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AN INVESTIGATION OF THE SURFACE ELECTROMYOGRAMS SPATIAL DISTRIBUTION OF THE PECTORALIS MAJOR MUSCLE DURING FLAT AND INCLINED BENCH PRESS EXERCISES

Felipe Dias Mancebo

Dissertação de Mestrado apresentada ao Programa de Pós-graduação em Engenharia Biomédica, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Mestre em Engenharia Biomédica.

Orientadores: Liliam Fernandes de Oliveira
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DISSERTAÇÃO SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA (COPPE) DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE MESTRE EM CIÊNCIAS EM ENGENHARIA BIOMÉDICA.

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Dedicatória

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"*Persistir é pouco. É mais do mesmo. Persista ao extremo e aumente suas chances de êxito!*"

Filipe Ret

Resumo da Dissertação apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Mestre em Ciências (M.Sc.)

INVESTIGAÇÃO DA DISTRIBUIÇÃO ESPACIAL DOS ELETROMIOGRAMAS DE SUPERFÍCIE NO MÚSCULO PEITORAL MAIOR DURANTE O EXERCÍCIO SUPINO RETO E INCLINADO

Felipe Dias Mancebo

Junho/2018

Orientadores: Liliam Fernandes de Oliveira
Taian de Mello Martins Vieira

Programa: Engenharia Biomédica

No primeiro estudo utilizamos a eletromiografia de superfície de alta densidade para investigar a localização da zona de inervação (ZI) no músculo peitoral maior (PM) e o quanto ela se desloca durante o exercício supino. Onze participantes realizaram o exercício isometricamente em duas amplitudes de movimento: com o cotovelo flexionado a 0° e 100°. Os Eletromiogramas (EMGs) foram adquiridos com um vetor de 16 eletrodos posicionado paralelo às fibras do PM. Os deslocamentos na posição da ZI variaram entre 0,5 cm e 3,5 cm. No segundo estudo investigamos a distribuição dos EMGs no PM durante o supino reto e inclinado. Sete indivíduos realizaram duas séries do supino reto e duas do inclinado (45°). Os indivíduos executaram para as duas inclinações, 8 repetições com carga de 70% de uma repetição máxima (1RM) e 15 repetições com 50% de 1RM. O vetor de 16 eletrodos foi posicionado paralelamente ao esterno entre a ZI e a região do tendínea do PM para aquisição dos sinais. O valor médio quadrático (RMS) foi calculado separadamente para cada contração. EMGs com amplitude RMS maior que 70% da amplitude máxima foram definidos como canais ativos. Considerando os canais ativos, a coordenada do baricentro foi calculada indicando a posição média da distribuição RMS ao longo do eixo crânio-caudal do PM. Para todos os voluntários, identificamos que durante o supino inclinado a coordenada do baricentro estava localizada próximo à região clavicular, e para o supino reto estava próxima da região esternocostal.

Abstract of Dissertation presented to COPPE/UFRJ as a partial fulfilment of the requirements for the degree of Master of Science (M.Sc.)

AN INVESTIGATION OF THE SURFACE ELECTROMYOGRAMS SPATIAL DISTRIBUTION OF THE PECTORALIS MAJOR MUSCLE DURING FLAT AND INCLINED BENCH PRESS EXERCISES

Felipe Dias Mancebo

June/2018

Advisors: Liliam Fernandes de Oliveira
Taian de Mello Martins Vieira

Department: Biomedical Engineering

For the first study we use high-density surface electromyography (HD-EMG) to investigate the location of the innervation zone (IZ) on the pectoralis major muscle (PM) and how it displaces during bench press (BP) exercise. Eleven participants performed isometric BP at two conditions: elbow joint flexed at 100° and at 0°. Electromyograms (EMGs) were detected with a dry array of 16 electrodes parallel to the PM fibres. Shifts in IZ position ranged from 0.5 cm to 3.5 cm across all subjects over the detection sites. For the second study, we investigated the distribution of PM activity during the flat and inclined (45°) BP. Seven individuals performed two sets of flat BP and two sets of inclined BP. They used two different load levels, 70% of their one maximum repetition load (1MR) to perform 8 repetitions and 50% of 1MR for 15 repetitions. EMGs activity was recorded with an array of 16 electrodes placed parallel to the sternum and between IZ and PM tendon region. For each contraction, the root mean square (RMS) value was computed. Additionally, active channels were defined as EMGs with RMS amplitude greater than 70% of the maximum amplitude for each contraction. Considering the active channels, the barycentre coordinates were calculated indicating the mean position of the RMS distribution along cranio-caudal axis of PM. For all the volunteers, we identified for the inclined BP that the barycentre was located near to the clavicular region, and for the flat BP it was near to the sternocostal region.

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I. Overview of the dissertation

1.1 General Introduction

The selective activation of muscle regions was extensively demonstrated within human muscles during recent years (BOTTER *et al,* 2015; WATANABE et al., 2012). In this regard, to detect myoelectric activity using groups of electrodes organized in arrays or grids, known as high-density surface electromyography technique (HD-EMG), has been proved a promising technology for this type of investigation (MERLETTI *el al.*, 2009). For instance, studies using both linear arrays (DE SOUZA *et al*., 2017) and large grids of electrodes (WATANABE *et al*., 2012) reported a localized activation of the rectus femoris muscle. The same uneven distribution of electromyograms amplitude was observed in the trapezius (FARINA *et al*., 2008). It is therefore a common view that this behavior occurs mainly in multi-functional muscles depending on the movement direction (PATON AND BROWN, 1994; WICKHAM AND BROWN, 2012).

The pectoralis major (PM) is one of these muscles with distinct lines of action, which are capable of moving the shoulder in different directions (TREBS *et al*., 2010). It is thereby feasible to think that PM could be spatially activated. Indeed, researches using bipolar detection systems reported a higher activation of the PM clavicular region with respect to PM sternocostal region, during the inclined bench press exercise (LAUVER *et al*., 2015; TREBS *et al*., 2010). However, other works did not identify differences among PM regions during the same exercise (BARNETT *et al*., 1995). These distinct results could be explained by the electromyography technique used. First, the bipolar configuration allows to detect the activity of a limited muscle volume (FARINA *et al.*, 2004). Additionally, several studies had shown that the EMGs detected by a pair of surface electrodes are strongly dependent on different factors not related to pure physiological responses of muscle activity, as the innervation zone location (IZ) (BERETTA PICCOLI *et al*., 2014; FALLA *et al*., 2002; MARTIN *et al*., 2006).

