Direction-specific recruitment of rotator cuff muscles during bench press and row

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ABSTRACT

Recent studies indicate that rotator cuff (RC) muscles are recruited in a reciprocal, direction-specific pattern during shoulder flexion and extension exercises. The main purpose of this study was to determine if similar reciprocal RC recruitment occurs during bench press (flexion-like) and row (extension-like) exercises. In addition, shoulder muscle activity was comprehensively compared between bench press and flexion; row and extension; and bench press and row exercises. Electromyographic (EMG) activity was recorded from 9 shoulder muscles sites in 15 normal volunteers. All exercises were performed at 20, 50 and 70% of subjects’ maximal load. EMG data were normalized to standard maximal voluntary contractions. Infraspinatus activity was significantly higher than subscapularis during bench press, with the converse pattern during the row exercise. Significant differences in activity levels were found in pectoralis major, deltoid and trapezius between the bench press and flexion exercises and in lower trapezius between the row and extension exercises. During bench press and row exercises, the recruitment pattern in each active muscle did not vary with load. During bench press and row exercises, RC muscles contract in a reciprocal direction-specific manner in their role as shoulder joint dynamic stabilizers to counterbalance antero-posterior translation forces.

1. Introduction

A recent study has indicated that the rotator cuff (RC) muscles are recruited in a reciprocal pattern during shoulder flexion and extension exercises (Wattanaprakornkul et al., 2011a). During flexion, the posterior RC muscles (supraspinatus and infraspinatus) were activated at significantly higher levels than the anterior RC muscle (subscapularis), while during extension the anterior RC muscle was activated at significantly higher levels than the posterior RC muscles (Wattanaprakornkul et al., 2011a). The authors concluded that during these sagittal plane tasks, the RC muscles are recruited in a direction-specific manner to prevent potential antero-posterior humeral head translation caused by flexion and extension torque producing muscles, similar to the role of the inferior RC muscles in preventing superior humeral head translation during shoulder abduction (Blasier et al., 1992; Inman et al., 1944; Sharkey et al., 1994).

The shoulder flexion and extension exercises investigated in the study by Wattanaprakornkul et al. (2011a) were performed in prone lying. Such shoulder exercises are not commonly performed during shoulder exercise programs. Bench press and row exercises, however, are common and popular strength training exercises which require shoulder flexion and extension movements, respectively. The results of Wattanaprakornkul et al. (2011a) would suggest that RC muscles are recruited in a similar reciprocal manner during bench press (flexion-like) exercises and row (extension-like) exercises.

Previous electromyography (EMG) studies examining RC muscle recruitment patterns during bench press (Decker et al., 2003; Hintermeister et al., 1998; Illyes and Kiss, 2005) and row (Hintermeister et al., 1998; Illyes and Kiss, 2005; Townsend et al., 1991) exercises using dumbbell (Townsend et al., 1991) and elastic resistance (Decker et al., 1999, 2003; Hintermeister et al., 1998; Illyes and Kiss, 2005) lend some support to this hypothesis. Two studies suggest that the average activity levels in supraspinatus during bench press are higher than subscapularis activity levels (Decker et al., 2003; Hintermeister et al., 1998) although another study appears to indicate similar activity levels in infraspinatus and subscapularis (Decker et al., 2003). Only two studies have reported RC muscle activity levels during the row exercise with results implying similar activity levels in supraspinatus and infraspinatus (Illyes and Kiss, 2005) which were higher than subscapularis levels (Hintermeister et al., 1998). However, all these potential differences in muscle activity levels were evaluated using mean values from tables provided in these previous studies but were not confirmed using statistical analysis. Consequently, the normal recruitment pattern of RC muscles activated during bench press and row
exercises has not been established. Therefore, the primary aim of this study was to investigate whether there is a similar reciprocal recruitment pattern in the RC muscles during bench press and row exercises as has been reported for flexion and extension exercises, by comparing RC muscle recruitment levels between bench press and flexion exercises, between row and extension exercises, and between bench press and row exercises.

