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MESTRADO INTEGRADO EM MEDICINA

2018/2019

José Lotário Sousa da Cunha Santos

Avaliação Isocinética da Reparação Isolada do Músculo Supraspinhoso aos 4 meses / *Isokinetic Evaluation of the Isolated Repair of the Supraspinatus Muscle at 4 Months*

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Mestrado Integrado em Medicina

Área: Ciências médicas e da saúde

Tipologia: Dissertação

Trabalho efetuado sob a Orientação de:

Professor Doutor Manuel António Pereira Gutierres

E sob a Coorientação de:

Professora Doutora Filipa Manuel Alves Machado de Sousa

Trabalho organizado de acordo com as normas da revista:

Clinical Biomechanics

março, 2019

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DESIGNAÇÃO DA ÁREA DO PROJECTO

Ortopedia/Traumatologia

TÍTULO DISSERTAÇÃO/~~MONOGRAFIA~~ (riscar o que não interessa)

Avaliação Isocinética da Reparação Isolada do Músculo Supraespinhoso aos 4 Meses / Isokinetic Evaluation of The Isolated Repair of the Supraspinatus Muscle at 4 months

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Gostaria de dedicar este trabalho a toda a minha família e a todos os meus amigos.

Uma palavra especial de agradecimento ao meu orientador, Professor Doutor Manuel Gutierres, e à minha co-orientadora, Professora Doutora Filipa Sousa, por todo o apoio, dedicação e compreensão demonstrados.

Isokinetic evaluation of the isolated repair of the supraspinatus muscle at 4 months

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Word count: abstract (244 words); main text (3706 words).

Article

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Statement of equal authors contribution: all authors contributed equally to this manuscript.

Declarations of interest: none.

Abstract

Background: Double row arthroscopic rotator cuff repair has been the gold-standard for rotator cuff repair in the last few years. The supraspinatus is the most susceptible muscle to rupture in this context. The aim of this study was to evaluate patients submitted to a double row arthroscopic repair of the rotator cuff with isokinetic tests, surface electromyography and Constant-Murley Score, and correlate these data with their clinical evolution four months after surgery.

Methods: Six patients with isolated and unilateral ruptures of the supraspinatus muscle, confirmed by MRI, were submitted to isokinetic dynamometry, surface electromyography and Constant-Murley functional Score. Injured and uninjured shoulder results were collected immediately before and four months after the surgery.

Findings: Our results show improvements in isokinetic, strength and functional parameters. Isokinetic results correlate well with functional and clinical scores and add value to the follow-up process. For the angular velocity of 90º/s in post-op, the angle at Peak Torque for the injured and uninjured limb was approximately the same (~42º). Electromyographic measurements provided valuable insight over the electrical activation of muscles of the shoulder girdle. After surgery, electromyographic measurements showed a lower normalized activation pattern for the injured and uninjured muscles, suggesting an increased efficiency in post-operative muscle function.

Interpretation: The performed surgery was effective. The selected four-month time frame is an important landmark to evaluate patients´ recovery, since our data showed that most variables collected on the injured limb tend to evolve towards the values of the uninjured limb.

Keywords: supraspinatus, double row repair, rotator cuff, isokinetic, surface electromyography.

