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Three-dimensional scapular motion during arm elevation is altered in women with fibromyalgia

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ABSTRACT

Background: The core feature of fibromyalgia is pain, which may play a role in various mechanisms that might lead to alterations in shoulder kinematics. Alterations in muscle activity and presence of tender points in the shoulder girdle have already been described in this population; however there is lack of evidence on three-dimensional scapular motion in women with fibromyalgia.
Methods: Forty women with fibromyalgia and 25 healthy women (control group) matched in terms of age, weight and height, took part in this study. Three-dimensional scapular kinematics of the dominant arm were collected during elevation and lowering of the arm in the sagittal and scapular planes. Pain was evaluated by the Visual Analogue Scale and the Numerical Pain Rating Scale. Group comparisons were performed with one-way ANOVA for pain and two-way ANOVA for the kinematic variables (scapular internal/external rotation, upward/downward rotation and anterior/posterior tilt), with group and humeral elevation angle as categorical factors. Significance level was set at $P < 0.05$.
Findings: Fibromyalgia women presented higher pain scores ($P < 0.001$) than the control group. Fibromyalgia women also presented greater scapular upward rotation ($P < 0.001$, both planes) and greater scapular posterior tilt ($P < 0.001$, both planes) than the control group.
Interpretation: Women with fibromyalgia present greater scapular upward rotation and posterior tilt in the resting position and during arm elevation and lowering of the arm in sagittal and scapular planes. These alterations may be a compensatory mechanism to reduce pain during arm movement.

1. Introduction

Fibromyalgia (FM) is a chronic non-inflammatory syndrome, in which diagnosis is basically clinical as there are no supplementary exams that identify it (Wolfe et al., 1990, 2010). The global prevalence of FM is 2.7%, based on 26 studies worldwide, and is more prevalent in women than in men (Queiroz, 2013). Although there are other common symptoms and comorbidities (e.g., non-restorative sleep, fatigue, morning stiffness), the core feature of FM is the widespread musculoskeletal pain (Wolfe et al., 1990). The American College of Rheumatology established, as the diagnostic criteria for FM, the widespread pain for more than 3 months, and at least 11 out of 18 active tender points, sensitive sites in which a digital pressure of 4 kg/cm^2 or less induces pain (Wolfe et al., 1990). Ten of these 18 points are located in the cervical and shoulder girdle regions (Mease, 2005).

Previous studies have shown that FM patients present altered muscular functions such as less oxygen extraction and longer oxygenation recovery following exercise and muscle ischemia (Shang et al., 2012), increased DNA fragmentation and changes in the number and size of mitochondria (Sprott et al., 2004), and unspecific alterations that might affect muscle microcirculation and lead to sensitization of the intramuscular nociceptors (Bengtsson, 2002). They also present reduced maximal exercise capacity (Bachasson et al., 2013), impaired postural control and low balance self-efficacy (Muto et al., 2014). These alterations might precede the physical deconditioning status inherent to the FM patients (Nielens et al., 2000; Panton et al., 2006) and affect their daily life.

Studies have already shown that FM patients present altered gait kinematics, with lower walking speed, stride length and cadency than healthy volunteers (Auvinet et al., 2006; Heredia-Jiménez et al., 2009), and higher metabolic demand to walk at a comfortable speed (Pierrynowski et al., 2005). However, no studies involving upper limb kinematics in FM patients have been found.

Considering that FM patients present several tender points in the cervical and shoulder girdle regions, along with alterations in activity of the trapezius muscle (Gerdle et al., 2010), scapular kinematics

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might probably be altered in FM patients. Normal shoulder kinematics are vital to everyday activity performance (Roy et al., 2010), given that the shoulder is the reaching guide joint (Vandenberghe et al., 2010). Compromised shoulder movement can cause substantial disability and affect the person's ability to carry out work and daily activities such as eating, dressing, and personal hygiene (Mitchell et al., 2005). Abnormalities in scapular kinematics as well as altered muscle activation have been associated with shoulder pathologies (Ludewig and Reynolds, 2009; Phadke et al., 2009).

Due to the lack of studies that have evaluated shoulder biomechanics in women with FM, the aim of the present study was to characterize the 3D scapular motion during elevation and lowering of the arm in women with FM. The hypothesis is that women with FM show altered pattern of scapular motion relative to a control group.

2. Methods

This study was approved by the Ethics Committee of the University (protocol number 485/2011), and is registered at the ClinicalTrials.gov under the number NTC01839305. Patients gave their written and informed consent to participate in this study, which was conducted according to the Helsinki Statement.

2.1. Subjects

Two-hundred and fifty women were recruited to take part in the study. FM volunteers (n = 172) were recruited from local community after they responded to flyers posted in university buildings, orthopedic and rheumatologic clinics, or from our database of FM patients that enrolled to other studies. All of them had the FM diagnosis given by their doctors already. The control group (n = 78) was recruited from local community and through personal contacts of the investigators (Fig. 1).

