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Electromyographic analysis of muscles of the shoulder complex during external rotation exercises with elastic band

Análise eletromiográfica de músculos do complexo do ombro durante exercícios de rotação externa com faixa elástica

Análisis electromiográfico de los músculos del complejo del hombro durante ejercicios de rotación externa con banda elástica

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ABSTRACT | In shoulder arthrokinematics, the rotator cuff acts on a lower base to counterbalance a glenoid cavity, while performing a lower translation to counterbalance a rotational force mostly provided by the deltoid. External rotation (ER) exercises have been used in the rehabilitation of patients with shoulder joint dysfunction, with the aim of restoring arthrokinematics. Few studies approached the use of the elastic band and the evaluation of the shoulder girdle muscles, essential for suitable kinematics. The objective of this study was to compare the electromyographic activity (EMG) of the muscles from the shoulder complex during external rotation exercises with elastic band. A total of 11 male subjects were evaluated during (1) ER in orthostasis; (2) ER with shoulder abduction; (3) ER with lateral decubitus. The muscles assessed by the EMG were: (a) upper trapezius (UT); (b) middle deltoid (MD); (c) posterior deltoid (PD) and (d) infraspinatus (IS). Resistance was made with a gray elastic band calibrated with a load of 5% body weight. Data analysis was performed using the *application software* BIOMEC-SAS and statistics for the repeated measures using ANOVA in SPSS version 20.0. The UT and MD muscles were found to have increased EMG activity during ER exercise with shoulder abduction, as well as the PD muscle during ER with shoulder abduction and ER in lateral decubitus, whereas IS had increased EMG activity during an ER in orthostasis and ER in lateral decubitus.

Keywords | Shoulder; Electromyography; Rotator Cuff; Exercise Therapy.

RESUMO | Na artrocinemática do ombro, o manguito rotador atua estabilizando a cabeça umeral em contato com a cavidade glenoidal, enquanto realiza a translação inferior para contrabalancear a força rotacional promovida principalmente pelo deltoide. Exercícios de rotação externa (RE) vêm sendo utilizados na reabilitação de pacientes com disfunções no complexo do ombro buscando restaurar a artrocinemática. Porém, poucos estudos abordam a utilização da faixa elástica e a avaliação dos músculos da cintura escapular, determinantes para uma cinemática adequada. O objetivo deste estudo é comparar a atividade eletromiográfica (EMG) de músculos do complexo do ombro durante exercícios de rotação externa com faixa elástica. Participaram 11 sujeitos do sexo masculino que foram avaliados durante os movimentos de (1) RE em ortostase; (2) RE com abdução de ombro; (3) RE em decúbito lateral (DL). Os músculos avaliados pela EMG foram: (1) trapézio superior (TS); (2) deltoide médio (DM); (3) deltoide posterior (DP); e (4) infraespinal (IN). A resistência foi determinada por uma faixa elástica cinza calibrada com carga de 5% do peso corporal. A análise dos dados foi realizada no *software* Biomec-SAS e as estatísticas foram calculadas por meio da Anova de medidas repetidas no *software* SPSS v20.0. Pôde-se constatar que os músculos TS e DM

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obtiveram maior atividade EMG durante o exercício de RE com abdução de ombro, o músculo DP durante a RE com abdução de ombro e RE em decúbito lateral, enquanto o IN a obteve durante a RE em ortostase e RE em decúbito lateral.

Descritores | Ombro; Eletromiografia; Manguito Rotador; Terapia por Exercício.