1. Introduction

The shoulder is the most mobile joint in the human body (Kumar et al., 2018). It includes four bones (sternum, clavicle, humerus and scapula), four joints (sternoclavicular, acromioclavicular, glenohumeral and scapulothoracic) and a set of muscles, tendons and ligaments. Due to its complex anatomy it is frequently affected by injuries such as tendinopathies or ruptures (Huegel et al., 2015; In Bo and Do Keun, 2014). The muscles that produce movement at the glenohumeral joint are mainly the *deltoid, pectoralis major, latissimus dorsi* and *teres major*. These muscles are stabilized by the rotator cuff, a small group of muscles (*subscapularis, supraspinatus, infraspinatus and teres minor*) attached to the greater and lesser tuberosity of the humerus, that provide dynamic stabilization, by compressing the humeral head within the concave glenoid fossa of the scapula, and enable humeral mobility. Due to its important role as a dynamic stabilizer, when a pathologic condition targets the rotator cuff, the decrease in the compressive force may result in a superior humeral head migration and potential impingement against the acromion (2008; Huegel et al., 2015). Rotator cuff disease is the most common cause of chronic shoulder pain and shoulder dysfunction among middle-aged and elderly people (Analan et al., 2015; Eljabu et al., 2015; Haahr and Andersen, 2006; Leblebici and Celik, 2016; Luime et al., 2004; Parks et al., 2017; Porcellini et al., 2011; Steinbacher et al., 2010; Williams et al., 2004). Degenerative rotator cuff (RC) tears are very rare in individuals younger than 40 years but with increasing age tendons of the RC tend to undergo progressive degenerative changes. This may lead to partial or full disruption of the involved structures resulting in pain, weakness and dysfunction with stiffness and postural changes being common in this setting (Haahr and Andersen, 2006; Haahr et al., 2005; MacDermid et al., 2004; Melis et al., 2009; Michener et al., 2003; Porcellini et al., 2011). The most susceptible muscle to rupture in this context is the supraspinatus (SE) (Melis et al., 2009; Wening et al., 2002; Williams et al., 2004) due to its predisposition to impingement, conflict with other structures, and decreased vascularity (Matthews et al., 2006). This muscle, besides being an important stabilizer of the shoulder complex also contributes to the humeral abduction on the coronal plane, making SE ruptures more common in laborers and athletes that overdo repetitive overhead movements due to its active function in generating the required torque (Steinbacher et al., 2010). Conservative treatments and symptomatic control are the first line options in the management of patients with RC tears. However, these may eventually fail and at that point, surgical approaches become an option. Arthroscopic procedures have earned high popularity over the open interventions (Deniz et al., 2014; Huegel et al., 2015; Williams et al., 2004) due to their minimally invasive technique and significant ability to provide stable and solid fixation of the tendons to bone. The double-row repair technique is currently the most accepted option for the arthroscopic RC repair (Abdelshahed et al., 2016; Millett et al., 2014; Senna et al., 2018). The main purpose of this technique is efficiently restore the anatomic footprint of the tendon, increase the tendon-bone surface area, improve shoulder function and prevent progression of arthropathy and muscle degeneration (Bartl et al., 2012; Ghazanfari et al., 2017). When compared with single-row procedures the main advantages of double row techniques are improved stability, wider contact with the bone footprint and the ability to assure a large healing area.

Isokinetic muscle tests are a reliable and validated method for muscle function assessment, allowing the collection of a wide range of parameters with the aid of isokinetic dynamometers. They are performed at a constant angular speed allowing the monitoring of the joint muscle activity in a controlled manner. Peak torque is considered the most representative parameter of muscle performance in isokinetic dynamometry and as a parameter of muscular strength it represents the maximum energy generated during a muscular contraction (Oh et al., 2010).

Surface Electromyography (sEMG) is a noninvasive technique used to assess superficial muscles´ activity and can estimate muscle forces. Contrary to intramuscular EMG, sEMG is a non-invasive, painless and easy to use technique, allowing data collection during the production of dynamic movements.

The Constant-Murley Score (CMS) is a staging system used by clinicians to access the functional status of the patients´ shoulder (Constant et al., 2008). It comprises objective and subjective measurements and allows numerical comparison between injured and uninjured limbs. It is divided in four subscales: pain (15 points), activities of daily living (20 points), strength (25 points) and range of motion: forward elevation, external rotation, abduction and internal rotation of the shoulder (40 points), with a maximum possible score of 100. The higher the score, the higher the shoulder function quality (Hirschmann et al., 2010; Romeo et al., 2004).

2. Methods

2.1. Participants

Six patients with rotator cuff disorder treated at the Orthopedic and Traumatology Department of Centro Hospitalar S. João, Porto were included: one male and five females (mean ± SD: age (years) 59.83 ± 9.37; height (m) 1.62 ± 0.06; weight (kg) 72.00 ± 14.38). The project was approved by the local ethics committee and all patients were properly informed of the study´s objectives and procedures and given an informed consent to sign.

The inclusion criteria for the participants were: age between 40 and 75 years, unilateral symptomatic RC, no contralateral disease or symptoms, unilateral limited RC active movement, Rotator Cuff Tear (RCT) confirmed by Magnetic Resonance Imaging (MRI), no previous history of shoulder surgery, systemic inflammatory or neoplastic diseases and not having participated in any clinical study in the previous three months. The exclusion criteria were: irreparable RCT, massive RCT, presence of extensive fatty muscle degeneration, moderate to severe muscle retraction or atrophy.