In this present study, HD-EMG was therefore used to investigate whether the distribution of PM muscle activity indeed alters with increase in bench press inclination. Specifically, two works were developed aiming to answer the main questions: i) *Location of innervation zone on pectoralis major muscle and its shift during the bench press exercise* (Chapter II); ii) *Does the surface EMG distribution of PM muscle alter with increase in bench press inclination?* (Chapter III).

1.2 Objectives

1.2.1 General objectives

- Localize the innervation zones on pectoralis major muscle
- Investigate the surface EMG distribution of PM muscle during the bench press exercise

1.2.2 Specific objectives

- Determine the amount of innervation zone shift with changes in joint angle
- Investigate with the surface EMG distribution of PM muscle alter with increase in bench press inclination

II. Location of innervation zone on pectoralis major muscle and its shift during the bench press exercise

2.1. Introduction

Surface electromyography has been extensively used to investigate the pattern of PM activation in resistance training studies. Attention is often focused on the effect of exercise variants, such as trunk inclination, hand grip distance on the barbell and different training methods, on PM activation (BARNETT *et al.*, 1995; GOMO AND VAN DEN TILLAAR, 2015; GLASS AND ARMSTRONG, 1997; KEOGH *et al.*, 1999; LAUVER *et al.*, 2015; LEHMAN, 2005; MOOKERJEE AND RATAMESS, 1999; SAKAMOTO AND SINCLAIR, 2012; SNYDER AND FRY, 2012; TREBS *et al.*, 2010). Notwithstanding such well-conducted researches, contradictory findings on the pattern of PM activation have been reported. For example, while GLASS *et al*. (1997) did not observe a significant effect of bench press inclination on the degree of activation of the PM clavicular region, TREBS *et al*. (2010) observed greater activation of this region for more inclined bench press positions. Whether such discrepancies indicate different patterns of PM activation between individuals or are possibly attributable to a broad spectrum of well-described limitations in surface electromyography remains an open issue.

Inferences on the pattern of PM activation are usually drawn from variations in the amplitude of surface electromyograms (EMGs). There is however a number of factors limiting the interpretation of changes in EMG amplitude in terms of variations in the degree and timing of muscle activation (FARINA, 2006; VIGOTSKY *et al.*, 2018). Muscle fiber orientation, thickness of subcutaneous tissues and the proximity of electrodes to tendon regions and to the IZ location are some examples of non-physiological sources affecting the amplitude of EMGs (FARINA *et al.*, 2004). In particular, studies using arrays of electrodes have consistently reported spurious decreases in the amplitude of bipolar EMGs when detected nearby the muscle IZ (NISHIHARA *et al.*, 2010; RAINOLDI *et al.*, 2004). This issue is especially critical in dynamic contractions or when comparing the amplitude of EMGs collected for different joint angles, given the relative position between IZ and electrodes changes with changes in joint angle (FARINA *et al.*, 2001). Innervation zone displacement has been indeed quantified for the neck muscles (FALLA *et al.*, 2002), facial muscles (LAPATKI *et al.*, 2010) and muscles in the lower and upper limbs (DE SOUZA et al., 2017; MARTIN AND MACISAAC, 2006; NISHIHARA et al., 2010). Similar quantifications seem nevertheless undocumented for the PM muscles.

Here we therefore investigate how much the IZ position changes in the PM muscle during bench press exercise. We specifically collect EMGs from multiple PM regions to quantify: i) the IZ position in different cranio-caudal regions and ii) how much IZ position changes during the bench press exercise. Given the wide range of elbow joint motion reported during bench press execution (CHOU *et al.*, 2012), in agreement with previous reports on other muscles (MARTIN AND MACISAAC, 2006; NISHIHARA *et al.*, 2010; RAINOLDI *et al.*, 2000) we expect to observe IZ shifts of at least 1 cm. In addition to enlightening researchers and practitioners on the validity of previous EMG results, addressing this issue would potentially assist in the acquisition and interpretation of EMGs collected from PM.

2.2. Methods

2.2.1. Participants

Eleven healthy, male subjects (mean ± S.D.: 27.2 ± 5.0 years; 174.2 ± 7.8 cm; 77.5 ± 5.4 kg) were recruited to participate in the study after provided written informed consent. Previous experience with bench press exercise (at least 1 year) and lack of injuries in elbow and shoulder joints at the occasion of experiments were the inclusion criteria. The study was conducted in accordance with the latest revision of the *Declaration of Helsinki* and approved by our University Hospital Ethics Committee (HUCFF/UFRJ – 204/17).

2.2.2. Experimental protocol

While laying comfortably on a flat bench in supine position, participants were instructed to perform four gentle isometric contractions against a fixed barbell in two different conditions: (i) elbow joint flexed at 100°; (ii) elbow joint at 0° (elbow fully extended). These joint angles have been shown to roughly define the elbow range of motion during the bench press exercise (CHOU *et al.*, 2012). Each contraction lasted 10 s with a rest-in-period of 3 min. The barbell grip was defined as 200% of biacromial distance (LEHMAN, 2005) and the barbell was aligned to the midpoint of the sternum with a shoulder abduction of 80° during contractions.

2.2.3. Electrode placement and EMG recordings

Surface EMGs were collected with a dry array of sixteen silver-bar electrodes (10 mm inter-electrode distance; LISiN-Politecnico di Torino, Turin, Italy). Since PM covers a broad area, EMGs were detected from four, cranio-caudal PM regions (Figure 1). First, the PM insertion into the intertubercular sulcus of the humerus bone was marked on the skin with the aid of ultrasound imaging (10 MHz B mode linear probe with 40 mm width, 70% gain and 7 cm depth view; MYLab25 Gold; ESAOTE S.p.A., Italy). The manubrium and the xiphoid processes were identified and the distance between them was considered to define the sternum length. *Reference lines* (RLs) connecting four equally spaced sites along the sternum length (*cranial*, *centro-cranial*, *centro-caudal*, *caudal*) to the PM muscle insertion were drawn on the skin (Figure 1). The dry array was then centred at and aligned parallel to the *caudal reference line*, with the first electrode placed as close as possible to the sternum. Subjects were asked to gently, isometrically contract their PM muscles and EMGs were visually inspected. While keeping the centre of the array over the RL, its orientation was changed slightly until the propagation of action potentials could be clearly observed across electrodes (CABRAL *et al*., 2018). This orientation was deemed parallel to the PM fibres. Finally, EMGs were detected with the dry array held at this location while the participant performed isometric contractions for 10 s. This procedure was repeated for the other three detection sites (Figure 1) and for the two elbow joint angles. In 5 out of 11 participants, as we often did not observe propagation in PM *caudal* region, we used ultrasound to identify the orientation of PM *caudal* fascicles and then guide array positioning. The reference electrode was positioned at the olecranon process of the ulna and the skin was cleaned with abrasive paste and slightly bathed with water before positioning the dry array.