RESUMEN | En la artrocinemática del hombro, el manguito rotador actúa estabilizando la cabeza umeral en contacto a la cavidad glenoidal, mientras realiza la traslación inferior para contrarrestar la fuerza rotacional promovida principalmente por el deltoides. Los ejercicios de rotación externa (RE) se han utilizado en la rehabilitación de pacientes con disfunciones en el complejo del hombro buscando restaurar la artrocinemática. Pocos estudios abordan la utilización de la banda elástica y la evaluación de los músculos de la cintura escapular, determinantes para una cinemática adecuada. El objetivo de este estudio es comparar la actividad electromiográfica (EMG) de los músculos del complejo del hombro durante ejercicios de rotación externa con banda elástica. Participaron 11 sujetos, varones, que fueron evaluados durante el movimiento de (1) RE en ortostasis; (2) RE con abducción de hombro; y (3) RE en decúbito lateral (DL). Los músculos evaluados por la EMG fueron: (a) trapecio superior (TS); (b) deltoides central (DC); (c) deltoides posterior (DP) e (d) infraespinoso (IN). La resistencia se determinó mediante una banda elástica gris calibrada con carga del 5% del peso corporal. El análisis de los datos se realizó con la utilización del *software* BIOMEC-SAS, y las estadísticas por medio de la ANOVA de medidas repetidas en el *software* SPSS v20.0. Se pudo constatar que los músculos TS y DC obtuvieron mayor actividad EMG durante el ejercicio de RE con abducción de hombro, el músculo DP durante la RE con abducción de hombro y RE en decúbito lateral, mientras que el IN durante la RE en ortostasis y en decúbito lateral.

Palabras clave | Hombro; Electromiografía; Manguito de los Rotadores; Terapia por Ejercicio.

INTRODUCTION

In normal shoulder arthrokinetics, the rotator cuff (RC) muscles act in a joint manner, stabilizing the humeral head in contact with the glenoid cavity[1-3] while lowering the humeral head, avoiding subacromial impact during superior limb elevation movements[2-6]. In addition, the demand caused by the scapulothoracic muscles contributes to an effective shoulder complex function[7-10].

During rotator cuff prevention or rehabilitation programs, external rotation (ER) exercises are generally used to improve the RC stabilization and recruitment ability to restore the functional and arthrokinetic balance of the shoulder complex. In the literature, ER exercises have been analyzed by means of electromyographic assessment (EMG)[2,3,11-13]. Although the literature presents several studies evaluating ER exercise, they still have limitations. One such limitation would be the disregard for the influence of shoulder girdle muscles such as the upper, middle, and lower trapezius, as well as the serratus anterior, which are determinant for proper kinematics. In addition, it is worth mentioning that patients with shoulder impingement syndrome (SIS) have reduced electromyographic activity of the anterior serratus, delayed activity of the middle and lower trapezius, and greater activation of the upper trapezius[14-19] and minor pectoral compared to healthy individuals[20], a fact which supports the importance of EMG evaluation of these muscles.

Another relevant aspect is that studies evaluating EMG activity during ER exercises usually with a dumbbell as external load[11-13] or perform the exercises in an isometric manner[2,3]. However, in physical therapy, external rotation exercises are commonly prescribed using elastic bands as external load[21]. In addition to being costworthy, bands are easy to handle and have individualized adjustments, and as such the physical therapist can vary the attachment point, the direction where resistance is applied, and the tension/resistance of the band by means of variation in length or different colorings, for instance[21,22]. These adjustments are directly related to load progression during the evolution of prevention/rehabilitation[8]. This demonstrates the importance of investigating muscle overload during variations of different shoulder ER exercises.

Assuming that ER exercises with elastic band as external load are important in shoulder rehabilitation, this study aims to compare the EMG activity of shoulder complex muscles during ER exercises with use of elastic bands.

METHODOLOGY

Study design and sampling

This is a quantitative observational and cross-sectional study with randomized sampling and

11 male subjects (mean age: 25.2±3.7 years; mean weight: 76.6±7.7kg; mean height: 175.2±6.4cm) with right upper limb dominance who have a range of motion (ROM) of at least 30° of external shoulder rotation and preserved muscle strength (grade 5). The following were exclusion criteria: (1) history of shoulder muscle injury; (2) shoulder joint fracture; (3) luxation or subluxation; (4) cervical dysfunction irradiated to upper limb. Sample size calculation was performed using the *application software* G*Power version 3.1.9.2 by adopting the following criteria: effect size of 0.5; 5% probability of error; 0.8 statistical power; correlation between measurements of 0.5; and assuming sphericity (E=1) for the Anova statistical test family for repeated measures.