All patients were evaluated immediately before surgery and 4 months (16-20 weeks) afterwards. Procedures were always performed by the same examiner and consisted in the application of a CMS and on an isokinetic evaluation of both shoulder complexes with simultaneous sEMG recording. Before data collection, subjects were familiarized with the procedures and a CMS was applied, followed by the isokinetic and sEMG recording.

2.2. Isokinetic assessment

A Biodex System Pro 4 (Biodex Medical Systems, Shirley, NY, USA) was used to assess the shoulder concentric abduction-adduction of the injured and uninjured shoulder at 90°/s and 180°/s angular velocity, starting by the uninjured shoulder. According to some authors (Ellenbecker and Davies, 2000; MacDermid et al., 2004; Oh et al., 2010; Plotnikoff and MacIntyre, 2002; Rabin and Post, 1990; Szuba et al., 2016), isokinetic tests have high accuracy and test-retest reliability when evaluating complex shoulder musculature. Five repetitions for each testing velocity and shoulder were performed, with a three-minute rest between velocities. The patient was positioned on the Biodex chair according to the manufacturer recommendations, with the trunk and legs stabilized using the Biodex' straps. The dynamometer's axis of rotation was adjusted so that it aligned with the head of the humerus and center of the glenohumeral joint in the horizontal plane. The range of motion was defined as 180º of abduction, with the stating position at 0º abduction with the arm fully extended along the trunk. The system implemented gravity correction was used. The following parameters were extracted for each testing velocity for further analysis: peak torque (PT), peak torque normalized to body weight (PT/BW), angle at which peak torque was achieved (ANGLE@PT), power (POWER) and total work (WORK).

2.3. Surface electromyography

Surface EMG was performed simultaneously and in synchrony with the isokinetic assessment of the three portions of the deltoid muscle (anterior, medial and posterior) and the supraspinatus during the abduction/adduction movements. In order to do that, surface bipolar EMG electrodes (Dormo&Blaico SX-30, Telic S.A. Spain) were placed on the muscles´ bellies according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM,1999) recommendations and an inter-electrode distance of 20 mm was preserved. The skin was lightly scrubbed with a cotton swab soaked in 90% alcohol prior to electrode´s placement. The sEMG signals were bandpass filtered (5-500 Hz), amplified (pre-amplification = 11, common mode rejection ratio >90dB, second-stage amplification: 100) and recorded with a BIOPAC MP100 (BIOPAC Systems, INC, USA) analog-to-digital converter operating at a 2000Hz sampling frequency. A custom written Matlab R2014a (MathWorks, MA, USA) routine was used to process the sEMG data. This step included a 20-450Hz Butterworth band-pass filter, full-wave rectification and the calculation of the signal's linear envelope with a 3 Hz low pass Butterworth filter. The isokinetic dynamometer range of motion was used to set four performance ranges: 0-45º, 45-90º, 90-135º 135-180º. The EMG envelopes of each muscle was then normalized to its maximum value of each range, and the average muscle activation in each range was extracted.

2.4. Surgical procedure

After the pre-surgery assessments, an arthroscopic inspection of the patient's joint was performed, in order to check the inclusion criteria, and a double-row technique was performed by the same surgeon to repair the supraspinatus gap. Two rows of suture anchor fixation of tendon-to-bone type were used: one row (medial) was placed close to the humeral head, near the cartilage-footprint transition, where the bone is stiffer, using a Healix Advance anchor (DePuy Synthes Mitek Sports Medicine, MA, USA); and a second row (lateral) was placed near the humerus´ greater tuberosity with a Versalok Suture Anchor (DePuy Synthes Mitek Sports Medicine, MA, USA). An acromioplasty was added to the procedure to reduce the subacromial impingement.

2.5. Rehabilitation procedure

Postoperative rehabilitation was guided under the supervision of a physiotherapist. The protocol followed general recommendations for rotator cuff surgery and consisted in four phases of different approaches and exercises. The first phase was accomplished in the first month of recovery and focused mainly in protecting the healing tendon. The patient's operated limb was immobilized with a sling and some pendular movements were allowed. There was no place for any active range of motion (ROM) movements and passive exercises were only gently introduced at the end of this phase. The second phase was implemented during the second month of recovery and consisted in the consolidation of passive ROM and stretching exercises. Sling hanging was discontinued in the beginning of this phase and patient was expected to tolerate smooth, controlled and assisted active ROM exercises at the end of it. Phase three took place during the third month of recovery and was characterized by the full incorporation of active ROM exercises as well as the pursue of muscle strength regain. In order to achieve these goals, the patient was exposed to more aggressive active ROM exercises as well as shoulder strengthening exercises. The fourth phase was conducted during the fourth and last month of the recovery protocol and was expected to consolidate muscle strength and allow the patient to return to daily life and sports activity.

