J Shoulder Elbow Surg (2010) 19, 224-229

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Journal of Shoulder and Elbow Surgery

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Voluntary activation of the infraspinatus muscle in nonfatigued and fatigued states

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Hypothesis: Failure of voluntary activation is an important source of weakness in several different muscles after injury or surgery. Despite the high prevalence of shoulder rotator cuff disorders and associated weakness, no test currently exists to identify voluntary activation deficits for the rotator cuff. The purpose of this study was to develop a test to quantify voluntary activation of the infraspinatus. We hypothesized that there would be a consistent relationship between the voluntary activation level and different force levels and that reduced voluntary activation would partially account for reduced force with fatigue.
Materials and methods: Twenty healthy volunteers underwent assessment of voluntary activation using an electrical stimulus applied to the infraspinatus muscle during active isometric external rotation. Voluntary activation was assessed across several levels of external rotation effort and during fatigue.
Results: The voluntary activation-percent force relationship was best fit using a curvilinear model, and the fatigue test reduced both force and voluntary activation by 46%.
Discussion: In the nonfatigued state, the voluntary activation-percent force relationship is similar to that reported for the quadriceps. After fatigue, however, greater failure of voluntary activation was observed compared with reported values for other upper and lower extremity muscles, which may have implications for the understanding and treatment of rotator cuff pathology.
Conclusion: A measure of voluntary activation for the infraspinatus varied with the percent maximum force in a predictable manner that is consistent with the literature. The infraspinatus may be more susceptible to failure of voluntary activation during fatigue than other muscles.
Level of evidence: Basic Science Study.

Keywords: Voluntary activation; infraspinatus; rotator cuff; fatigue; young adults; exercise; isometric contraction

The infraspinatus muscle is a key part of the rotator cuff that serves to stabilize the humeral head during functional activity.[5,7,23,39,55] Specifically, rotator cuff tears and fatigue both have been shown to produce abnormal superior humeral head translation, which may promote subacromial impingement.[5,39,41,54,57] Although fatigue may result from depletion of local muscle energy sources known as peripheral fatigue, it may also be associated with a lack of central drive from the nervous system known as failure of voluntary activation (VA).[36,38] VA failure has been well documented in several muscles,[3,13,36,38] but to our knowledge, it has not been studied in the shoulder.

This material was presented at the 2008 Combined Sections Meeting of the American Physical Therapy Association, Nashville, Tennessee, February 6-9, 2008.

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1058-2746/2010/$36.00 - see front matter © 2010 Journal of Shoulder and Elbow Surgery Board of Trustees.
doi:10.1016/j.jse.2009.07.006

Volitional muscle contraction requires both central nervous system activation and peripheral neuromuscular pathway propagation to occur. Impairments at any step within these processes may reduce muscle force generation. In recent years, there has been increasing interest in using techniques to quantify the central or voluntary component of muscle activation in healthy and patient populations.[12,28,37,40,48,50,53] Failure of VA may result in the inability to recruit all of a muscle's motor units or to attain optimal discharge rates from the motor units that are recruited.[22]

Deficits in VA are a commonly observed after central nervous system injury,[37,48] joint injury/disease,[12,28] joint surgery,[36] and immobilization.[53] In the lower extremity, strength loss in the quadriceps from preoperatively to approximately 1 month after total knee arthroplasty was attributed to failure of VA and atrophy.[36] In fact, failure of quadriceps VA contributed nearly twice as much as atrophy did to the loss of quadriceps strength.[36] In addition, during a 10-week course of rehabilitation after ankle malleolar fracture immobilization, a larger percentage of the variance in plantarflexion torque could be explained by changes in VA compared with changes in cross-sectional area.[53]

Although VA has not been specifically tested in the shoulder, authors have documented decreased muscle activation and altered kinematics associated with shoulder pain that are improved after subacromial injection with pain relief.[4,45,51] Pain, especially in muscle, tendon, and joint structures, has been hypothesized to cause failure of voluntary activation through activation of inhibitory circuits in the spinal cord and through decreased cortical excitability.[20,34,44] This suggests that shoulder weakness commonly observed in patients may be the result of VA failure as well as other documented mechanisms such as tendon tears,[19,29] suprascapular nerve entrapment,[10] intramuscular fat deposition, and muscle atrophy.[15,17]

