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Acromiohumeral Distance During Neuromuscular Electrical Stimulation of the Lower Trapezius and Serratus Anterior Muscles in Healthy Participants

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Context: Compromise to the acromiohumeral distance has been reported in participants with subacromial impingement syndrome compared with healthy participants. In clinical practice, patients with subacromial shoulder impingement are given strengthening programs targeting the lower trapezius (LT) and serratus anterior (SA) muscles to increase scapular posterior tilt and upward rotation. We are the first to use neuromuscular electrical stimulation to stimulate these muscle groups and evaluate how the muscle contraction affects the acromiohumeral distance.

Objective: To investigate if electrical muscle stimulation of the LT and SA muscles, both separately and simultaneously, increases the acromiohumeral distance and to identify which muscle-group contraction or combination most influences the acromiohumeral distance.

Design: Controlled laboratory study.

Setting: Human performance laboratory.

Patients or Other Participants: Twenty participants (10 men and 10 women, age = 26.9 ± 8.0 years, body mass index = 23.8) were screened.

Intervention(s): Neuromuscular electrical stimulation of the LT and SA.

Main Outcome Measure(s): Ultrasound measurement of the acromiohumeral distance.

Results: Acromiohumeral distance increased during contraction via neuromuscular electrical stimulation of the LT muscle ($t_{19} = -3.89$, $P = .004$), SA muscle ($t_{19} = -7.67$, $P = .001$), and combined LT and SA muscles ($t_{19} = -5.09$, $P = .001$). We observed no differences in the increased acromiohumeral distance among the 3 procedures ($F_{2,57} = 3.109$, $P = .08$).

Conclusions: Our results supported the hypothesis that the muscle force couple around the scapula is important in rehabilitation and scapular control and influences acromiohumeral distance.

Key Words: subacromial impingement syndrome, real-time ultrasound, rehabilitation

Key Points

- Acromiohumeral distance increased during neuromuscular electrical stimulation of the lower trapezius muscle, serratus anterior muscle, and combined lower trapezius and serratus anterior muscles.
- The increase in acromiohumeral distance was not different among the 3 neuromuscular electrical-stimulation procedures.
- The muscle force couple around the scapula is important in rehabilitation and scapular control and influences acromiohumeral distance.

Optimal upper limb function depends on the ability to statically and dynamically position the shoulder girdle in an optimal coordinated fashion.[1,2] Suboptimal motor control is considered a risk factor for developing shoulder subacromial impingement syndrome.[3–14] Alterations in scapular motion have been linked to a decrease in serratus anterior (SA) muscle activity, an increase in upper trapezius muscle activity, and an imbalance of forces between the upper and lower parts of the trapezius muscle.[15] This may adversely affect scapular positioning, resulting in reduced scapular upward rotation, increased anterior scapular tilt, and scapular winging.[4,9,16] In turn, scapular upward rotation and posterior tilt are considered vital for elevating the acromion and, hence, widening the subacromial space, thereby preventing impingement of the subacromial tissues.[17,18] Atalar et al[19] suggested that reduced scapular mobility led to a decrease in acromiohumeral distance (AHD) during upper extremity abduction. Therefore, when developing rehabilitation strategies for patients with subacromial impingement syndrome, correcting neuromuscular control of the SA and trapezius muscles is important.[20,21]

Overall, researchers[22,23] have supported the theory that altered activity in the scapular rotator muscles is present in patients with subacromial impingement syndrome and have highlighted the role of scapular rotator muscle training as an essential component of shoulder rehabilitation. A clinical practice strategy, supported by research data,

Figure 1. Standardized participant position.

recommends that patients who have subacromial shoulder impingement and present with primary movement dysfunction of the scapula should be given strengthening programs targeting the lower trapezius (LT) and SA muscles.[24,25] The LT muscle is reported to increase posterior scapular tilt, and the SA muscle is believed to increase upward rotation of the scapula.[2] In turn, posterior scapular tilt and upward scapular rotation are associated with increased AHD.[17,18]

Authors[9,23,26–29] of electromyographic (EMG) studies have tested muscle activity in participants with subacromial impingement syndrome and in healthy persons. In patients with subacromial impingement syndrome, when the upper extremity was at rest and during flexion and abduction, the EMG signal amplitude of the upper trapezius muscle increased, whereas the EMG signal amplitude of the LT and SA muscles decreased.[30,31] These researchers have considered the immediate changes in the surface EMG activity of the scapular rotator muscles. However, to our knowledge, we are the first to use neuromuscular electrical stimulation (NMES) to stimulate the muscle groups of the LT and SA and evaluate the effect of muscle contraction in these muscles on the AHD. Neuromuscular electrical stimulation is used for various medical applications and is a common intervention during rehabilitation to improve function and motor control,[32] prevent and treat shoulder pain,[33] increase range of motion,[34] and facilitate changes in muscle action and performance.[35] Therefore, the purpose of our study was to investigate whether stimulation of the LT and the SA muscles (separately and simultaneously) with NMES would increase the AHD and to investigate which muscle-group contraction or combination most influenced the AHD.