The inclusion criteria for the FM group were: 1) to have a clinical fibromyalgia diagnosis according to the 1990 ACR criteria, which includes the examination of the 18 tender points; and 2) to be aged from 30 to 60 years old. The control group had to be age-, height- and weight-matched with the FM subjects, and report good health conditions. The exclusion criteria for both groups included: 1) Body Mass Index > 28 kg/m^2, as it could influence the accuracy of the kinematics; 2) Cognitive deficits that prevented volunteers to understand the evaluation procedures; 3) Uncontrolled systemic illnesses (e.g. diabetes mellitus and systemic arterial hypertension); 4) Neurological and musculoskeletal conditions that could have directly interfered in the evaluations, as paresis, important sensitive alterations, advanced joint diseases (e.g. arthroplasties or osteoarthritis); 5) Infections; 6) Urinary incontinence; and 7) Pregnancy.

2.2. Study design

All volunteers underwent the initial interview, in which the inclusion and exclusion criteria were evaluated, and those who fit the study were invited to participate. Those who agreed to take part answered the Fibromyalgia Impact Questionnaire (FIQ, only applied for the FM subjects), the Beck Depression Inventory (BDI) and the Visual Analogue Scale (VAS) for pain and fatigue at the moment of admission in the study. A week after this interview, subjects underwent the evaluation session, which comprised the three-dimensional (3D) scapular data collection, VAS and the Numerical Pain Rating Scale for pain in different situations.

2.3. Scapular kinematics data collection

3D motion data using the Flock of Birds® electromagnetic tracking system (Ascension Technology, Burlington, VT, USA) were collected and integrated with MotionMonitor software (Innovative Sports Training, Chicago, IL, USA), with a sampling rate of 100 Hz per sensor. In a metal free environment up to a distance of 76 cm from the transmitter the root mean square (RMS) accuracy of the system is 0.5° for orientation and 0.18 cm for position, as reported by the manufacturer.

Three surface sensors were attached with double-sided adhesive tape to the sternum and acromion and a thermoplastic cuff was secured to the distal humerus. The transmitter was onto a wooden rack directly behind the evaluated shoulder. Bony landmarks on the thorax, scapula and humerus were palpated and digitized with a stylus with known offsets to allow transformation of the sensor data to local anatomically based coordinate systems. Local coordinate systems were established for the trunk, clavicle, scapula and humerus using the digitized landmarks following the International Society of Biomechanics recommended protocol (Wu et al., 2005). The z-axis pointed laterally, the x-axis anteriorly and the y-axis superiorly.

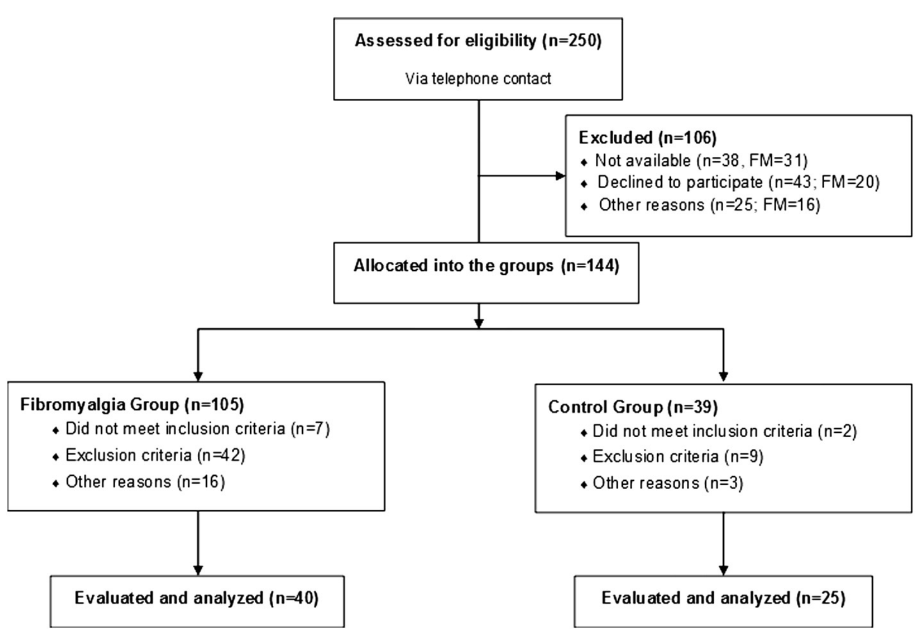

Fig. 1. Flowchart of the study.