2.6. Statistical analysis

Statistical Analysis was performed using IBM SPSS Statistics software (IBM Corporation, NY, USA). All data are expressed as means ± standard deviation. The Wilcoxon test was used to assess differences between variables before and after surgery for injures and uninjured clusters. The probability level $p<0.05$ was defined as statistically significant.

3. Results

3.1. Constant-Murley Score

CMS´s from pre- and post-surgery evaluations were registered and compared for each limb. Significant differences were observed between the injured (IL) and uninjured limbs (UL), pre and post-operatively (Table 1). Before surgery all subjects reported lower values of CMS on both limbs (IL: 37.83 ± 15.90; UL: 70.33 ± 19.90). Four months after surgery all patients reported higher values of CMS on both limbs (IL: 67.83 ± 15.15; UL: 77.50 ± 20.06). The global difference found in both limbs was greater in the IL (30.00) than in the UL (7.17).

3.2. Isokinetic dynamometry tests

No statistically significant differences were found in any results from the isokinetic measurements related to peak torque (N.m), normalized peak torque (%BW), angle at peak torque (degrees), power (W) and work (J) in the uninjured limb (UL) before and after surgery. Nevertheless, the injured limb (IL) measurements did not follow the same tendency. All the results were significantly different with exception for the angle at which PT was achieved (Table 2 and Table 3). At the angular velocity of 90º/s, when comparing pre- and post-surgery results, PT increased 4.63 N.m in the UL and 10.93 N.m in the IL. The same trend was observed in the normalized PT that showed an increase of 8.13% in the UL and an increase of 17.30% in the IL.

After surgery, PT was achieved by the UL 7.33º below in the abduction movement, while the IL managed PT 12.00º later when comparing with the pre-surgical data (Figure 3). For the parameters POWER and WORK there was an increase in both values, more pronounced in the IL. At the angular velocity of 180º/s, when comparing pre- and post-surgery results, PT increased 8.29 N.m in the UL and 10.24 N.m in the IL. The same trend was observed in the normalized PT that showed an increase of 7.45% in the uninjured limb and 16.74% in the injured limb. Relatively to the angle of PT after surgery, results were not similar with those collected at the previous angular velocity (90º/s). The UL achieved PT 25.67º later in the abduction movement and the injured limb achieved PT 30.50º later (Figure 4).

3.3. Electromyography

Prior to surgery, at 90º/s, the injured shoulder presented an increased SE and deltoid activity in the 0-45º and 45-90º ranges, with the deltoid portions showing an average activity of 65% to 75%, and the SE of 55% (Figure 3a). After surgery, the activation of this muscles decreased, with every muscle showing an activity below 55%, and the SE showing an activity under 25% (Figure 3b). It should also be noticed that while in the pre-surgical assessment, the muscle activity had a sharp decrease after 90º of abduction toward a null activity at the end of the isokinetic range of motion, during the post-surgical measurement this muscle activity decrease is more subtle, still showing some muscle activity at the final range. Similar results were observed on the sEMG recordings collected at 180º/s (Figure 3c-d).

The uninjured shoulder at 90º/s and 180º/s, whilst showing muscle activities between 45% and 75%, did not have a clear differentiation between SE and deltoid activity during the pre-surgical assessment (Figure 4a-d). The activity decrease during the range of motion is smoother than the observed in the injured limb. After surgery, the deltoid muscles were able to reduce its activation to under 55% at 90º/s (Figure 4b) and 60% at 180º/s (Figure 4d). The SE showed an activation decrease similar to the observed in the injured limb after surgery.

4. Discussion

Although isokinetic muscle tests are being more frequently used in clinical practice, its correlations with sEMG activity and the commonly used clinical scores are not clearly available in the literature. The information regarding shoulder muscle strength assessed pre- and post-surgery appears to be very important in the treatment, rehabilitation and follow-up of a RCT patient. It allows clinicians to realize the real disease progression and compare measurable data.

4.1. Constant-Murley Score

The results of this study show significant differences in most parameters of the injured limbs (IL) between pre- and post-surgical moments.