METHODS

Study Design

We used a 1-group, pretest/during-test repeated-measures design to compare how muscle stimulation of the LT and SA muscles affected AHD in healthy persons.

Participants

A power analysis was carried out using G*Power software (version 3.1.7; Heinrich Heine University, Dusseldorf, Germany), with an effect size of 0.5, an α level of .05, and statistical power of 0.8. The required sample size was calculated to be 16 participants. Twenty participants (10 men and 10 women, age = 26.9 $\pm$ 8.0 years, body mass index = 23.8) were screened. Participants needed to meet the following inclusion criteria: be between 18 and 50 years old with no history of shoulder pain or stiffness in the 6 months before the study and no history of fracture or surgery to the shoulder girdle. An investigator (T.A.M.) with more than 5 years of experience in musculoskeletal physiotherapy screened participants to ensure that they met the inclusion criteria. All participants provided written informed consent, and the study was approved by the Ethics Committee of Salford University.

Participant Position

Participants were seated with their shoulders exposed on a customized armless chair with a short back support for the lumbar region. Their hips and knees were flexed to 90°, and their feet rested flat on the floor. Participants maintained a standardized position of 60° of passive abduction in the coronal plane during all ultrasound (US) imaging measurements with the upper extremity resting on a precut, 60° foam wedge that was on a table with adjustable height (Figure 1). The height of the table could be adjusted according to the participant's body length, ensuring that the limb was abducted to 60° without shoulder girdle elevation. The amount of shoulder abduction was verified with goniometry. Neutral humeral rotation was maintained because the foam wedge supported the humerus and forearm, with 90° of elbow flexion and the participant's palm resting on the wedge. Only the right shoulder of each participant was evaluated.

Instrumentation

The neuromuscular electrical stimulation device (Compex mi-Sport; DJO Global, Vista, CA) we used is a portable unit that stimulates efferent motor neurons with a biphasic waveform.[36] Rectangular wave-pulsed currents with a pulse width of 200 microseconds were used. The frequency of the output was set at 80 Hz. A rise and fall time of 2 seconds with a tetanic muscle stimulation lasting 8 seconds and a 3-second duration between stimulations were used for all participants. This enabled sufficient time for US image capture. Participants required varying intensity levels of the stimulation to induce a contraction in the respective muscle; therefore, visual observation of the contraction

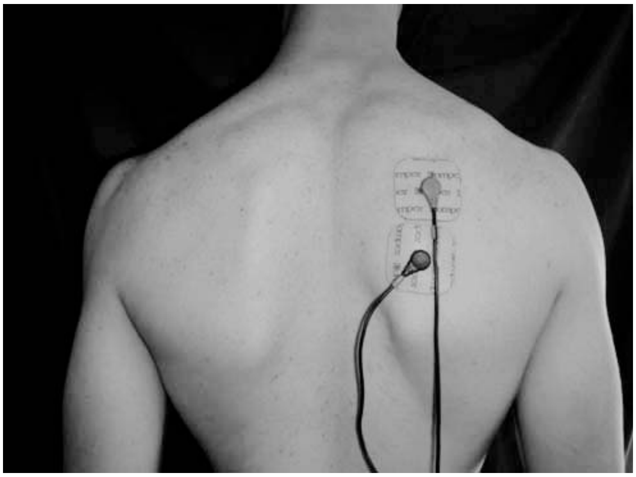

Figure 2. Lower trapezius muscle stimulation.

was used to determine the stimulation intensity. A rest time of 2 minutes was given between the tests of the muscle groups.

Application of NMES

The physiotherapist applied NMES. She placed the NMES sensor surface electrodes over the muscle belly of each participant according to the protocols described by Basmajian and De Luca.[37] We used 3 procedures: LT muscle stimulation, SA muscle stimulation, and combined LT and SA muscle stimulation. For the LT muscle stimulation, electrodes were positioned over the muscle belly of the LT muscle and placed midline along a line between the inferior angle of the scapula and the insertion of the LT muscle onto the lateral side of the seventh thoracic spinous process (Figure 2). For the SA stimulation, the electrodes were placed at the intersection of the sixth rib and the midaxillary line parallel to the muscle fibers and anterior to the latissimus dorsi muscle fibers (Figure 3). For stimulation of the combined LT and SA muscles, electrodes were placed in the same manner as when each muscle was stimulated individually but were applied simultaneously (Figure 4).