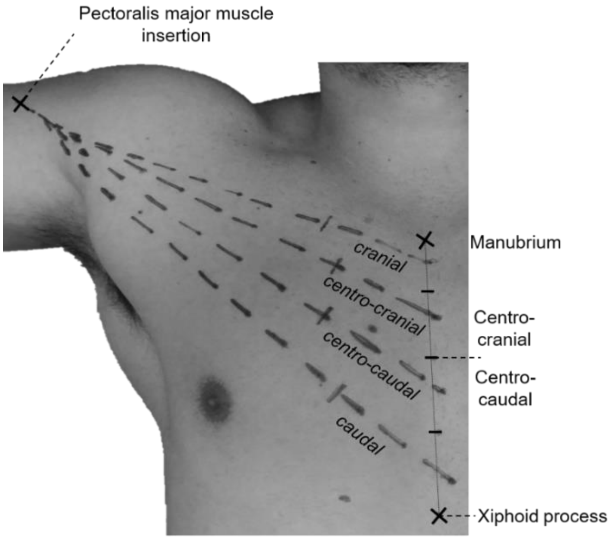

Fig. 1. *The regions of pectoralis major muscle (PM) considered for the innervation zone investigation. Specifically, the PM was respectively divided in cranial, centro-cranial, centro-caudal, caudal.*

Surface EMGs were acquired in single-differential derivation and amplified by a variable factor, ranging from 2,000 to 10,000 (10-900 Hz bandwidth amplifier; CMRR>100 dB; EMG-USB2, OTBioelettronica, Turin, Italy). EMGs were digitised at 2048 samples/s using a 12-bit A/D converter (5V dynamic range).

2.2.4. Identifying the IZ location and calculating its shifts

Innervation zone location was identified through visual inspection of surface EMGs, after they were band-pass filtered with a fourth-order Butterworth filter (15-350 Hz cut-off frequencies). First, the IZ position was identified by inspecting EMGs over short epochs (~250 ms) throughout the 10 s contractions with the elbow joint first flexed at 100°. The IZ position was defined as the position of the channel (pair of electrodes) located between channels providing EMGs with clear phase opposition and after which propagation could be well apreciated (DE SOUZA et al., 2017; ULLAH et al., 2014), providing a resolution of half an inter-electrode distance (i.e., 5 mm) for the identification of IZ position (RAINOLDI *et al.*, 2004). This procedure was then repeated for the elbow extended position, whereby a new IZ position was identified (Figure 2B). The amount of

IZ shift was therefore computed as the difference between the IZ position identified for both, elbow joint angles (Figure 2) and for each of the four detection sites (Figure 1). To compensate for inter-individual differences in PM size, both the IZ position from the sternum as well as its shift between conditions were normalized with respect to the length of the *reference line* over which the array was centered (Figure 1).

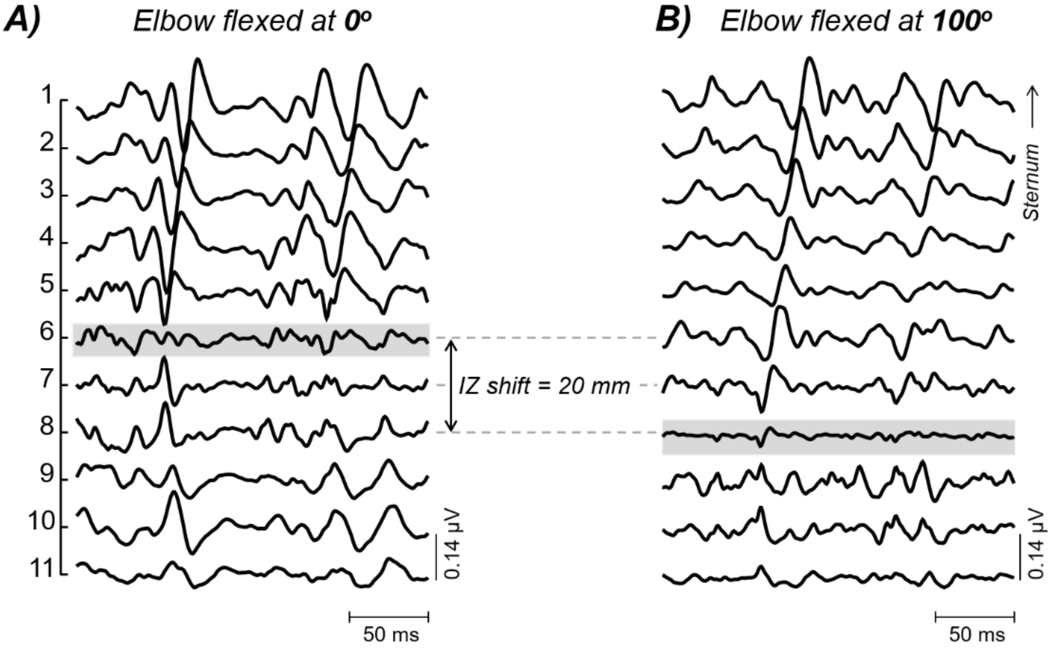

Fig. 2. *The panel A shows an example of EMGs during an isometric contraction of bench press with the elbow joint flexed at 0°. On channel 6 we can clearly see the innervation zone (IZ) marked on silver rectangle. The panel B shows that the IZ shifted 2cm away to the sternum when the elbow joint was moved from 0° flexion to 100°.*

2.2.5. Statistics

After ensuring the data homoscedasticity (Levene's test; $P > 0.1607$), parametric analysis was considered for inferential statistics. The two-way ANOVA was applied to compare main and interaction effect of the two elbow joint positions (flexed at 100° and 0°) and the four PM sites tested (*cranial*, *centro-cranial*, *centro-caudal* and *caudal*) on the IZ position. The Tukey's post-hoc test was used for paired comparisons. All analyses were carried out with Statistica (Version 10, StatSoft Inc., Tulsa, USA) and the level of significance was set at 5%.