We observed a significant difference between pre- and post-surgery values of the CMS, for both injured (IL) and uninjured (UL) limbs. The difference between IL and UL scores in pre-surgery (~33 points) corresponded to a grading of “Poor” in the CMS. This condition changed dramatically four months after surgery, with differences between the IL and UL scores in post-surgery attaining <11 points (~10 points), grading as “Excellent”, as described by Fabre et al. (1999). The CMS score improvement is consistent with the satisfactory outcomes reported by patients and corroborated by clinicians (Bartl et al., 2012; Burkhart et al., 2001; Deniz et al., 2014; Wilson et al., 2002)

4.2. Isokinetic dynamometry tests

When the muscle strength is compromised it contributes to the loss of function and capacity of the rotator cuff (In Bo and Do Keun, 2014), and this work shows that the IL improved its force production and function four months after surgery. We relate this fact with the effectiveness of the performed surgical procedure (Double Row Repair) and with a greater potential to evolve towards its normal health status.

However, the uninjured limb (UL) also showed improvements in most of the parameters in post-surgical measurements. This could be related with the correction of the overuse this limb was subjected to during the waiting time for surgery when the IL was unable to perform daily-life activities. We assume this overuse decreased considerably as soon as the IL became functional after surgery. Moreover, the physiotherapy protocols comprise bilateral exercises that may also have helped the UL to improve its functional status. Furthermore, we admit preoperative pain of the IL may have affected the performance of the UL.

Regarding isokinetic variables evaluated, we observed that, for both angular velocities analyzed (90º/s and 180º/s), there was an overall trend for increasing values. There were significant differences in peak torque, normalized peak torque, power and work for the injured limb (IL), in both velocities. These observations highlight the positive aftereffect of the performed rotator cuff tear repair.

The angle at PT for the post-operative IL was closer to the angle at PT of the UL, especially during the isokinetic evaluation at 90º/s (~42º). This result is in line with our expectations, and corroborates the trend IL follows towards meeting the results of the UL. Moreover this angular speed (90º/s) offers more resistance to the movement, requiring more work and power to produce the same force.

The uninjured limb (UL) presented no statistically significant differences for the pre-/post-surgery comparison, as expected, since this limb was not the target of the surgical procedure nor the rehabilitation protocol.

4.3. Electromyography

Similarly to the isokinetic correlations with clinical scores, there is also a lack of literature publications evaluating the post-op recovery of the supraspinatus muscle, combining isokinetic measurements and surface EMG. In a study of Waite et al. (2010), about the suitability of surface electrodes used to estimate muscle activity of the rotator cuff muscles, it was suggested that sEMG, even being more suitable for analyzing superficial muscles, was also adequate to determine muscular activity of the supraspinatus. This muscle is located in the supraspinous fossa of the scapula and is in close proximity with the deltoid and the upper trapezius muscle. However, these other muscles are quite thin and composed of mostly fascia over the belly of the supraspinatus, allowing a fairy accurate surface electrode placement on the skin above this muscle.

In our study, the decrease of SE activation in both velocities after surgery is a good indicator of the recovery of this muscle and its ability to provide glenohumeral stability.

Its abduction function seems also to be improved since the deltoid muscles activation decreased, which can be related with the SE performing a supportive role. We hypothesize there was a global biomechanical improvement of the shoulder complex that allowed SE to work more as a humeral head depressor and stabilizer and less as an active abductor of the humerus. The fact that after surgery muscles activation during the range of motion shows a slower decrease, may be also indication of stability and muscle function along a wider range, eventually even providing some eccentric activation during the final range of 135-180º in order to decelerate the limb abduction. This is not so obvious at 180º/s, but that could be due to the higher angular velocity, which increases the difficulty in controlling the movement.

Although the uninjured arm was not intervened, the results are similar to those of the post-surgery injured shoulder, which are encouraging results. The fact the injured and uninjured shoulder share a similar sEMG pattern of activation is a good indicator of the success of the surgical procedure and shoulder recovery. The fact that the uninjured shoulder presents differences after surgery could be related once again with the overuse compensation, pain relieve and bilateralism of the physiotherapy protocols.

4.4. Further studies

Our study has several limitations. The number of subjects involved is very small and provided low statistical power. We did not perform any data collection beyond four months after surgery. It would be interesting to compare our measurements with others collected at different time frames. Also, most patients exhibited significant preoperative pain. This fact probably had a great influence on the isokinetic muscle strength measurements. Further studies with larger samples might consider including the classification provided by the CMS in order to cluster participants according to their pain scale. The overall analysis of the current study lead us to consider comparing IL and UL, in both time frames evaluated, in order to quantify the bilateral discrepancies in all variables and their temporal evolution.