Ultrasound Measurements

Intrarater reliability for the use of US to measure the AHD in 60° of passive abduction was established in pilot work (intraclass correlation coefficient = 0.76–0.98, standard error of the mean = 0.24 mm, minimal detectible difference 95% [$MDC_{95\%}$] = 0.67 mm). Real-time US measurement of the AHD was performed by an investigator (A.H.B.) with 4 years of experience using US in research to collect data on the shoulder before and during muscle stimulation with the NMES. She used MyLab 60 (model XVision; Esaote North America, Indianapolis, IN) with a 523 linear transducer and the image frequency set at 13 MHz. The US transducer was placed on the lateral aspect of the acromion in line with the longitudinal axis of the humerus to visualize the shortest distance between the humerus and acromion. Three consecutive US images of the AHD were captured before NMES stimulation. The physiotherapist applied the chosen NMES stimulation procedure to the participant. The investigator captured 3 more consecutive US images during muscle contraction while the participant was in 60° of passive shoulder abduction in the scapular plane (Figures 1 and 5). The stored images were reviewed using ImageJ software (version 1.32; National Institutes of Health, Bethesda, MD, http://imagej.nih.gov/ij/). Hyperechoic landmarks were marked consistently to identify the external inferior aspect of the acromion and the most superior aspect of the humerus, yielding the shortest distance between the 2 hyperechoic landmarks on the US images. Electronic line

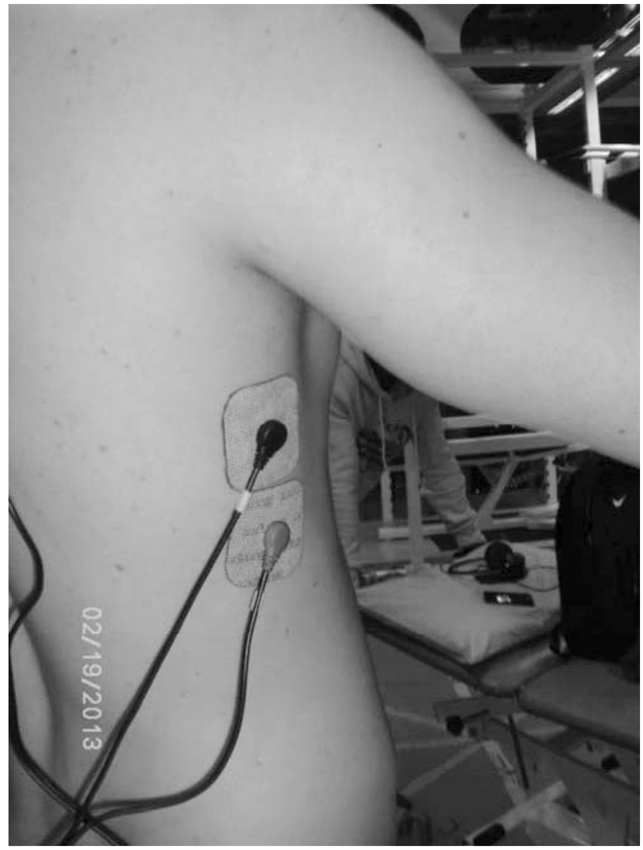

Figure 3. Serratus anterior muscle stimulation.

Figure 4. Combined lower trapezius and serratus anterior muscle stimulation.

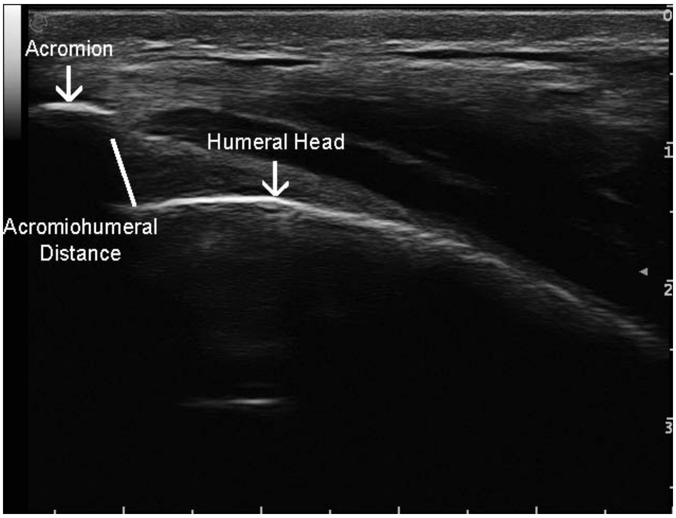

Figure 5. Ultrasound image shows the shortest tangential measure between the hyperechoic landmarks of the most superior aspect of the humerus and acromion.

calipers (ImageJ software) were used to make the measurements.