Procedures

All collections were performed by two evaluators and scheduled according to participant availability. Prior to data collection, each subject signed an Informed Consent Form and performed a characterization evaluation, containing data such as age, weight and height. Initially, each subject underwent trichotomy and skin cleaning with alcohol in the sites where electrodes were placed. Electromyographic variables were obtained using the four-channel EMG Miotec with a 32bit A/D converter connected to a Lenovo brand notebook. The *application software* MiotecSuite was used with a sampling rate of 2,000Hz.

After skin preparation, surface electrodes (Ag/AgCl) were placed as recommended in the literature[23-25] under bipolar configuration for the upper trapezius (UT), middle deltoid (MD), posterior deltoid (PD) and infraspinatus (IS) muscles, whereas the reference electrode was positioned in the individual's collarbone (Figure 1).

After electrode placement, the subjects were instructed to sit in a chair with fixed support to perform maximal voluntary isometric contractions (MVIC) for each muscle evaluated in this study[23–25]. Collection of MVIC was randomized and consisted of two MVICs for each muscle, keeping the contraction for five seconds and with a three-minute interval between each repetition.

The MVIC of the posterior deltoid muscle was performed with shoulder abduction and elbow flexion at 90°, with 30° medial rotation. The subject was attempting to perform the abduction, extension and external rotation movements against the examiner's manual resistance. The MVIC for the middle deltoid muscle was performed with the subject's upper limb maintained at 90° abduction and with elbow flexed, and the examiner applied resistance in the distal region of the arm towards shoulder adduction. The MVIC of the upper trapezius muscle was performed by lifting the shoulders and tilting the head to the same side where a band was placed over the shoulder, which prevented elevation as the examiner kept their hands on the head, thus preventing inclination. The infraspinatus MVIC was tested with the upper limb close to the body and the elbow flexed at 90°. The subject would then perform the movement of external rotation and the examiner put resistance at the elbow level[23-25].

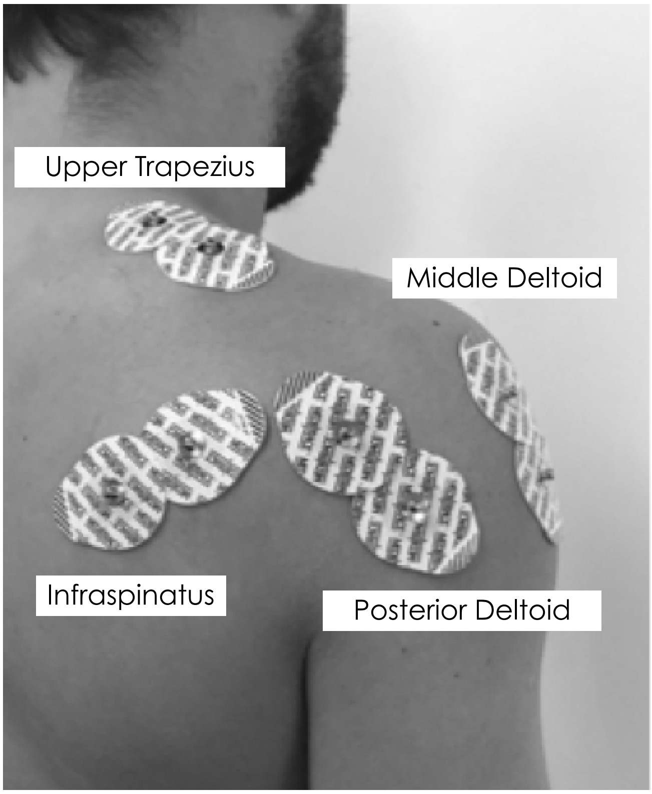

Figure 1. Surface electrode positioning for the UT, MD, IS and PD muscles

The following movements were demonstrated and performed by the individuals, consisting of: (A) external rotation in orthostasis with elbow flexion at 90°; (B) external rotation with shoulder abduction and 90° elbow flexion; (C) external lateral decubitus (LD) rotation and 90° elbow flexion (Figure 2).