2.3. Results

A total of 88 EMG acquisitions were analysed (4 detection sites x 2 elbow angles x 11 participants). IZ position could not be identified for six cases, as no phase opposition and action potential propagation were clearly observed in the EMGs. As shown for a representative participant in Figure 3, the IZ position could be clearly identified for the 82 remaining cases. Inspection of single-differential EMGs collected for this participant indicates the IZ position shifted towards the sternum when the elbow joint was moved from 100° flexion to full extension (Figure 3A). IZ shifts amounted to 3, 2, 1 and 3 cm from the *cranial* to the *caudal* detection sites, respectively (cf. grey rectangles in Figure 3B).

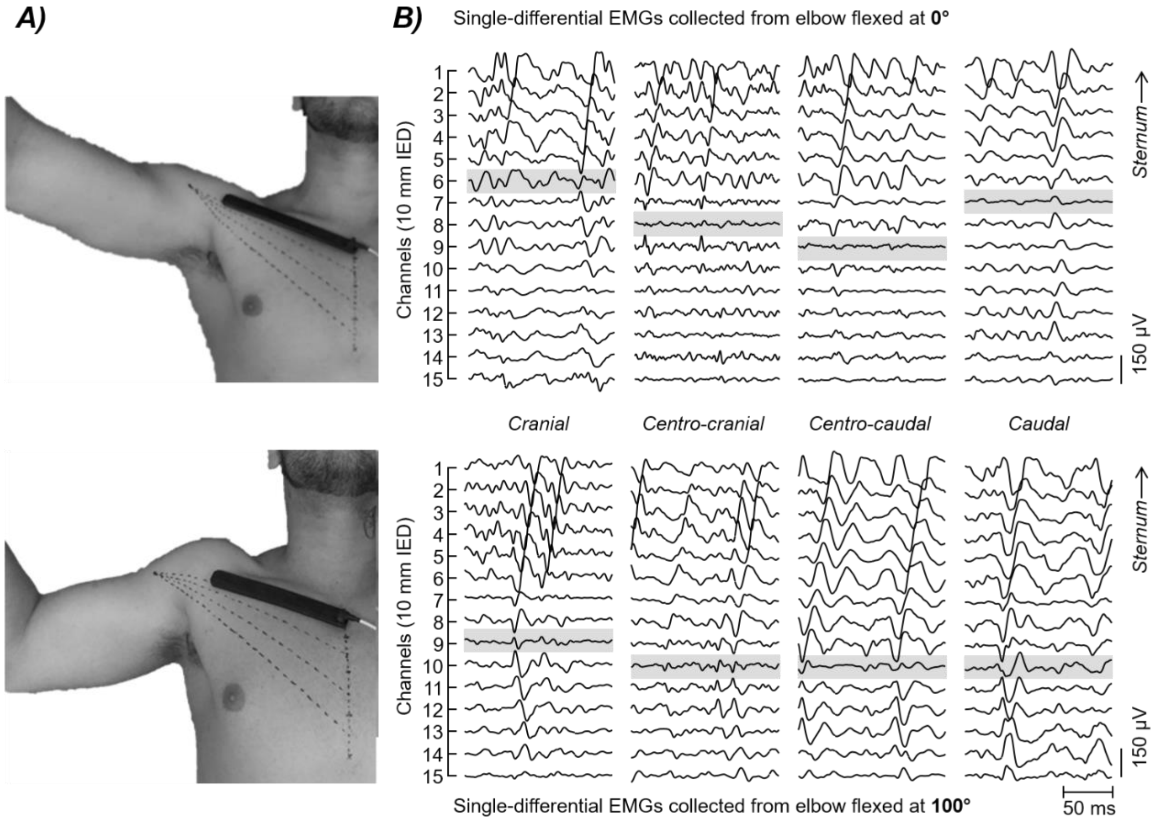

Fig. 3. *The panel A shows the two elbow positions flexed at 0° and 100°. Panel B shows single-differential EMGs collected using a dry array of 16 electrodes. The innervation zone (IZ) is marked on silver rectangles. Note that for all reference lines the IZ shifts away to the sternum when the elbow joint was moved from 0° flexion to 100°.*

Group data revealed a significant effect of elbow joint angle on the shift of IZ position during the bench press exercise. For all PM detection sites considered, the IZ moved medially when the elbow moved from flexed to fully extended position (ANOVA main effect; F = 51.273, *P* < 0.001, *N*=88 cases). Shifts in IZ position ranged from 0.5 cm to 3.5 cm across all subjects and detection sites. These shifts respectively amounted to 1.5% and 12.5% of the PM fibre length and did not depended significantly on the detection site (Figure 4; ANOVA interaction effect; F = 0.328, *P* = 0.8051). Post-hoc analysis indicated IZ position changed medially for all PM regions from which EMGs were detected (cf. asterisks in Figure 4).

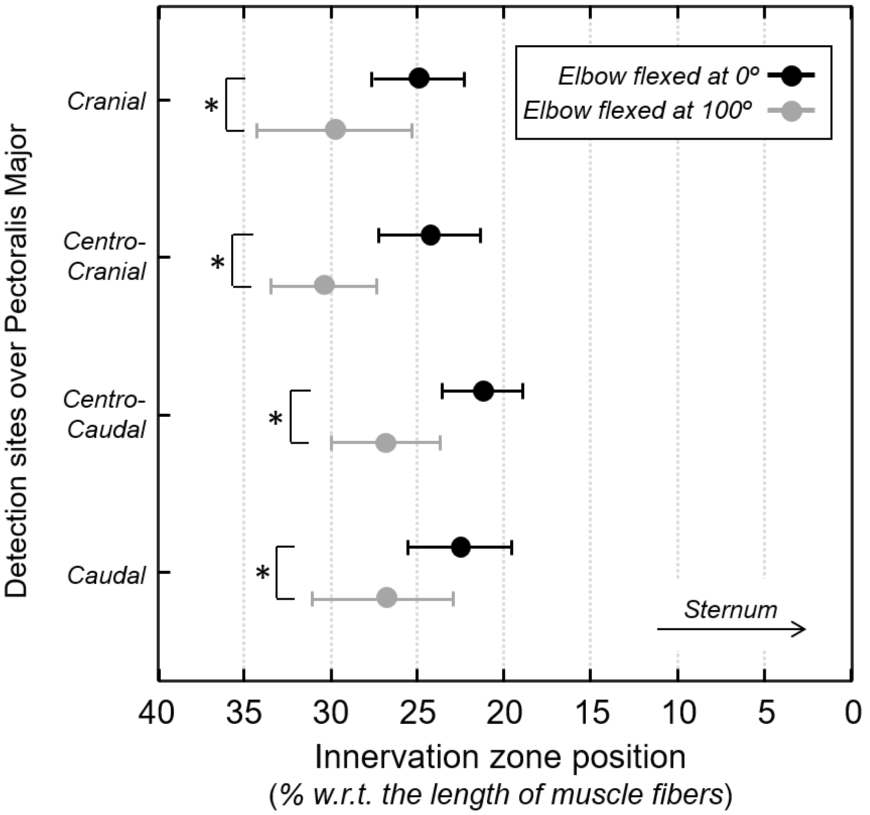

Fig. 4. *Groupe results. Figure 4 shows the mean position of innervation zone (IZ) over the detections sites on pectoralis major muscle (PM). Black circles represent IZ location with respect to the length of reference lines when the elbow joint was full extended. Gray circles represent IZ location when the elbow joint was flexed at 100°. Asterisks indicate that IZ position significantly changed for all PM regions.*