To perform bench press and row exercises, coordinated movement of the humerus and scapula is necessary in order to achieve the range of motion required and to maintain optimal scapulohumeral (including RC) muscle alignment. However, none of the previous studies that have investigated shoulder muscle activity during bench press and row exercises (Decker et al., 1999, 2003; Ekstrom et al., 2003; Hintermeister et al., 1998; Illyes and Kiss, 2005; Moseley et al., 1992; Townsend et al., 1991) have simultaneously investigated activity in muscles from each of the axiohumeral, axioscapular and RC muscle groups during these exercises. To gain a thorough understanding of shoulder muscle coordination during bench press and row exercises, a comprehensive investigation of the recruitment patterns of all the shoulder muscle groups is required. Therefore, additional aims of this study were to compare:

- Activity levels of muscles from all shoulder muscle groups between the bench press and row exercises; bench press and flexion exercises; and row and extension exercises
- Recruitment patterns of muscles from all shoulder muscle groups during the bench press and row exercises.

Finally, as most exercise programs use gradually increasing load to achieve strength gains, investigation of shoulder muscle recruitment patterns during low, medium and high load conditions is also necessary to understand muscle recruitment requirements as load increases. No previous EMG studies investigating shoulder bench press and row exercises have compared muscle recruitment patterns with increasing load. Therefore, the final aim of this study was to compare recruitment patterns of muscles from all shoulder muscle groups during bench press and row exercises under low, medium and high load conditions.

2. Materials and methods

The comparison in muscle activity levels, as well as the consistency of activation pattern as load increases, have been previously reported (Wattanaprakornkul et al., 2011a) for the flexion and extension exercises in the same subject cohort examined in the current study. Consequently, the following methods are similar to those previously described by Wattanaprakornkul et al. (2011a).

2.1. Subjects

Ten males and five females (15 subjects) with normal dominant shoulder function participated in this study. The mean (standard deviation) age of this group was 21.9 (±3.0) years, mean height 170.5 (±12.2) cm, and mean weight 67.1 (±13.9) kg. Shoulder function was defined as normal if the subject had not experienced pain in their dominant shoulder for at least the previous two years and had never sought treatment for pain in their dominant shoulder. In addition, volunteers were examined by an experienced physical therapist to confirm they had full pain-free normal range of shoulder motion, normal scapulohumeral rhythm (assessed by visual inspection) and no pain during maximal voluntary isometric internal and external shoulder strength testing of their dominant shoulder. This research was approved by the University of Sydney Human Research Ethics Committee (Reference No.: 07-2007/10122) and all subjects gave written informed consent before participating in the study.

2.2. Instrumentation

EMG data were collected simultaneously from nine shoulder muscle sites using a combination of indwelling and surface electrodes. The indwelling electrodes were constructed according to the method of Basmajan and De Luca (1985). Two strands of Teflon coated stainless steel wire of 0.14 mm diameter were inserted through a hypodermic canula. Each wire was bent back to form a barb, one wire at 2 mm from the end and the other at 4 mm. The terminal 1 mm of each end was de-insulated. Using the canulae, indwelling electrodes were inserted into supraspinatus, infraspinatus, subscapularis, lower trapezius, serratus anterior, and latissimus dorsi with the subject lying prone. The electrode insertion site for the subscapularis was standardized as described by Kadaba et al. (1992), with all other placements as described by Geiringer (Geiringer, 1994). Indwelling electrodes were used for muscles that either underlie more superficial muscles (supraspinatus, subscapularis), are thin and overlie other muscles (lower trapezius, latissimus dorsi), or for muscles that shift with respect to the overlying soft tissue during shoulder movement (infraspinatus, serratus anterior). Correct indwelling electrode placement was confirmed by the visual comparison of the EMG signals during standardized submaximal tests expected to produce a large amount of activity in each of these muscles compared with tests expected to generate low activity in these muscles or activate surrounding muscles into which the electrode may have been incorrectly placed (Boetchter et al., 2008).

The subjects were then seated and their skin prepared with alcohol and an abrasive gel to reduce skin impedance prior to surface electrode application. Two Ag/AgCl surface electrodes (Red Dot, 2258, 3 M, Sydney, Australia) were placed 2 cm apart over upper trapezius (McLean et al., 2003), deltoid (middle section), and pectoralis major (Kelly et al., 1996). Inter-electrode resistances were measured and ensured to be below 10 kΩ. A large ground electrode (Universal Electrosurgical Pad: Split, 9160F, 3 M, Sydney, Australia) was placed over the scapula extending along the spine and acromion of the non-dominant shoulder.

