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Shoulder muscle activation patterns and levels differ between open and closed-chain abduction

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ABSTRACT

Objectives: Open and closed-chain abduction of the shoulder are commonly used in rehabilitation and exercise programs to assess and/or improve shoulder muscle function. However, it is not known if shoulder muscle activation patterns differ between these two exercises. Therefore the purpose of this study was to compare muscle activation patterns during closed-chain shoulder abduction performed using a shoulder press machine with open-chain abduction using free weights.
Design: Experimental study.
Methods: Open and closed-chain abduction were performed by 15 and 14 subjects respectively at low (25%), medium (50%) and high (75%) load. Surface and indwelling electrodes were used to record the activation pattern of seven shoulder muscles during the concentric phase of each exercise. Data were normalised to maximum voluntary contractions (MVC), time normalised and compared over the common range of motion (40°–140° abduction).
Results: Only the activation pattern of middle deltoid had a strong positive correlation between exercises ($r \geq 0.65$, $p < 0.05$) with similar activation levels at all loads (35%, 50% and 60% MVC, $p = 1.0$). All other muscles tested had inconsistent, low or negative correlations between exercises. Significantly lower average activation levels were recorded during closed-chain abduction for subscapularis at all loads, upper trapezius at medium and high loads and infraspinatus and lower trapezius at high load ($p < 0.05$).
Conclusions: Open-chain abduction is required to facilitate the stabilising role of the rotator cuff and axioscapular muscles, in response to middle deltoid activity. Closed-chain exercises may enable full range shoulder abduction earlier in rehabilitation programs, with an inherent stability and less demand on the rotator cuff.

1. Introduction

Open-chain exercises have traditionally been used in shoulder rehabilitation but closed-chain exercises are becoming increasingly popular. Open-chain exercises were originally defined by Steindler as exercises where the distal segment moves freely without any resistance. Closed-chain exercises were then described as exercises where the distal segment meets 'considerable' resistance and therefore restrains free motion.[1] With 'considerable' not being well described, this definition has been modified in recent literature and a continuum from closed to open chain has been proposed as a better way of explaining the closed/open-chain phenomenon.[2] An open-chain exercise would be freely moving with no external load and then the other end of the continuum would be a fixed distal segment with an immoveable load. Somewhere in the middle would include exercises where the distal segment is guided through the movement by a machine or wall as resistance e.g. a military press or leg press machine. It is thought that closed-chain exercises provide greater axial loading and compression to the joint than open chain exercises reducing translation of the joint surfaces during movement.[3–5] For this reason they are recommended for use early in rehabilitation programs.[5–7]

Shoulder abduction in the scapular plane is considered the most functional plane of abduction with optimal bony and muscle alignment of the glenohumeral joint.[8] Abduction of the shoulder can be performed as an open-chain exercise with free weights and as a closed-chain exercise using a shoulder press machine. Open-chain shoulder abduction is used routinely in the assessment of shoulders[9] and both exercises are commonly used in shoulder rehabilitation and strength training programs[10,11] to restore or improve

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normal muscle function. It has been suggested that the closed-chain shoulder press, also referred to as the military press, is a similar exercise to open-chain shoulder abduction[12] and that the shoulder press, or bent arm abduction, would be a suitable precursor exercise to straight arm abduction in a rehabilitation program.[7,12]

Previous electromyography (EMG) research during open-chain scapular plane abduction indicates that deltoid, supraspinatus, subscapularis, infraspinatus, upper and lower trapezius and serratus anterior are activated at moderate (20–50% maximum voluntary contraction (MVC)) average activation levels.[13,14] The shoulder press exercise has traditionally been regarded as an exercise for deltoid and upper trapezius[15] but has also been shown to activate subscapularis,[10] supraspinatus[10] and serratus anterior[11] at high (>50% MVC) peak activation levels. To effectively prescribe open-chain shoulder abduction and the closed-chain shoulder press exercise during rehabilitation and strength training programs a clear understanding and comparison of the muscle activity levels and activation patterns during these exercises needs to be established. As no EMG study has directly compared muscle activity during the shoulder press exercise and shoulder abduction using free weights, the aim of this experiment was to compare shoulder muscle activity levels and activation patterns during the closed-chain shoulder press with open-chain shoulder abduction, both in the scapular plane, under different loading conditions.

2. Methods

Twenty nine asymptomatic volunteers were recruited for this study. Fifteen (ten male and five female, average age 21.9 ± 3.0 years) participated in the closed-chain protocol and 14 (nine male and five female, average age 22.5 ± 7.7 years) participated in the open-chain protocol. Subjects were included if they reported no shoulder pain in the previous two years and had never received treatment for shoulder pain. Prior to testing a physical examination was performed by the same experienced physiotherapist, to confirm normal range of shoulder movement, normal scapulohumeral rhythm and no pain during isometric rotation testing. The dominant shoulder (defined as the preferred hand to perform fine motor tasks) of all volunteers was examined. The protocol was explained to all subjects prior to testing and each subject gave written consent. The study was approved by the University Human Research Ethics Committee.