5. Conclusions

After a careful analysis of collected data we concluded that isokinetic measurements are useful in a post-operative RCT patient follow-up.

For the angular velocity of 90º/s in post-op, the angles at PT for the injured (IL) and uninjured limb (UL) were similar (~42º). This evidence suggests effectiveness of the surgical repair in terms of shoulder biomechanics, as reinforced by statistically significant differences attained for the pre-/post-surgery IL in peak torque, normalized peak torque, power and work.

We suggest the selected four-month time frame is an important landmark to the majority of the physiotherapy recovery protocols, since our data showed that most variables collected on the IL tend to evolve towards the values of the contralateral UL.

EMG measurements provided insight over the electrical activation of muscles of the shoulder girdle. For both limbs and angular velocities we noticed an overall decrease of the normalized EMG activity with the shoulder abduction, suggesting an increased efficiency in post-operative muscle function.

The isokinetic variables correlate well with functional and clinical scores (CMS) and add value when incorporated in the clinical evaluation protocols, as commonly used in other joints. These allow clinicians to have more consistent and reliable measurements in order to quantify the real evaluation and progress of the patient status.

Acknowledgments

The authors of this article would like to express their most sincere gratitude to Professor João Paulo Vilas-Boas, director of Porto Biomechanics Laboratory (LABIOMEP), for supporting this research, and to the involved participants for their full availability and cooperation.

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Tables

Table 1. CMS mean values for injured and uninjured limbs in the pre- and post-surgery timings.

Limb	Pre Mean (SD)	Post Mean (SD)	dif	Z	p
Uninjured	70.33 (19.90)	77.50 (20.06)	7.17	-2.02	0.043
Injured	37.83 (15.90)	67.83 (15.15)	30.00	-2.20	0.027

Table 2. 90º/s: isokinetic variables expressed as mean and standard deviation (SD) values of peak torque, PT (N.m), normalized peak torque, PT/BW (%), angle at PT, ANGLE @ PT (degrees), power (watts) and work (J) in uninjured and injured limbs, in pre- and post-operatory timings.

Variables	Uninjured limb				Injured limb			
	Pre Mean (SD)	Post Mean (SD)	*z*	*p*	Pre Mean (SD)	Post Mean (SD)	*z*	*p*
PT (N.m)	22.98 (14.2)	27.61 (12.13)	-0.73	0.46	11.98 (13.51)	22.91 (9.19)	-2.20	0.028
PT/BW (%)	29.83 (16.31)	37.96 (11.93)	0.94	0.34	14.41 (16.31)	31.71 (10.86)	-2.20	0.028
ANGLE@PT (deg)	49.33 (28.21)	42.00 (17.30)	0.73	0.46	30.67 (36.74)	42.67 (30.28)	0.73	0.463
POWER (W)	20.61 (14.16)	21.83 (14.30)	0.42	0.67	8.53 (11.21)	15.61 (12.28)	-1.99	0.046
WORK (J)	228.9 (144.63)	232.83 (14.39)	0.10	0.91	64.81 (81.96)	142.11 (126.95)	-2.20	0.046

Table 3. 180º/s: isokinetic variables expressed as mean and standard deviation (SD) values of peak torque, PT (N.m), normalized peak torque, PT/BW (%), angle at PT, ANGLE @ PT (degrees), power (watts) and work (J) in injured and uninjured limbs, in pre- and post-operatory timings.

Variables	Uninjured limb				Injured limb			
	Pre Mean (SD)	Post Mean (SD)	*z*	*p*	Pre Mean (SD)	Post Mean (SD)	*z*	*p*
PT (N.m)	20.55 (12.26)	24.80 (8.97)	0.95	0.34	11.66 (10.94)	21.90 (6.70)	-1.99	0.046
PT/BW (%)	27.23 (15.10)	34.68 (9.67)	0.52	0.66	14.06 (15.72)	30.80 (6.70)	-1.99	0.046
ANGLE@PT (deg)	40.00 (29.10)	65.67 (44.88)	-1.57	0.11	21.17 (36.14)	51.67 (30.80)	-1.78	0.075
POWER (W)	22.75 (17.46)	27.55 (15.77)	-1.35	0.17	11.45 (15.55)	20.03 (17.88)	-2.20	0.028
WORK (J)	177.90 (109.93)	207.61 (98.41)	-2.20	0.11	91.48 (109.26)	134.70 (108.77)	-2.20	0.028