Figure 2. External rotation movements evaluated with elastic band

Participants were aligned to the computer *webcam* and performed five repetitions of each movement at a self-selected speed. In all cases, resistance provided by a 60cm gray elastic band (*Theraband*) was used, with the strain previously calculated by the researchers through a literature calibration procedure[21]. The subject had to reach a maximum resistance of approximately 5% of body weight at the end of their range of motion[26] determined by calibration. After performing the movements, the cables and electrodes were disconnected, the individual's skin was cleaned, and participation in the research ended.

Data analysis

Electromyographic signals were analyzed using the *application software* Biomec SAS[27]. Initially, the signals collected during MVIC and rotational movements were subjected to a digital filtering procedure using a fourth-order Butterworth bandpass filter with a frequency band between 20Hz and 400Hz. After the filtering procedure, the first and last repetitions were discarded, leaving three central signals with kinematic data that were obtained by the *webcam* remaining. In the MVICs, the *root mean square* envelope (RMS) peak value of each muscle collected was used. The electromyographic signal was processed during the period starting from RMS envelope calculation with the one-second Hamming window function. The RMS value of each muscle analyzed was normalized by the ratio between the RMS value and the MVIC peak value.

Statistical analysis

Statistical analysis was performed using the *application software* SPSS version 20.0. Initially, data normality was verified by the Shapiro-Wilk test. Comparisons of the electromyographic data for each muscle were performed by means of repeated measures ANOVA, taking into account the factor exercise with three levels: (1) external rotation in orthostasis with elbow flexion at 90°; (2) external rotation with shoulder abduction and 90° elbow flexion; and (3) lateral decubitus external rotation and 90° elbow flexion. Statistical results are reported by the value of the F ratio (Anova), level of significance (p-value), and effect size eta^2 (eta squared). In the case of comparisons displaying differences, the Bonferroni *post hoc* test was used, with a level of significance of $\alpha<0.05$.

RESULTS

Considering the electromyographic activity of the shoulder complex muscles during the variations of external rotation exercises with elastic band (Figure 3), according to repeated measures ANOVA, it was possible to observe differences for the "movement" factor for UT (F=23.582; p<0.0001; eta^2=0.702), MD (F=20.174; p<0.0001; eta^2=0.669), PD (F=15.343; p<0.0001; eta^2=0.605) and IS (F=4.783; p=0.020; eta^2=0.324).

The Bonferroni *post hoc* test shows that the UT and MD muscles had higher EMG activity during ER exercise with shoulder abduction compared to ER in orthostasis (p=0.001; p=0.015) and LD (p=0.005; p=0.001). Higher EMG activity was also observed during ER in LD compared to ER in orthostasis (p=0.033; p=0.006).

Regarding PD muscle, higher EMG magnitudes can be found during ER exercises with shoulder abduction and LD compared to orthostasis ($p=0.003$; $p<0.0001$). No difference was observed when comparing ER exercises with shoulder abduction and LD ($p=0.941$).

Considering the IS muscle, higher EMG magnitudes can be observed during ER exercise in LD compared to ER with shoulder abduction ($p=0.05$). No difference was observed when comparing ER exercises in orthostasis and LD ($p=0.395$) with ER with shoulder abduction ($p=0.435$).