EMG signals from surface and intramuscular electrodes were amplified (Iso-DAM 8 amplifiers, World Precision Instruments, Sarasota, FL; gain = 1000, CMRR > 100 dB at 50 Hz) and hardware band-pass filtered (10–1000 Hz). The data were acquired using a 16 bit analog to digital converter (1401, Cambridge Electronics Design, Cambridge, UK) using Spike2 software (version 4.00, Cambridge Electronics Design, Cambridge, UK) at a sample rate of 3571 Hz for later off-line analysis (Matlab version 7, The Math Works, Natick, MA).

The bench press and row exercises were performed in sitting on the Hyper Extension Gym 50036 equipment (Fig. 1) and the flexion and extension exercises were performed in a prone lying position (Fig. 2). The movement of the arm through each exercise cycle was recorded using a draw-wire sensor (Micro-Epsilon, WPS-1000-MK46-P10, Germany). All exercises were performed with constant resistance and each repetition of each exercise consisted of both concentric and eccentric phases.

2.3. Examination procedure

Prior to electrode placement, each subject practiced correct performance of the four exercises under investigation at a standardized speed. Each exercise was to be completed in approximately four seconds – two seconds for each of the concentric and eccentric phases. In addition, the maximal load each subject could lift during these exercises was determined. The maximal load for each subject was defined as the maximum load to complete a 1-repetition
maximum for each exercise ensuring normal scapulohumeral rhythm and without compensatory movement of the trunk. Following confirmation of correct electrode placement, subjects performed three repetitions of the four Shoulder Normalization Tests in random order: resisted abduction with the shoulder abducted 90° and internally rotated; resisted internal rotation at 90° shoulder abduction; resisted flexion at 125° shoulder flexion; resisted adduction at 90° shoulder flexion. A rest period of at least 60 s was given to the subjects between repetitions of each of the Shoulder Normalization Tests. These maximum voluntary isometric contractions have been reported to have a 95% chance of eliciting maximum activity in all the muscles tested in the current study (Boettcher et al., 2008). Resting EMG levels were then established, before the subject performed the bench press, row, flexion and extension exercises with 20%, 50%, and 70% of maximal load. The order of exercise was block randomized and load levels were randomized within each exercise to avoid any systematic influences of fatigue and/or learning effects. Four consecutive repetitions of each exercise were performed at each load and a rest period of at least 60 s was given between each load and at least 5 min between each exercise.

2.4. Signal and statistical analyses

All raw EMG signals were preprocessed in the same way: high pass filtered (10 Hz, 8th order Butterworth), rectified, and low pass filtered (3 Hz, 8th order Butterworth). After subtracting resting EMG levels the envelopes of EMG activity extracted in this way were normalized to the maximum value measured during the standard Shoulder Normalization Tests. The EMG signals were then time normalized and averaged across the middle two trials (the trials not influenced by the initiation or completion of the exercise) for each subject, each exercise and each load. Three factor repeated measures ANOVAs (Statistica Version 7.1 Statsoft, US) were performed to compare the EMG levels between bench press and flexion exercises, row and extension exercises and bench press and row exercises, nine shoulder muscles tested, and low, medium and high load levels. Tukey's post hoc analysis was used when significant ANOVA results were found. The level of significance was set at $p < 0.05$. In addition, Pearson's correlation analyses were conducted between each pair of the average time normalized muscle activation signals to evaluate the consistency of the pattern of activation across muscles and loads.