Figures

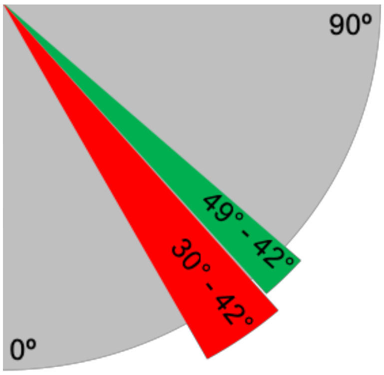

Figure 1. Range of ANGLE@PT (angular velocity 90º/s) for the movement of abduction. Red: Injured limb; green: uninjured limb.

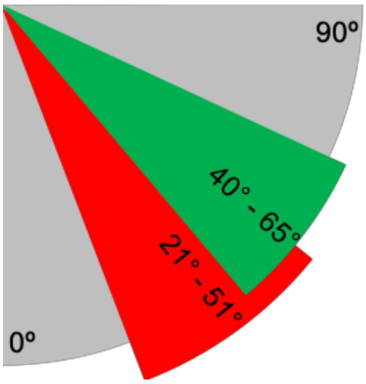

Figure 2. Range of ANGLE@PT (angular velocity 180º/s) for the movement of abduction. Red: Injured limb; green: uninjured limb.

