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BASIC SCIENCE

Reduced muscle fiber force production and disrupted myofibril architecture in patients with chronic rotator cuff tears

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Background: A persistent atrophy of muscle fibers and an accumulation of fat, collectively referred to as fatty degeneration, commonly occur in patients with chronic rotator cuff tears. The etiology of fatty degeneration and function of the residual rotator cuff musculature have not been well characterized in humans. We hypothesized that muscles from patients with chronic rotator cuff tears have reduced muscle fiber force production, disordered myofibrils, and an accumulation of fat vacuoles.

Methods: The contractility of muscle fibers from biopsy specimens of supraspinatus muscles of 13 patients with chronic full-thickness posterosuperior rotator cuff tears was measured and compared with data from healthy vastus lateralis muscle fibers. Correlations between muscle fiber contractility, American Shoulder and Elbow Surgeons (ASES) scores, and tear size were analyzed. Histology and electron microscopy were also performed.

Results: Torn supraspinatus muscles had a 30% reduction in maximum isometric force production and a 29% reduction in normalized force compared with controls. Normalized supraspinatus fiber force positively correlated with ASES score and negatively correlated with tear size. Disordered sarcomeres were noted, along with an accumulation of lipid-laden macrophages in the extracellular matrix surrounding supraspinatus muscle fibers.

Conclusions: Patients with chronic supraspinatus tears have significant reductions in muscle fiber force production. Force production also correlates with ASES scores and tear size. The structural and functional muscle dysfunction of the residual muscle fibers is independent of the additional area taken up by fibrotic

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tissue. This work may help establish future therapies to restore muscle function after the repair of chronically torn rotator cuff muscles.
Level of evidence: Basic Science, Histology.

Keywords: Rotator cuff; fatty degeneration; myosteatosis; permeabilized muscle fibers; macrophages; sarcomeres

Rotator cuff tears are among the most debilitating and frequent upper extremity injuries, with more than 250,000 surgical repairs performed annually in the United States.[7] Although there have been important improvements in surgical repair and rehabilitation techniques, many patients continue to have symptoms after repair, and re-tear rates for surgical repair of full-thickness tears remain high.[2,11] A set of common pathologic changes often occurs in patients with chronically torn rotator cuff muscles, including muscle fiber atrophy, fibrosis, and accumulation of fat within and around muscle fibers.[15] These changes are commonly referred to as fatty degeneration. The severity of fatty degeneration is positively correlated with poor functional outcomes, and despite successful surgical repair of the tear of the torn rotator cuff, fatty degeneration often does not improve after repair and for some patients continues to worsen over time.[13,14]

Given the anatomic and biomechanical complexity of the shoulder girdle, it can be challenging to specifically isolate the rotator cuff during strength testing in the clinical setting,[24] making it difficult to measure rotator cuff function by conventional biomechanical testing methods. Whole muscle force measurements have been performed in rotator cuff muscles from sheep and rats,[20,22] but these techniques are invasive and can be difficult to perform in a fashion that allows the animal to recover. Whereas whole muscle force measurements can be informative, force measurements from single muscle fibers obtained from small tissue biopsy specimens provide a wealth of information about the function of muscle as a whole and are predictive of strength measurements performed at the whole muscle level.[6,19] Using a rat model of full-thickness rotator cuff tears, we measured force production of individual muscle fibers and demonstrated a 40% reduction in maximum isometric force (F_o) and an 18% reduction in specific force (sF_o, defined as F_o normalized to the muscle fiber cross-sectional area [CSA]) in torn muscles compared with controls.[16] This reduction in F_o and sF_o at the level of individual muscle cells indicates that chronic rotator cuff tears disrupted the abundance or function of myofibrils, which are the fundamental contractile structures of muscle cells. Further, whereas fat accumulation was previously noted to occur in animal models of chronic rotator cuff tears, we identified a pool of macrophages that accumulate around fatty plaques present in injured rotator cuff muscles.[16] Although these studies provided insight into potential mechanisms that result in muscle weakness after rotator cuff tears, the pathophysiologic mechanism of fatty infiltration and the impact of chronic tears on the ability of the rotator cuff muscle fibers to generate force in humans have not been defined.

The primary objective of this study was to measure the contractile and morphologic properties of muscle fibers from patients with chronic rotator cuff tears. A secondary objective was to determine if there were correlations between muscle fiber contractility and American Shoulder and Elbow Surgeons (ASES) survey instrument scores or the size of the tear. We hypothesized that patients with rotator cuff tears would have reduced muscle fiber force production compared with healthy muscle fibers and that force production would be positively correlated with ASES scores and negatively correlated with tear size.

Materials and methods

Subjects

All subjects provided informed, written consent before participation in this study. Subjects who were 18 years of age or older, who had a full-thickness supraspinatus tear as diagnosed by ultrasound or magnetic resonance imaging, had a history of shoulder pain for at least 5 years, and consented to undergo arthroscopic rotator cuff examination were eligible for participation in the study. Patients who were undergoing revision rotator cuff tear, had previous shoulder or upper extremity surgery, or had a history of a myopathy or metabolic or rheumatologic disorder were excluded from participation in the study. Patients also completed the ASES survey instrument to measure shoulder-specific function[26] 1 week before surgery. The ASES activities of daily living (ADL) subscale for the involved shoulder as well as the composite score that includes the ADL of the uninvolved shoulder and a visual analog pain scale were used for analysis.

Diagnostic imaging

The diagnosis of a full-thickness supraspinatus tear was assessed from ultrasound or magnetic resonance imaging studies before surgery. The gap distance between the free tendon end and the anatomic footprint on the humeral head was measured from scans in coronal and sagittal planes. A single board-certified and fellowship-trained musculoskeletal radiologist read the imaging studies and calculated the gap distances with Imagecast PACS 3.6 software (IDX Systems, Burlington, VT, USA).