VA assessment of key rotator cuff muscles using electrical stimuli superimposed on maximum effort contractions has not been previously reported, to our knowledge. The purpose of this study was to test VA of the infraspinatus muscle across different levels of effort during isometric shoulder external rotation contractions and to see if failure of VA occurred after an isometric fatigue protocol. We hypothesized that the VA-percent force relationship of the infraspinatus would be similar to that reported for the quadriceps femoris and that fatigue would reduce the degree of VA similarly to that reported from other upper and lower extremity muscle groups in young adults.

Materials and methods

This study was approved by the Arcadia University Committee on the Protection of Research Subjects, protocol #06-08-79. All study participants reviewed and signed informed consent forms that were approved by the University Institutional Review Board.

Study participants

The study recruited 20 volunteers (10 men; mean age, 24.7 ± 2.3 years) from a cohort of students and staff from the local setting. A brief general health checklist was used to screen for current musculoskeletal, neurologic, and cardiovascular compromise. A physical screening ruled out any potential full-thickness rotator cuff pathology (painful arc sign, drop-arm test, gross external rotation weakness assessed by a manual muscle test) and shoulder impingement (Hawkins, Neer, painful arc sign, and no history of pain in the C5-6 dermatome).

Experimental session

The infraspinatus muscle motor point of each participant was identified using 2-Hz electrical stimulation (400 μs pulse; Empi 300PV; Empi, St. Paul, MN) with a 1.5-cm-diameter point stimulator. Next, 1 electrode was placed over the motor point along the medial border of the scapula, and the other was placed more laterally and in line with the direction of the infraspinatus muscle fibers. An electrically elicited contraction (50 Hz) was used to check electrode placement by observing only shoulder external rotation without shoulder extension.

Participants were seated in a high-back chair with the shoulder girdle maximally retracted and thoracic spine stabilized with a belt, and the forearm was secured to a KIN-COM 500H dynamometer (Chattecx Corp, Chattanooga, TN; Figure 1, *A*). Each shoulder was abducted 30°, with 0° of shoulder flexion, 5° of internal rotation, and 90° of elbow flexion. The axis of rotation of the dynamometer was aligned with the long axis of the humerus through the humeroulnar joint.

Next, the infraspinatus muscle was stimulated and the voltage of a Grass S48 stimulator (West Warwick, RI) was gradually increased until a plateau was reached in isometric external rotation force. The stimulus used for VA assessment was a 3-pulse train (600-μs pulses) delivered at 50 Hz.

Participants were then given up to 3 attempts to produce a maximal voluntary isometric contraction (MVIC), during which an electrical stimulus was applied during a force plateau and again in the resting state when the force returned to baseline. Visual force feedback and strong verbal encouragement were given during the MVIC attempts. VA was calculated as (1 − augmentation from the stimulus during the isometric contraction/force of the stimulus while at rest), where a value of 1.0 is considered full activation (Figure 1, *B*.). All participants achieved VA of 0.90 or higher and were given a 5-minute rest. They were then asked to perform contractions with VA assessment at force levels of 25%, 50%, and 75% of their original MVIC. The order of force levels was randomized to prevent systematic error, and there was a 5-minute rest between each level. The VA was then calculated after each force percentage. A final MVIC was recorded to ensure the volunteer did not fatigue greater than 10% during the experimental protocol.

Eight participants (4 men) returned for a second test session approximately 4 to 5 months after the first test session. The setup procedure was as described above, and each person had up to 3 attempts to achieve a MVIC with a VA of 0.90 or higher. After a 5-minute rest, an isometric fatigue test was initiated that consisted of a series of 25 MVICs, during which each contraction was held for 5 seconds, followed by 2 seconds of rest.[50] During the fatigue test, participants were given strong verbal encouragement