2.4. Discussion

The main purpose of the present study was to identify the IZ for different regions of the PM muscle. Additionally, by mimicking the range of motion limits of bench press exercise, we sought to describe the amount of IZ shift of PM muscle during this exercise. Our results suggested that the IZ shifts on average of 1.16, 2, 1.75 and 1.5 cm from cranial to caudal detection sites, respectively.

The characteristics of muscle geometry and its relation with IZ investigations.

Given the particular arrangement of PM fibers, it is relevant to explain why distinct PM muscle regions were considered for the purpose of the present study. Several studies had shown that the EMGs detected by a pair of surface electrodes are strongly dependent on different factors not related to pure physiological responses of muscle activity (BERETTA PICCOLI *et al*., 2014; FALLA *et al*., 2002; MARTIN *et al*., 2006). In this sense, it is well-stablished that electrodes pair placed over the innervation zone provide a very small and noisy signal (FALLA *et al*., 2002; FARINA *et al.*, 2001; RAINOLDI *et al*., 2000). A typical procedure to scan the IZ location is made by using a single linear electrode array (CABRAL *et al*., 2017; MERLETTI *et al*., 2003; RAINOLDI *et al*., 2000) placed parallel to the muscle fibers. As showed in Figure 2, when the linear electrode array is aligned with the muscle fibers, it is possible to identify the location of the muscle IZ as the point of inversion of the propagation of the detected potentials (BERETTA PICCOLI *et al*., 2014; FALLA *et al*., 2002). This procedure therefore becomes more feasible in fusiform muscles parallel to the skin, as the biceps brachii muscle (MARTIN *et al*., 2006). However, in pinnate muscles parallel to the skin, where the fibers have an orientation-varying spectrum (e.g. vasti muscles; trapezius muscle), this task might be more challenging using a single linear electrode dry-array. An alternative to solve this issue is to cover a large area of the muscle with multiple electrodes, as conducted by GALLINA and colleagues (2013), where they investigated the position of the vastus medialis IZ using a 16 × 8 electrode grid. Another possibility is to consider distinct regions of the muscle and investigate the IZ location separately for each region. Indeed, BERETTA PICCOLI and colleagues (2013) considered three regions of the trapezius muscle to determine its IZ location using a linear array of 16 electrodes. Given the arrangement of PM fibers (FUNG *et al.*, 2009), the present study also divided the muscle in different regions and investigated them individually using a single linear electrode array. When observed our results separately for each participant, as showed in Figure 3, it is noteworthy that the IZ location was not the same among regions. Thus, to investigate the pectoralis major IZ placement considering a single region indeed could provide unrepresentative results.

How much does the IZ of PM muscle shift during the bench press exercise?

During dynamic contractions the length of muscle fibers changes, and hence a displacement of the IZ location occurs in relation to the electrodes positioned on the skin (FARINA *et al.,* 2001). Specifically, the IZ may shifts 1 to 2 cm, depending on the muscle architecture and joint angle variation (FARINA *et al.*, 2001). For muscles involved in considerable joint range of motion, as the biceps brachii and the vasti muscles, this displacement may vary from 0.5 to 3cm (MARTIN AND MACISAAC, 2006; RAINOLDI *et al.,* 2000). RAINOLDI *et al.* (2000) reported a displacement of 1cm for the vastus medialis muscle comparing isometric knee extension contraction with knee joint flexed at 75° with the same contraction at 165° of knee flexion (180° corresponding to knee fully extended). Since the bench press exercise also involves a wide range of joint motion (~ 100°; CHOU *et al.*, 2011) and given the similarities in PM and vastus medialis muscles architecture (i.e., fibers with angle-varying spectrum along the muscle), we expected to observe IZ shifts of at least 1 cm. Indeed, the present results are in accordance with our hypothesis with the IZ displacement of PM muscle ranging from 0.5 to 3.5 cm for all subjects and regions.

Practical applications of IZ localization in the PM muscle

In the last years, the significant upsurge of the surface electromyography technique in distinct research fields created a strong demand to define methodological standards for its use, mainly concerning the positioning of the electrodes. The Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project was a well-known first effort to meet this need. Since then, the knowledge about the non-physiological factors that hamper the interpretation of changes in EMG amplitude quickly moved on, particularly with the using of electrodes arrays (HERMES *et al.*, 2000). As described by FARINA *et al.* (2001), positioning the electrodes in the placement less affected by these geometrical factors might avoid misunderstanding interpretations. In this sense, several studies started to study how these variables (e.g., the muscle fiber orientation, the thickness of subcutaneous tissues and the proximity to tendon regions and to the innervation zone; BERETTA PICCOLI *et al.*, 2014; FALLA *et al.*, 2002; MARTIN *et al.*, 2006) could affect the electrodes positioning. However, these issues were lacking addressed for the PM muscle until now. BERETTA PICCOLI *et al.* (2013) were the first to investigate the IZ location on the PM muscle. While the subjects were positioned standing with a shoulder abduction of 30° and performed an isometric contraction, they found that the IZ was located between 45% and 76% of the line marked between the acromion and the xiphoid process. However, in our study we aimed to positioned the subjects to represent a condition similar to bench press exercise, for that reason, the angle of shoulder abduction was 80° and two elbow joint angles were considered (flexed at 100° flexion to full extension).