Data Analysis

We used a Kolmogrov-Smirnov test to assess the normality of distribution for the AHD variables. Normal distribution was observed. Paired-samples *t* tests were used to identify the differences between the AHD before and during each NMES procedure. A repeated-measures analysis of variance was used to detect between-groups differences. We set the α level at .05. The data were analyzed using SPSS statistical software (version 20.0; IBM Corporation, Armonk, NY).

RESULTS

The greatest increase in AHD was seen with NMES of the combined LT and SA muscles (Table). However, we observed no differences in the increased AHD among the 3 NMES procedures ($F_{2,57} = 3.109$, $P = .08$).

DISCUSSION

Reduced AHD has been associated with subacromial impingement syndrome in patients compared with healthy participants in studies involving real-time US, magnetic resonance imaging, and radiographs[6,38–41] and has been proposed as a predictive marker.[42] Intervention to increase the AHD with rehabilitation is common clinical practice. We are unaware of other investigators evaluating AHD as an outcome measure during NMES of the LT and SA muscles. Our study was designed to determine the immediate effect of muscle contraction stimulated by NMES on the AHD in asymptomatic shoulders. We observed that the AHD measured by US increased during muscle contraction when NMES was used to stimulate contraction of the SA muscle ($P = .001$) and the combined LT and SA muscles ($P = .001$). We noted no differences in the increased AHD among the NMES procedures ($P = .08$).

Whereas AHD increased during all 3 NMES procedures, the changes in AHD must be interpreted in relation to the $MDC_{95\%}$ to ensure that the change was not due to random measurement error. The change in AHD during NMES of LT was different, but the difference (0.45 mm) did not exceed the $MDC_{95\%}$ (0.67 mm) and cannot be interpreted as meaningful with complete confidence. In contrast, the changes in AHD during NMES stimulation of the LT and combined LT and SA (SA = 0.65 mm, combined LT and SA = 0.90 mm) in our study exceeded the $MDC_{95\%}$ measure and, therefore, can be interpreted with confidence.

Our results supported the hypothesis that the muscle force couple around the scapula is important in rehabilitation and scapular control. Isolated isometric hold of the individual muscles of LT and SA did not yield as great a change in the AHD as when the muscles were contracted simultaneously (Table). Our observation corroborates the ideas of researchers[2,9,23] who have suggested that training the LT and SA muscles maintains the AHD.

A number of methodologic limitations should be considered when interpreting our results. We could not blind the investigator to the NMES procedure being applied to rule out investigator bias. Only short-term effects on AHD were investigated, as the NMES contraction lasted merely 8 seconds. Further research is required to investigate the long-term effects of muscle strengthening on the AHD. All participants had healthy shoulders. Additional study is necessary in participants with subacromial impingement syndrome to determine if our results can be extrapolated to this group of patients. Furthermore, we did not address the difference in AHD when participants actively contracted their scapular muscles and when they received isolated NMES treatments. Research into these factors is important to clinicians treating patients with subacromial impingement syndrome.

CONCLUSIONS

Acromiohumeral distance increased during NMES of the LT muscle, SA muscle, and combined LT and SA muscles. No differences were observed in the increased AHD among the 3 NMES procedures. Further studies are needed to establish whether these changes are clinically important and could improve treatment outcomes in persons with subacromial impingement syndrome. Our results supported the hypothesis that the muscle force couple around the scapula is important in rehabilitation and scapular control and influences the AHD.

Table. Change in Acromiohumeral Distance With Neuromuscular Electrical Stimulation

	Time, mm				
Muscle(s)	Pretest	During Test	Mean Change, mm	*P* Value	t_{19} Value
Lower trapezius	9.80 ± 2.31	10.25 ± 2.43	0.45	.004	−3.89
Serratus anterior	9.35 ± 2.32	10.00 ± 2.36	0.65	.001	−7.67
Combined lower trapezius and serratus anterior	9.35 ± 2.64	10.25 ± 2.43	0.90	.001	−5.09

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