3. Results

3.1. Average muscle activity levels

3.1.1. (i) A comparison between bench press and flexion and between row and extension exercises

The normalized average EMG (group mean ± SD) of the nine muscles examined across loads for the bench press and flexion and for the row and extension exercises are shown in Figs. 3 and 4, respectively. The results of the repeated measures ANOVA indicated the following effects:

- Significant difference in overall muscle activity levels between the bench press and flexion ($F_{1,14} = 21.5$, $p < 0.01$) but not between the row and extension exercises ($F_{1,14} = 1.4$, $p = 0.25$).
- Significant differences in activity levels for different muscles ($F_{8,112} = 17.2$, $p < 0.001$).
- The activity levels in individual muscle(s) were different between bench press and flexion exercises and between row and extension ($F_{8,112} = 3.7$, $p < 0.001$).
The results of the Tukey post hoc analyses which showed differences in the average muscle activation between the bench press and flexion exercises and between the row and extension exercises are indicated with “*” in Figs. 3 and 4, respectively. The differences are summarized as follows:

- During the flexion exercise, deltoid, upper trapezius and lower trapezius were more active while pectoralis major was less active than during the bench press exercise ($p < 0.05$).
- During the extension exercise, lower trapezius was less active than during the row exercise ($p < 0.05$).
3.1.2. (ii) Comparison between bench press and row exercises

The normalized average EMG (group mean ± SD) of the nine muscles examined at 20%, 50%, and 70% of maximal load for the bench press and row exercises are shown in Fig. 5A. The results of the repeated measures ANOVA indicated the following effects:

- No significant difference in overall muscle activity levels between the two exercises examined ($F_{1,14} = 43$, $p = 0.06$)
- Significant differences in activity levels for different muscles ($F_{8,112} = 4.8$, $p < 0.001$)
- Significant differences in muscle activity levels for different loads ($F_{2,28} = 228.4$, $p < 0.001$)
- The activity levels in individual muscle(s) were different between the different exercise types ($F_{8,112} = 29.3$, $p < 0.001$) and loads ($F_{16,224} = 2.0$, $p < 0.05$)

The results of the Tukey post hoc analyses are summarized below:

- Significant differences in muscle activity levels between the bench press and row exercises (indicated with ‘*’ in Fig. 5A).
- Differences in muscle activity levels during the bench press exercise are shown in Fig. 5B – muscles are ordered by decreasing activity levels and muscles grouped by boxes have no significant differences.
- Significant differences in muscle activity levels between the bench press and row exercises (indicated with ‘*’ in Fig. 5A).
- Differences in muscle activity levels during the bench press exercise are shown in Fig. 5B – muscles are ordered by decreasing activity levels and muscles grouped by boxes have no significant differences.

Fig. 4. The average (+SD) EMG (% MVC) of the nine muscles during row and extension exercises across all loads. ‘Significant difference in muscle activity level between the row and extension exercises ($p < 0.05$).

Fig. 5. (A) The average (+SD) EMG (% MVC) of the nine muscles during bench press and row exercises at 20%, 50%, and 70% of maximal load. ‘Significant difference in muscle activity level between the bench press and row exercises ($p < 0.05$). Muscles ordered by level of activity and grouped by boxes indicating no significant differences together with associated $p$-value from Tukey post hoc tests for (B) bench press and (C) row exercises.
Differences in muscle activity levels during the row exercise are shown in Fig. 5C with muscles ordered by decreasing activity levels and boxes indicating no significant differences.

There was a significant increase in activity level with load \((p < 0.05)\) in all muscles that were activated at least 20% MVC during the high load condition in each of the bench press (i.e.

**Fig. 6.** Time normalized average EMG (% MVC) activity of the nine muscles and the draw-wire sensor (arbitrary units) during both bench press and row exercises at 20%, 50%, and, 70% load. The correlation co-efficients \(r\) between loads are indicated for each muscle. Note: grayed boxes indicate minimal average activation (<10% MVC) during the exercise.
supraspinatus, infraspinatus, lower trapezius, serratus anterior, deltoid, and pectoralis major) and row exercises (i.e. latissimus dorsi, subscapularis, upper trapezius, and lower trapezius).

3.2. Patterns of muscle activity

The average patterns of time normalized EMG for each muscle during both bench press and row exercises are illustrated in Fig. 6. For muscles recruited >10% MVC (i.e. greater than minimum levels) during each exercise, the results of the Pearson's correlation analyses indicated that within each muscle and for both exercises, the muscle activation pattern was similar for low, medium and high load conditions ($r > 0.63$, $p < 0.05$).