Studies in the field of resistance training have used the bipolar technique to answer questions about muscle activation during the bench press. However, specifically for the PM muscle, the results regarding muscle activation are still conflicting (GLASS *et al.*, 1997; TREBS *et al.*, 2010). Notwithstanding such well-conducted investigations, it is possible that these controversial results were influenced by the IZ displacement of PM muscle during the exercise execution. Although we cannot assert this with our current results, remarkable IZ displacements during the range of motion investigated were observed (until to 3.5 cm). Thus, our results aware the importance of the IZ identification for the electrodes placement in the PM muscle, mainly during resistance training investigations.

III. Does the surface EMG distribution of PM muscle alter with variations of the bench press trunk inclination?

3.1 Introduction

The PM muscle is characterised by within-a-muscle differences related to architecture (ELMARAGHY AND DEVEREAUX, 2012). Previous studies reported that some PM fibres have origin in the clavicle and converge into a single tendon inserted in humerus bone, whereas the majority of PM fibres (~80% of PM volume) have origin in sternum and ribs, converging into same tendon insertion (CHIAVARAS *et al.*, 2015; ZEMAN *et al.*,1979). Indeed, in an anatomical dissection and 3-dimensional modelling study, FUNG *et al.* (2009), demonstrated that the PM muscle is divided in a clavicular region (CR) and a sternocostal region (SR). This anatomical distinction along fibres leads to a fibre angle variation in relation to its cranial-caudal axis (CONNELL *et al.*, 1999; KAKWANI *et al.*, 2007; WOLFE *et al.*,1992). These findings suggest that activation of fibres in these distinct PM regions would result in force vectors oriented in distinct directions, accounting for functional differences within PM during resistance training exercises (e.g. flat bench press and inclined bench press).

In the light of this PM muscle fibres orientation, whether during the inclined bench press, the CR would be more demanded than the SR, and if the flat bench press instead, would require a higher SR is still debated in the literature (TREBS *et al.*, 2010; BARNETT *et al.*, 1995). Several investigations using EMGs bipolar electrodes technique have attempted to enlighten this issue (BARNETT *et al.*, 1995; GLASS AND ARMSTRONG, 1997; LAUVER; CAYOT *et al.*, 2015; TREBS *et al.*, 2010). For instance, LAUVER *et al.* (2015) observed that during 30º and 45º of bench press inclination, a greater EMGs amplitude of CR were found comparing with bench press at 0º. In agreement with this view, TREBS and colleagues (2010) reported similar findings.

Adversely, other researchers did not identify significant differences when comparing EMGs amplitude among distinct bench press trunk inclination (BARNETT *et al*., 1995; GLASS AND ARMSTRONG, 1997). These controversial results could be explained by some limitations of the EMG technique employed. As previously explained (see Chapter II) anatomical and methodological variables could affect results interpretation using EMG bipolar method.

Nonetheless, the advances in surface electromyography technique refined the understanding of the spatial distribution muscle activity pattern above the surface electrodes (GALLINA *et al*., 2013). For example, by using high-density surface electromyography, several studies investigated the distribution of EMGs amplitude within different regions of the same muscle during distinct tasks (AFSHARIPOUR *et al*., 2016; AVANCINI *et al*., 2015; BOTTER; VAZZOLER; VIEIRA, 2015; JORDANIC *et al*., 2016). For instance, AVANCINI and colleagues (2015) showed that there is redistribution of EMG activity within gastrocnemius medialis when performing isometric ankle plantar flexion with knee flexed in comparison with the same contraction with knee extended. However, investigations of the EMG distribution within PM muscle during variations of the same task using HD-EMG is currently unavailable to our understanding.

Therefore, the first purpose of the present study is to address the question: does the surface EMG distribution of PM muscle alter with increase in bench press inclination? If in higher angles of bench press exercise the CR is more activate *(*LAUVER *et al*., 2015; TREBS *et al.*, 2010;), then we expect to observe the EMG distribution localised in the channels over the CR. In addition, the second purpose of this work is to observe the EMG spatial distribution along PM muscle with variations in the exercise intensity. Addressing these goals would contribute to practical recommendations for strength training and clinical prescriptions.

3.2 Methods

3.2.1. Participants

Seven healthy males were recruited to participate in the study. At the time of data collection, subjects should regularly practice resistance-training exercises (minimum of three times a week) and have at least 1 year of training experience. Furthermore, experience in performing the flat and inclined bench press exercises and lack injuries on the joints involved in these required movements were also considered as the inclusion criteria. This study was conducted in accordance with the latest revision of the Declaration of Helsinki and approved by our University Hospital Ethics Committee (HUCFF/ UFRJ - 204/17).

3.2.2. Experimental protocol

For data acquisition, two separate visits to the laboratory were required. During the first visit, participants were comfortably positioned lying on a padded bed with bench press barbell aligned as coaxially as possible to the middle of sternum. Then, they were asked to perform the one repetition maximum (1RM) test for the bench press exercise at two different angles (at 0° and 45°). For each test, participants performed three attempts with 5-min rest interval in-between them (GARBER *et al.*, 2011). The maximum load was considered when the subject successfully performed one repetition but failed to achieve the second. In the case of the subject successfully reached two repetitions, the load intensity was increased in 2 kg for the next attempt. Furthermore, the barbell grip was defined as 200% of biacromial distance (LEHMAN, 2005) and the barbell should smoothly touch the chest for the full range of motion (MOOKERJEE AND RATAMESS, 1999). During the second visit, the participants performed two sets of flat bench press and two sets of inclined bench press, for each bench press condition were applied two different loads. Specifically, they performed one set of 8 maximum repetitions, for flat and inclined bench press using a load corresponding to 70% of each 1RM test. Moreover, all the volunteers also performed one set of 15 repetitions using a 50% load of the same 1RM for both bench press conditions. The order of bench press exercises and the repetitions was randomized. The PM muscle surface electromyography and the barbell movement were recorded.

3.2.3. Electrode placement and signal recordings

An adhesive array of sixteen, silver-bar electrodes (10 mm inter-electrode distance; Spes Medica, Battipaglia, Italy) was used to acquire surface EMGs. Firstly, the superior and inferior PM boundaries were identified by using an ultrasound equipment (linear transducer; mode-B; 10 MHz; MYLab25 Gold; ESAOTE S.p.A., Italy) and marked on the skin (Figure 5). For all the participants, the IZ region was identified as previously described in Chapter II. The PM right side skin was shaved and cleaned with abrasive paste. An adhesive array of electrodes was then perpendicularly positioned to the sternum and far from IZ region. The first electrode of the adhesive array was positioned as close as possible to clavicle aiming to cover all the PM muscle (Figure 5).

