges and forms a tendon that inserts onto the lesser tuberosity.

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At the most superior aspect, subscapularis muscle fibers interdigitate with the anterior fibers of the supraspinatus.[3] The inferior third of the subscapularis inserts as a muscular attachment to the proximal humeral metaphysis, and the average size of its footprint is 25.8 by 18.1 mm.[6] A number of studies have attempted to delineate the details of the subscapularis insertion onto the lesser tuberosity.[13,25,33] The concept of the insertional footprint as broad proximally and narrow distally,[6,25] formerly likened to the shape of a comma,[5] has been questioned, and it may actually narrow less distally.[33] Klapper et al[17] first identified separate tendinous bands within the subscapularis and described them as migrating superiorly as they insert on the lesser tuberosity. Clark and Harryman[3] described 5 to 6 bundles of collagen fibers in cadaveric specimens, and Totterman et al[28] identified 4 to 6 bundles in a magnetic resonance imaging study. While the understanding of subscapularis anatomy has developed secondary to this research, the biomechanical contribution from the individual components of the subscapularis remains unknown.

Because of advances in arthroscopy and imaging, the prevalence of subscapularis tears has been shown to be higher than reported historically. Degeneration, internal impingement at the site where the subscapularis contacts the anterior superior glenoid rim, and external impingement with the coracoid process have all been described as etiologies for subscapularis tears.[23] The superior two-thirds of the subscapularis is more commonly involved in tears. The incidence of isolated subscapularis tears has been reported to be between 3.5% and 50% among all patients based on cadaveric and arthroscopic studies.[4,18,33] Multiple studies have reported good to excellent outcomes with open or arthroscopic repair of isolated subscapularis tears.[7,8] There is no consensus regarding the need to treat partial subscapularis tears, in part because the biomechanical role of this region has yet to be elucidated.

We hypothesized that the superior aspect of the subscapularis plays a disproportionately important role in shoulder function in a healthy shoulder when compared with the middle and lower portions. Furthermore, we hypothesized that the forces generated by the subscapularis must increase in the presence of a supraspinatus tear.

Materials and methods

Biomechanical computer shoulder model

A 3-dimensional biomechanical model, the Newcastle shoulder model,[2] was used to investigate the load sharing on the rotator cuff muscles and especially the subscapularis during common activities of daily living (ADLs). Charlton and Johnson[2] previously used the model to investigate glenohumeral joint contact forces during ADLs. In summary, it represents a normal shoulder and arm that were digitized from the Visible Human Project dataset.[27] It includes 6 rigid segments (thorax, clavicle, scapula, humerus, radius, and ulna) that are connected at the corresponding joints (sternoclavicular, 3 *df*; acromioclavicular, 3 *df*; glenohumeral, 3 *df*; and elbow, 2 single *df*). The model includes 31 muscles and 3 ligaments of the upper extremity, and most of the parameters were taken from the studies of Johnson et al,[15] van der Helm,[30] and Veeger et al.[32] Muscles are simulated as elastic strings that wrap around bones. Large-sized muscles were modeled with multiple muscle lines that represent anatomic fascicles. In total, there are 96 lines of action representing shoulder and elbow muscles and ligaments. The subscapularis muscle is represented with 3 lines of action that represent the superior, middle, and inferior bands (overall physiological cross-sectional area, 7.8 cm^2, with 2.7, 2.2, and 2.9 cm^2 for the superior, middle, and inferior band, respectively) (Fig. 1). In contrast, the supraspinatus is modeled with a single line of action (physiological cross-sectional area, 3.0 cm^2).

Model visualization and muscle wrapping were performed using specialized software (SIMM; MusculoGraphics, Santa Rosa, CA, USA). The model can predict muscle and joint contact forces for any given kinematic input using inverse dynamics and static optimization methods as Charlton and Johnson[2] described. The focus of this investigation was the muscle force of the different subscapularis

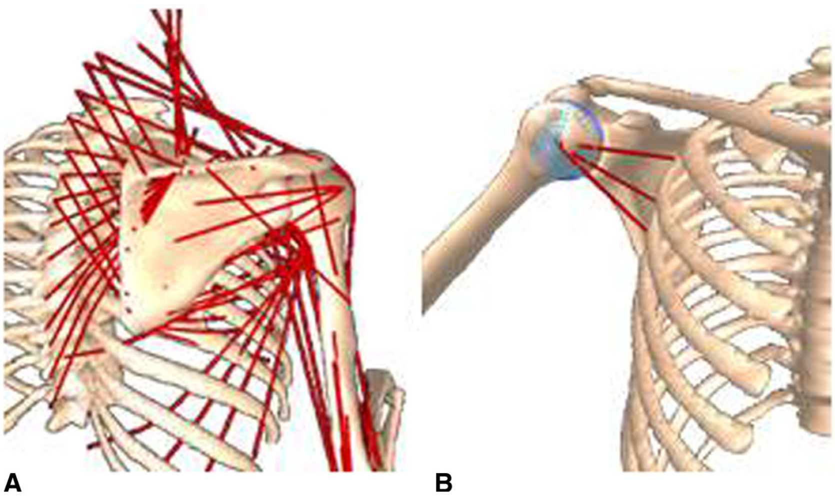

Figure 1 (**A**) Newcastle shoulder model. The model consists of 90 lines of action including 31 muscles and 3 ligaments. (**B**) The subscapularis is modeled as 3 lines of action, wrapped around the humeral head, which is modeled as a sphere.