4. Discussion

The results of this study indicate that the commonly performed bench press and row exercises recruit RC muscles at levels similar to flexion and extension exercises performed in prone lying. There were no significant differences in the activity levels of the RC muscles between bench press and flexion exercises and between row and extension exercises.

The RC recruitment patterns during bench press and row exercises, however, differed from that observed between flexion and extension exercises. During the flexion and extension exercises performed in prone all RC muscles examined exhibited a direction-specific recruitment pattern (Wattanaprakornkul et al., 2011a). In contrast, only the posterior RC (supraspinatus and infraspinatus) were recruited at significantly higher levels during the bench press compared with the row exercise, with no significant difference in anterior RC (subscapularis) activity levels between these two exercises. In addition, although there was no significant difference in posterior RC activity levels during either the bench press or row exercises with infraspinatus and supraspinatus recruited at similar levels, only part of the posterior RC (infraspinatus) exhibited a reciprocal recruitment pattern with subscapularis during the bench press and row exercises. Infraspinatus was recruited at significantly higher levels than subscapularis during the bench press, while subscapularis was recruited at significantly higher levels than infraspinatus during the row exercise. Subscapularis and supraspinatus activity levels were not significantly different in either bench press or row exercises.

These results indicate that RC muscles are recruited in a direction-specific pattern during bench press and row exercises similar to the RC recruitment pattern previously demonstrated during flexion and extension exercise performed in prone (Wattanaprakornkul et al., 2011a). Part of the posterior RC (infraspinatus) was recruited at significantly different levels to the anterior RC (subscapularis) during both the bench press and row exercises. This reciprocal recruitment pattern of some RC muscles indicates that RC co-activation at similar levels – in order to globally compress the articular surfaces – cannot be the mechanism whereby the RC muscles are providing shoulder joint dynamic stability during bench and row exercises. The significantly higher posterior RC activity during bench press (a flexion-like exercise) and significantly higher anterior RC activity during row (an extension-like exercise) supports the hypothesis proposed by Wattanaprakornkul et al. (2011a) that the RC provides shoulder joint support by preventing flexion and extension prime movers of the humerus from translating the humeral head on the glenoid fossa.

With respect to the muscles examined which are capable of producing extension or flexion torque (Palastanga et al., 2006; Rockwood and Matsen, 2009), the results of this study indicate that activity levels were more similar between the row and extension exercises examined than between the bench press and flexion exercises. While latissimus dorsi and deltoid did not differ in their recruitment patterns between row and extension exercises, significant differences in activity levels in the muscles capable of producing flexion torque were found between the bench press and flexion exercises. Although there were no significant differences in pectoralis major and deltoid activation levels during the bench press exercise, pectoralis major was activated at significantly higher levels in the bench press exercise compared with flexion, while deltoid was activated at significantly higher levels during the flexion exercise compared with bench press. These differences are probably due to differences in the “flexion” tasks examined. The bench press exercise was performed from a starting position with the shoulder in 20–30° abduction while the flexion exercise was performed with the arm by the side of the body i.e. 0° abduction. Therefore, while both exercises involved movement into shoulder flexion, the bench press also involved shoulder adduction. Significantly higher recruitment of pectoralis major, which produces both shoulder flexion and adduction torque (Palastanga et al., 2006) would therefore, be expected during the bench press exercise compared with the flexion exercise.

The significantly different activity levels recorded in pectoralis major and latissimus dorsi during the bench press and row exercises examined, provide evidence to suggest that the RC muscles are functioning to stabilize the shoulder joint during these exercises in a similar manner to that proposed by Wattanaprakornkul et al. (2011) during flexion & extension exercises performed in prone (Wattanaprakornkul et al., 2011a). Higher pectoralis major activity was recorded during the bench press with higher latissimus dorsi activity during the row exercise. Evidence indicates that activity in pectoralis major can cause an anterior displacement of the humeral head (McMahon et al., 2002; Sinha et al., 1999) which infers that activity in latissimus dorsi will result in posterior humeral head translation. Similar to the manner in which the inferior RC muscles prevent deltoid from superiorly translating the humeral head during shoulder abduction (Basier et al., 1992; Inman et al., 1944; Sharkey et al., 1994), RC muscles are recruited during both exercises to prevent antero-posterior displacement of the humeral head. Infraspinatus (a posterior RC muscle) was recruited at significantly higher levels than subscapularis (anterior RC muscle) during bench press to counterbalance the potentially destabilizing anterior translational forces produced by pectoralis major. Similarly, subscapularis was recruited at significantly higher levels than infraspinatus during the row exercise to counteract unwanted posterior humeral head translation due to latissimus dorsi activity.