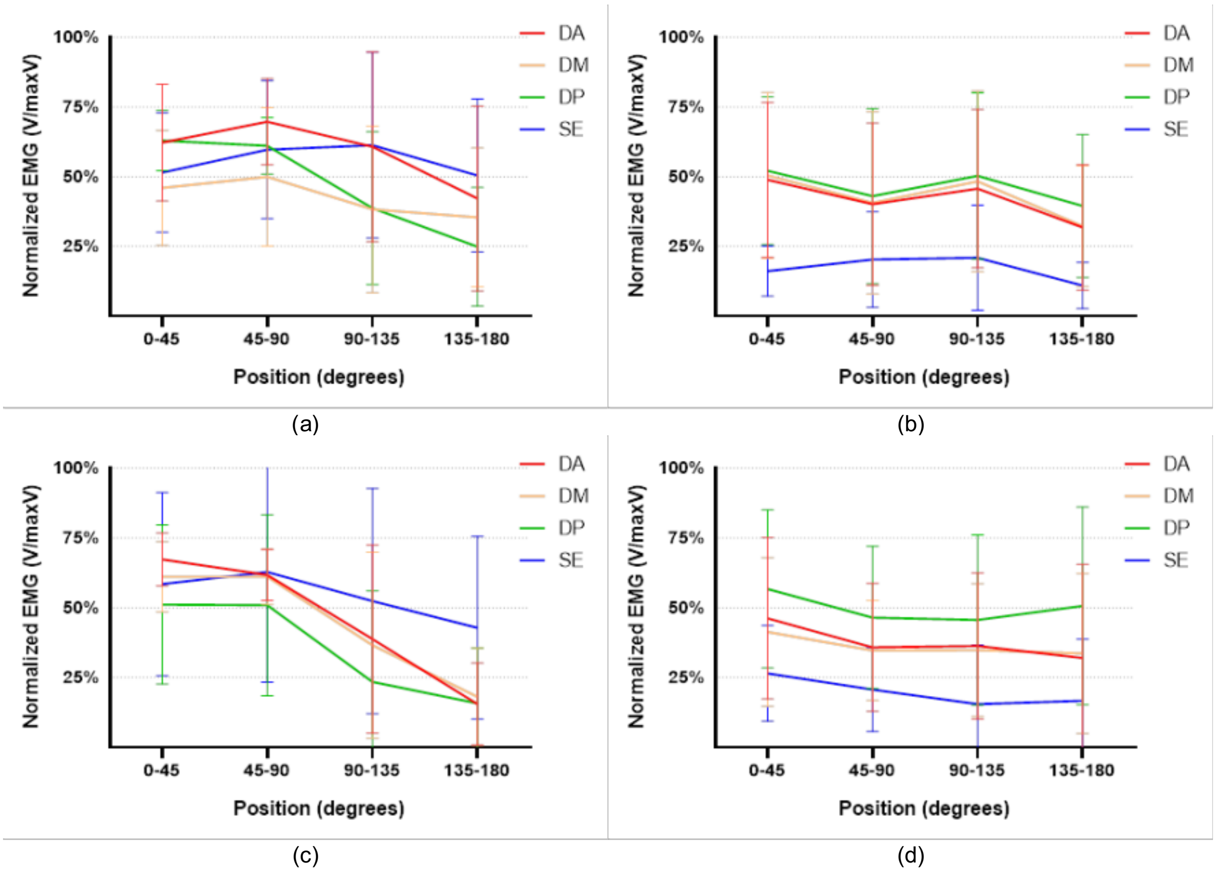

Figure 3. Uninjured limb (UL): a) EMG variation during the abduction movement of the UL at the angular velocity of 90º/s in the pre-surgery period; b) EMG variation during the abduction movement of the UL at the angular velocity of 90º/s in the post-surgery period; c) EMG variation during the abduction movement of the UL at the angular velocity of 180º/s in the pre-surgery period; d) EMG variation during the abduction movement of the UL at the angular velocity of 180º/s in the post-surgery period.

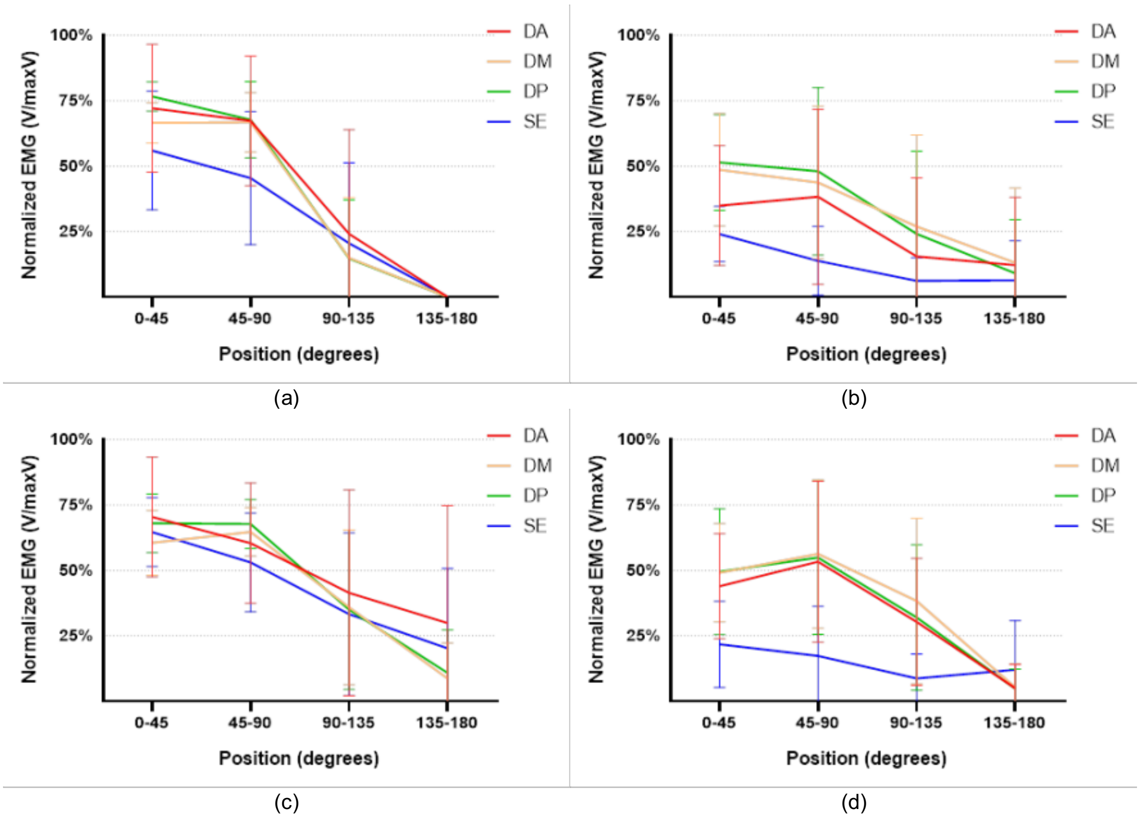

Figure 4 Injured limb (IL): a) EMG variation during the abduction movement of the IL at the angular velocity of 90º/s in the pre-surgery period; b) EMG variation during the abduction movement of the IL at the angular velocity of 90º/s in the post-surgery period; c) EMG variation during the abduction movement of the IL at the angular velocity of 180º/s in the pre-surgery period; d) EMG variation during the abduction movement of the IL at the angular velocity of 180º/s in the post-surgery period.

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