Seven shoulder muscles were investigated using a combination of surface and indwelling electrodes to simultaneously record electromyographic (EMG) data. Paired Ag/AgCl surface electrodes (Red Dot, 2258, 3M) were placed over the large superficial muscles; upper trapezius and middle deltoid. The skin was shaved if necessary, exfoliated with abrasive gel (Nuprep, DO Weaver and Co., Aurora, US) and cleaned with alcohol wipes. Electrodes were placed parallel to the muscle fibre direction, according to Palastanga et al.,[16] with a centre–centre distance of 20 mm and an inter-electrode resistance ≤5 kΩ measured by an ohm meter was confirmed.

Bipolar intramuscular electrodes were inserted into five shoulder muscles; infraspinatus,[17] and serratus anterior[18] where evidence indicates that valid data cannot be achieved with the use of surface electrodes; supraspinatus and subscapularis which are inaccessible to surface electrodes, and lower trapezius. Insertion sites followed the recommendations of Kadaba et al.[19] for subscapularis and Geiringer[20] for all other muscles tested. Electrodes were manufactured in our laboratory from 0.14 mm insulated wires with 2 mm on the ends stripped of the insulation and bent back to form a hook.[21] The wires were threaded through a 23 gauge needle which was used as a cannula to insert the electrodes. The skin around the insertion site was prepared with application of alcohol, antiseptic solution (Betadine, Faulding Healthcare Pty Ltd., Virginia, Australia) and anaesthetic gel (Xylocaine 2% jelly, AstraZeneca Pty Ltd., NSW, Australia). A large surface electrode (Universal Electrosurgical Pad: Split, 9160F, 3M) was placed over the spine and acromion of the scapula of the contralateral shoulder as an earth connection. The electrodes were connected to leads and taped to the subject's back to prevent the pulling of the wires from the muscle but at the same time enabling adequate excursion of the wires during testing. Intramuscular electrode placement was confirmed by observing signals during submaximal contraction expected to activate the target muscle and contractions where the target muscle would be expected to be relatively inactive.[22] Placement of electrodes into lower trapezius was confirmed using a digital ultrasonic diagnostic imaging system (Mindray, DP-9900) due to difficulty of accurately differentiating this thin muscle from neighbouring muscles with submaximal contractions.

EMG signals were amplified and filtered (Iso-DAM 8 amplifiers, World Precision Instruments, gain = 100–1000, bandpass filtered between 10 Hz and 1 kHz) before transferring to a personal computer with a 16 bit analog to digital converter (1401, Cambridge Electronics Design) at a sampling rate of 2564 Hz using Spike2 software (version 4.00, Cambridge Electronics Design).

Prior to electrode placement, the participants were familiarised with the equipment and exercise protocols. A one repetition maximum value of the load the subject could lift without compensatory scapular or trunk movements was recorded as the 100% maximum load for each of the closed-chain shoulder press and open-chain abduction exercises. This value was then used to calculate low load (25%), medium load (50%) and high load (75%) values to be used during testing.

Following electrode placement, four maximal isometric normalisation tests were then performed in random order, with three repetitions of each test and at least 30 s break between each repetition. These tests have been shown to have a 95% likelihood of producing maximum activity in all the muscles tested in the current study[23] and included; resisted shoulder internal rotation at 90° abduction, resisted horizontal adduction at 90° flexion, resisted abduction at 90° abduction and resisted flexion at 125° flexion. The maximum EMG value recorded for each muscle during these tests was used as the reference value to normalise data for that muscle during analysis.

Movement was determined using a draw wire sensor (Micro-Epsilon, WPS-1000-MK46-P10, Germany) attached to the weight stack during the shoulder press exercise and to a cuff on the participant's wrist during the abduction exercise and synchronised with the EMG signals. The shoulder abduction angle at the start and end of movement was measured using a hand held goniometer.

The closed-chain shoulder press exercise was performed in an upright sitting position with the lower back supported using a multipurpose gym machine (Hyper Extension Gym 50036). Seat height was adjusted so the starting position was at 40° shoulder abduction in the scapular plane and elbows flexed. The bar of the machine was lifted until the shoulders were abducted to 140° and elbows fully extended to a count of 2 s (~60°/s) during the concentric phase of abduction and the movement was performed twice.

The open-chain shoulder abduction exercise was performed with volunteers standing upright, looking forward with their feet comfortably spaced apart. Both scapulae were held in neutral position and the non-dominant hand was rested on the adjacent hip. The volunteer held a dumbbell weight with the elbow extended and thumb pointing outwards and leading through the movement. Tape markings on the floor were used as a guide to indicate the scapular plane of movement and an examiner standing on this line provided an additional visual target for the volunteer. The dominant arm was raised to full range (0°–180°) abduction to a count of 3 s during