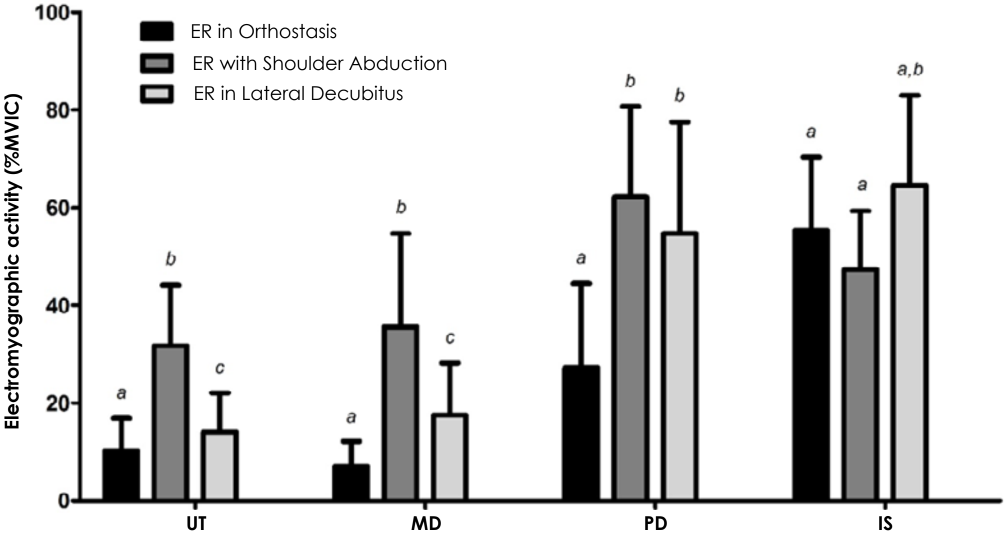

Figure 3. Electromyographic activity during variations of external rotation exercises with elastic band

UT: upper trapezius; MD: medium deltoid; PD: posterior deltoid; IS: infraspinatus.
Different letters indicate statistical difference.

DISCUSSION

The objective of this study was to compare the electromyographic activity of shoulder complex muscles during external rotation exercises with elastic band. It was found that the UT and MD muscles had higher EMG activity during shoulder abduction ER, the PD muscle during ER with shoulder abduction, and the IS during ER in orthostasis and LD exercises.

During the shoulder abduction ER exercise, the UT and MD muscles presented higher EMG activity compared to the orthostatic and LD muscles. These results may have occurred due to the higher demand for scapular stabilization of the UT to keep the scapula elevated and in superior rotation[9,15,19], together with the high demand of the MD in isometric abdomen glenohumeral abduction stabilization to perform the ER by means of the PD and IS muscles[11]. When we verified the ER in orthostasis, we found lower EMG activity of the UT, as there is no need to keep the scapula elevated and in superior rotation to assist in glenohumeral abduction; there was also a lower demand of the MD, as the shoulder remains in neutral position. Thus, the recruitment of both UT and MD is lower.

When comparing scenarios of ER in orthostasis with those of ER in LD, we speculate that individuals tend to perform an abduction of the glenohumeral joint, which may directly affect the EMG activity of the MD. Usually, this abduction is controlled with the use of a cushion or towel supported by the elbow[3,8]. The use of a cushion or towel seeks to decrease the contribution of MD and PD in the upper translation of the humeral head, which has already been evidenced with EMG[3,8]. However, we did not obtain kinematic data that support the hypothesis that individuals perform shoulder abduction.

Reinold et al.[11] evaluated several muscles during variations of external dumbbell rotation exercises. The MD muscle had its highest EMG activity during ER exercise in prone position and horizontal extension, followed by ER with shoulder abduction. Even though pronation movement was not evaluated, it is possible to assume that the results of that study are identical to those evaluated in the present study, which achieved the highest magnitudes of the MD during ER with abduction, followed by ER in LD and orthostasis.

Considering the results found in the literature for the UT muscle during ER[28], the different portions of the trapezius and posterior deltoid were evaluated by means of exercise variations. Comparisons of *timing/*

activation time (prone shoulder extension, ER in cushion LD, horizontal extension in LD and horizontal extension in prone) found that UT has greater activation at a later time than PD and thus ends up being used in the final part of the movement. The higher activation acquired by UT in LD compared to orthostasis is justified by the influence of gravitational force over the joints, which ends up requiring more from UT and PD in order to perform the movement.

As there was no statistical difference in *post hoc* for the PD muscle between ER abduction and LD, the DP muscle is considered to have had its highest EMG activity with both of those activities. Considering this statistical characteristic, the IS achieved its highest level of activity during ER in orthostasis and LD. The results pertaining to PD were similar to those found in the literature[12,11]. The PD muscle had the lowest level of EMG activity during ER in sitting position with elbow flexion and there were no differences in EMG activities between prone position, LD, and sitting with horizontal abduction[12]. Another study also found no differences between ER abduction and LD, but obtained the highest level of PD EMG activity in prone position with horizontal abduction[11]. Thus, it demonstrates that the contribution of PD seems to be greater in movements involving horizontal abduction, and there are studies mentioning how the posterior deltoid may contribute as an adductor to ER movement in neutral position, maintaining adduction with use of a cushion[2,3].