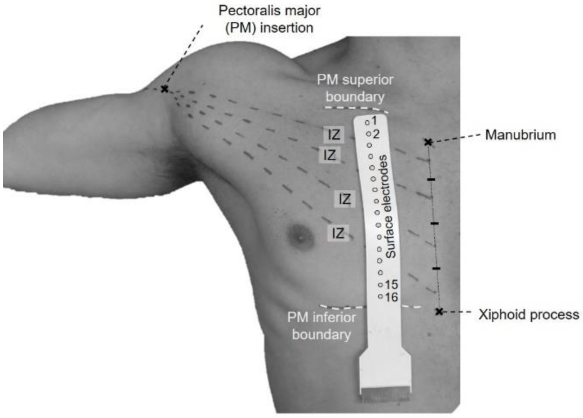

Fig. 5. Electrode placement. The innervation zone (IZ, gray rectangles) is marked for the four reference lines (dashed black lines). The limits of the pectoralis major muscle (PM) identified with the ultrasound are marked with dashed white lines. The adhesive vector of 16 electrodes was positioned parallel to the sternum, 1 cm below the upper limit of the PM and between the identified IZ and the sternum.

The electrode-skin contact was ensured with conductive paste (TEN 20 Conductive Paste, Weaver, Aurora, USA) and the reference electrode was positioned in the olecranon. Data was collected in monopolar derivation and sampled at 2048 samples/s using a 12-bit A/D converter, with ±5V dynamic range. Furthermore, EMGs were amplified by a 2,000-10,000 variable factor using a 10-900 Hz bandwidth amplifier (CMRR>100 dB; EMG-USB2, OTBioelettronica, Turin, Italy).

3.2.4. Assessing the EMGs spatial distribution within PM muscle

The vertical displacement signal of the barbell was obtained synchronous to EMGs data by a camera (Canon EOS 500D, 30mm focal distance, 15MP resolution, 720p format, 30fps sampling rate, Canon, Tokyo, Japan) positioned in front of the barbell (3 meters away) and after processed by Kinovea software (version 0.8.15, John Carmack *et al*., France). As showed in Figure 6, this signal was used in order to divide the EMGs into windows, corresponding to the eccentric and concentric phases, of each exercise repetition.

For each window, the distribution of the PM surface EMGs amplitude were calculated and assessed. First, all monopolar EMGs were filtered with a 2nd order, bandpass filter (Butterworth, 15–350 Hz cut-off frequencies). After that, the root mean square (RMS) value was computed separately for each of the 15 differential channels (i.e., each pair of electrodes) and for each movement phase. Only active channels, defined as channels which detected surface EMGs with RMS amplitude greater than 70% of the maximum amplitude (AVANCINI *et al*., 2015) were used for further analysis. From the RMS values of these active channels, the barycentre coordinate, which indicates the mean position of the RMS distribution along the cranio-caudal axis of PM muscle, were calculated. The barycentre coordinate was normalized in relation to the array of electrodes length.

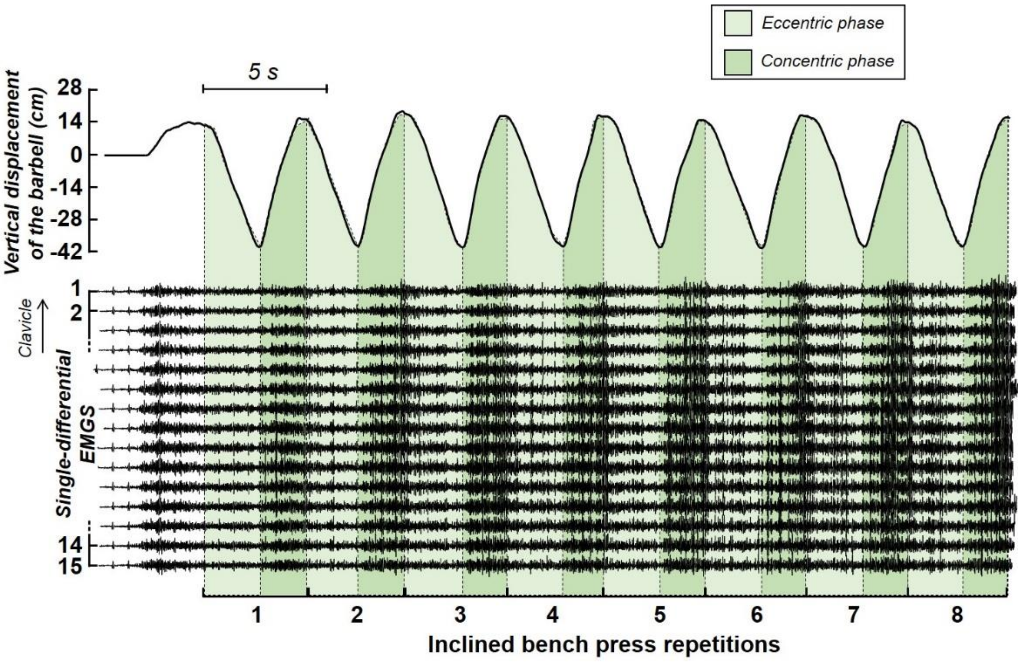

Fig. 6. Representative case of the signals acquired during 8 repetitions of the inclined bench press exercise. The signal on the top shows the vertical displacement of the bar. The dashed lines demarcate the different phases of the exercise. The 15 differential EMGs were therefore divided into 16 epochs of 2 seconds each (8 for the concentric phase, 8 for the eccentric phase).

3.3. Results

The barycentre coordinate of the RMS distribution was localized near to the clavicular region during the inclined bench press exercise. For the flat bench press barycentre coordinate was near to the sternocostal region. It was computed 3360 barycentre coordinates considering the group data (7 subjects x 8 repetitions x 15 repetitions x 2 conditions x 2 movement phases). The mean and standard deviation of the barycentre location was normalized with respect to linear array length. Figure 7 shows the mean barycenter locus separately for each movement phase and bench inclination (0° and 45°). Specifically, for the incline bench press, during 8 repetitions, the mean normalized barycentre locus of PM activation was 29% ± 1% for the concentric phase and 32% ± 2% for the eccentric phase. Similar results can be observed during 15 repetitions, the mean normalized barycentre was 28% ± 0.03% for the concentric phase and 30% ± 3% for the eccentric phase. On flat bench press the normalized barycentre locus of PM activation was located on caudal region of the vector, 66% ± 3% for the concentric phase and 69% ± 5% for the eccentric phase, during the 15 repetitions. Finally, for the flat bench during 8 repetitions the mean baricentre was 68% ± 1% for the concentric phase and 69% ± 4% for the eccentric phase. The Kruskal-Wallis test did not reveal differences in the barycentre location along the repetitions ($P = 0.9806$), indicating that its position remains approximately the same during the exercise.