The results of the current study have implications for RC rehabilitation programs. Since bench press and row exercises recruit the RC muscles in their role as stabilizers of the shoulder joint, these exercises offer a more functionally specific method of retraining the stabilizer function of these muscles than more commonly used rotation exercises which recruit the RC muscles in their torque producing role (Boetcker et al., 2010; Dark et al., 2007). In addition, as bench press and row exercises recruit different RC muscles, they can be used to target particular RC muscles. Similar to external and internal shoulder rotation exercises, bench press and row exercises can specifically recruit infraspinatus and subscapularis, respectively. In contrast to rotation exercises, however, bench press and row exercises will not only specifically strengthen these RC muscles but also train the co-ordination necessary to enable them to respond to the potentially destabilizing forces generated by flexion and extension torque producing muscles.

As has been implied in a previous EMG study (Illyes and Kiss, 2005), deltoid was recruited at similar levels during the bench press and row exercises examined in the current study. Since both the bench press and row exercises were performed in...
similar degrees of shoulder abduction, similar levels of deltoid activity would be expected in order to maintain this abduction position. In addition, the main torque producing muscles in both the bench press (pectoralis major) and row (lattissimus dorsi) exercises produce adduction torque (Palastanga et al., 2006; Rockwood and Matsen, 2009). Deltoid activity would therefore, be necessary to prevent these muscles from adducting the shoulder i.e. deltoid is required to act as a synergist to prevent the unwanted adduction that these torque producing muscles would otherwise produce. Finally, anterior and posterior deltoid could have been contributing to producing shoulder flexion torque during bench press, and shoulder extension torque during row, respectively. It is possible that some activity from these parts of deltoid could have been recorded by the surface electrode placed over the middle of the belly of deltoid.

The activity levels recorded in upper and lower trapezius in the exercises examined in this study are mostly explained by the amount of scapular upward (lateral) rotation required to perform each exercise. Scapular upward rotation accompanies shoulder flexion and abduction in order to maintain shoulder joint articular surface contact as well as optimal alignment of the RC muscles, and upper and lower trapezius are the main components of the scapular upward rotation force couple as full range flexion/abduction is approached (Bagg and Forrest, 1986). The bench press exercise required movement to a maximum of 50% flexion range while the flexion exercise performed in prone required movement into full range flexion necessitating increased scapular upward rotation and the higher activity levels recorded in upper and lower trapezius. As both the bench press and row exercises were performed at approximately the same shoulder abduction position, the similar levels of upper and lower trapezius activity recorded during these exercises were to be expected.

Scapular upward rotation requirements, however, cannot explain the higher activity levels recorded in lower trapezius during the row compared to the extension exercise, and the higher serratius anterior levels recorded during the bench press exercise compared to the row exercise. We can only hypothesise that lower trapezius may have been providing some scapular retraction force (Boettcher et al., 2010), and serratus anterior some scapular retraction force, to “assist” in performing the row and bench press exercises, respectively.

Similar to other studies investigating muscle recruitment, however, cannot explain the higher activity levels recorded in lower trapezius during the row compared to the extension exercise, and the higher serratus anterior levels recorded during the bench press exercise compared to the row exercise. We can only hypothesise that lower trapezius may have been providing some scapular retraction force (Boettcher et al., 2010), and serratus anterior some scapular retraction force, to “assist” in performing the row and bench press exercises, respectively.

5. Conclusion

During bench press (flexion-like) and row (extension-like) exercises, the RC muscles are recruited in a direction specific manner under all load conditions to prevent potential anterior-posterior humeral head translation caused by the respective torque producing muscles.

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