The EMG activity found in the IS muscle during external rotation exercise in LD and ER in orthostasis has also been verified in the literature[11]. Its highest level of activation occurred during ER exercise in LD, and it differed from the ER exercise in orthostasis with the use of an elbow roller. In this study, there was no difference between ER in DL and orthostasis, likely due to the use of a roller in the literature[11]. On the other hand, we found difference between ER in DL and ER with abduction. We speculate this result due to the fact that the external loads used are elastic bands, which caused a change in the force vector over the range of motion, whereas in dumbbells this vector follows gravitational force. Finding no difference between scenarios in orthostasis and LD for infraspinatus may also be related to the sampling size, since the effect size of IS was 0.324 lower than that stipulated during sample calculation.

Hintermeister et al.[22] also found that the infraspinatus achieved the highest level of EMG activity during ER in orthostasis. However, the researchers did not evaluate other ER variations. Another study evaluated the activation of IS, MD and PD during RE isometry with 10%, 40% and 70% of maximal repetition (MR)[3], and it was possible to observe lower MD and PD activities and higher IS activities when under a 40% MR load, which would be indicative of an ideal IS recruitment load. In the present study, we chose to use body weight percentage, which was approximately 3.8kg of resistance for the elastic band.

The results of the study lead to the conclusion that the use of the investigated exercises are scientifically justified for various prevention and rehabilitation programs[8,28]. The ER movement with glenohumeral abduction can be used in the final phase of rehabilitation, where the objective is to recruit the UT, MD and PD muscles, which are usually altered during the initial SIS phase. The IS muscle, on the other hand, presents hypoactivity during the initial SIS phase. Thus, the application of ER exercises with elbow flexion or in LD is indicated. Thus, the primary goals of an exercise program should focus on activating the rotator cuff and scapular muscles in movements that do not generate subacromial contact or that stress hyperactivated muscles[8]. It is worth mentioning that, when we observed PD and IS during ER abduction and LD movements, there was a reversal of activities. That is, it seems that if the professional seeks to optimize IS and decrease the unwanted influence of PD and MD[3,8], they should perform the exercises in LD or orthostasis.

This study presents limitations and future perspectives based on the results found. We mentioned that speed was self-selected and range of motion was maximally standardized for each individual, which may have influenced some results due to anatomical differences. However, care was taken to guide participants with controlled executions. In this study, the external load was fixed according to 5% of the individual's body weight, unlike studies that determined their loads in relation to MR percentage (10%, 40% and 70%)[2,3] or to fixed loads[12]. Such a methodological aspect can lead to different results when compared to other studies. Therefore, defining the magnitude of the external load is an important aspect that should be taken into account when prescribing exercises. Another limitation of this study is that several shoulder complex muscles were disregarded, since the EMG evaluation instruments had a restricted number of channels. Thus, muscles such as the middle trapezius, lower trapezius, anterior serratus, and minor round, which are related to SIS, need to be evaluated in future studies. The results found in this study do not apply to individuals with shoulder pathologies, as it was not evaluated in this study how EMG changes of patients with SIS influence on exercise performance. Nevertheless, the use of the evaluated exercises as a way to prevent injuries in the shoulder complex is fully plausible. We emphasize that muscle activation may change depending on the type of resistance employed (dumbbell or elastic band).

Thus, the results of this study in the field of rehabilitation are notorious, given its therapeutic applicability and since other studies in the literature are limited to investigating dumbbell loads only, in addition to lacking individualization according to the participants. There are still gaps to be explored from the perspective of ER exercises in different phases of movement (concentric and eccentric) and *timing* of EMG activation, as well as studies addressing the influence of these exercises on patients with SIS.

CONCLUSION

It was found that the upper trapezius and middle deltoid muscles had higher EMG activity during the external rotation exercise with shoulder abduction, the posterior deltoid muscle had higher EMG activity during external rotation with shoulder abduction and external rotation in lateral decubitus, whereas the infraspinatus muscle had higher EMG activity during external rotation in orthostasis and external rotation in lateral decubitus.

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