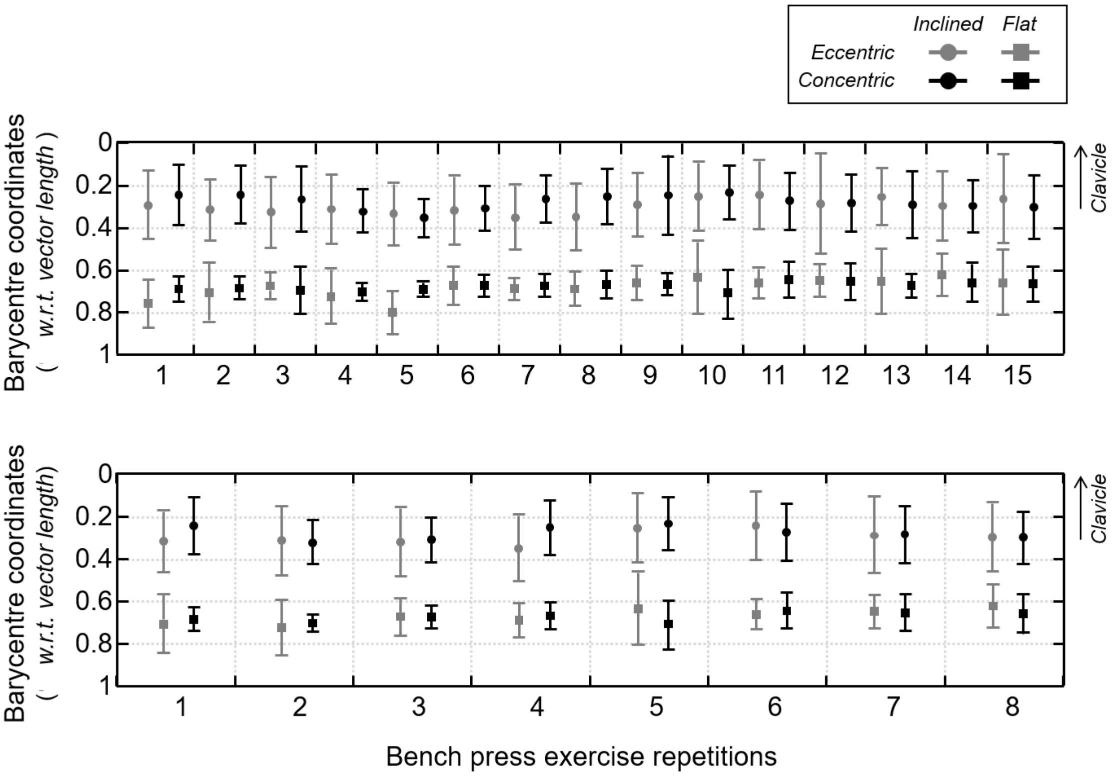

Fig. 7. Group results. The mean and standard deviation of the barycentre location was represented separately for movement phase and bench press inclination. Barycentre coordinate was normalized with respect to the length of array. The circles represent the inclined bench press (45°) and the squares represent flat bench press.

3.4. Discussion

The present study verified the distribution of the electromyographic activity along the PM muscle during 8 and 15 maximal repetitions in the flat and inclined bench press exercise. Our main results show that for the incline bench press the coordinate of the barycentre was around the channels located near to the clavicular region of the PM, however, for the flat bench press we observed that the coordinate of the barycentre was around the channels located over the sternocostal region of the PM.

The bipolar detection technique has been widely used in the field of strength training involving the pectoralis muscle. However, there is still no agreements when it comes to muscle activation during incline bench press exercise. For example, TREBS and colleagues (2010) suggested that the activation of the CR of the PM was significantly greater at 44° compared to 0°, adversely BARNETT and colleagues (1995) suggested that higher angles of bench press does not result in greater activation of CR in comparison to horizontal bench press. A possible explanation for these contradictory findings would be the fact that the bipolar detection technique is sensitive to non-physiological factors such as the location of the bipolar electrode. Studies using electrode matrices have consistently reported decreases in the amplitude of EMGs when detected over the innervation zone (IZ) muscle.

Methodologically, the question of the present study could only be answered because multiple detections sites were acquired simultaneously over the PM muscle, making possible to verify if the EMGs amplitude, away from IZ region and from different regions behaves similarly throughout the task proposed. The distribution of the electromyography activity by means of the number of active channels indicates the spatial pattern of muscle activity during a task (AVANCINI *et al.*, 2015; HOLTERMANN *et al.*, 2008; PATON

AND BROWN, 1994). The active channels were those that detected values of RMS amplitude greater than 70% of the maximum RMS separately for each 2s window considered (AVANCINI *et al*., 2015). Regarding the barycentre coordinates of the active channels, this analysis provided information on whether there was localized muscle activity during the incline bench press. It was possible to observe that along the repetitions the barycentre was localized in the proximal region of the vector, for 8 and 15 repetitions. This indicates that the active channels were more concentrated in the clavicular region of the PM during the incline bench press, which is in agreement with the results found in the literature (LAUVER *et al*., 2015; TREBS *et al*., 2010).

Participants performed only one set of the proposed exercise for each condition; this fact can be seen as a limitation of the study since it is possible that the pattern of myoelectric activity changes over several sets of the same exercise. Nevertheless, future studies might investigate if this PM spatial pattern muscle activation behaves consistently with multiple sets, where the fatigue may become more evident.

IV. General conclusions

We observed that in fact, during the bench press, the location of the IZ shifts in relation to the electrodes in the PM muscle. This displacement was between 0.5 and 3.5 cm towards the sternum when the elbow joint was moved from 100° flexion to full extension for the 11 subjects analyzed. Expanding our research to a large population, the proposed method could be used to construct a recommendation for the placement of electrodes in the PM muscle. Thus, non-physiological factors such as IZ and muscle architecture would not influence the results of investigations using EMG in dynamic contractions for the PM muscle.

When the goal of a training program is to increase muscular strength, selection of exercise is one of the important variables to considerate. Results from the second work (chapter III) show that bench press inclination alters the distribution of EMGs within the PM muscle. Indeed, clavicular region of PM has greater activation during incline bench press. Thus, individuals looking to maximize strength gains on clavicular region of PM should considered include incline bench press exercise to their training program.

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