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Subjects stood in a comfortable position with the arms relaxed in neutral position in front of a wooden flat planar surface, used to ensure the proper plane of elevation during arm movement. This position was maintained during the digitization and testing procedures. A rest position dataset was collected after setting up the sensors and digitizing the landmarks. Subjects performed three repetitions of arm elevation in both sagittal and scapular planes, only with the dominant arm. Each motion lasted approximately 6 s (3 s for the elevation and 3 s for the lowering of the arm), and subjects were instructed to elevate their arms as far as they could, with their thumbs pointing toward the ceiling, and lower their arms at the same speed of the elevation. The protocol used in the present study has been already used in other studies (Camargo et al., 2014; Haik et al., 2014b) and was considered a reliable method to evaluate scapular motion in subjects with and without shoulder impingement syndrome (Haik et al., 2014a).

The YXZ sequence was used to describe the scapular motions relative to the trunk. For the scapula, the rotations were described in the order of internal/external rotation, upward/downward rotation and anterior/posterior tilt. The humeral position with reference to the trunk was determined using the YX′Y″ sequence. The first rotation defined the plane of the elevation; the second defined the humeral elevation angle, and the third defined internal/external rotation.

Kinematic motion analysis involved selecting scapular data at 30°, 60°, 90° and 120° of humerothoracic elevation and at 120°, 90°, 60° and 30° of humerothoracic lowering.

2.4. Fibromyalgia Impact Questionnaire (FIQ)

The Fibromyalgia Impact Questionnaire (FIQ) is specific to fibromyalgia condition. It evaluates the fibromyalgia impact on the patient's quality of life, and involves questions related to functional ability, professional situation, psychological disturbances and physical symptoms (Burckhardt et al., 1991). The FIQ is comprised of 19 questions (10 quantitative and 9 qualitative questions) which are answered according to the patient's difficulty in performing daily tasks. FIQ has already been translated and validated to Brazil (Marques et al., 2006). Its score goes from 0 to 100 (Burckhardt et al., 1991; Marques et al., 2006).

2.5. Beck Depression Inventory (BDI)

The Beck Depression Inventory (BDI) is a 21-item self-report measure that assesses the cognitive, affective, and neurovegetative symptoms of depression (Furlanetto et al., 2005). A single summated score can range from 0 to 63, with the higher score indicating greater depression. There is substantial evidence for the BDI's reliability and validity in various populations including patients with FM (Burckhardt et al., 1994).

2.6. Pain intensity assessment

A 100-mm Visual Analogue Scale (VAS), in which 0 = no pain, 100 = worst pain ever, was used to assess: 1) current level of pain at rest; 2) current level of pain at movement; 3) greatest level of pain experienced in the week previous to the evaluation; and 4) lowest level of pain experienced in the previous week (Alburquerque-Sendín et al., 2013). Patients were asked to mark the amount of pain they felt in each situation described.

The Numerical Pain Rating Scale was used to assess pain during arm motion. After each arm movement, subjects were asked to rate their pain according to the instructions “0 means no pain and 10 means the worst pain you ever felt”. The scores were recorded and the mean of the three pain scores at each plane was used in the analysis.

2.7. Statistical analysis

Data were analyzed with the Statistica software (v.7.0). Kolmogorov–Smirnov tests were used to check data normality. A two-way ANOVA for each scapular kinematic movement was conducted for elevation and lowering of the arm, separately. For each analysis, categorical factors were group and humeral angle. If the interaction group × angle was not significant, main effects of group were observed. Main effect of angle was not of interest given the known differences between angles. The Tukey's HSD test was used for post-hoc analysis when necessary.

For the rest position, demographical and clinical characteristics as well as for the pain measurements, a one-way ANOVA was used (categorical factor was group). For all variables, a level of 5% of significance was adopted.

3. Results

Table 1 shows clinical and demographical characteristics of both groups. The FM group presented greater scores ($P < 0.05$) than the control group on BDI and VAS for pain and fatigue, along with a greater number of active tender points ($P < 0.05$).

In the resting position with the arms relaxed at the side of the body, scapular internal rotation was not different (P = 0.45) between groups (FM group: 37.0° (SD 6.5°); control group: (35.1° SD (5.8°)). The FM group presented more (P < 0.001) scapular upward rotation (11.5° (SD 5.4°)) and posterior tilt (1.1° (SD 8.0°)) than the control group (6.4° (SD 5.8°) and −5.7° (SD 6.5°), respectively).

3.1. Sagittal plane

For scapular internal rotation, the interaction group × angle was not significant as well as main effect of group for elevation ($P = 0.8$, $P = 0.12$, respectively) and lowering ($P = 0.99$, $P = 0.06$, respectively) of the arm (Fig. 2A).

For scapular upward rotation, the interaction group × angle was not significant for elevation ($P = 0.99$) and lowering ($P = 0.87$) of the arm. Main effect of group showed that the FM group presented greater upward rotation than the control group during elevation ($P < 0.001$) and lowering ($P < 0.001$) of the arm (Fig. 2B).

For scapular posterior tilt, the interaction group × angle was significant for arm elevation ($P = 0.01$), with the FM group presenting greater posterior tilt in all humeral angles but 120°. For arm lowering, there was no significant interaction group × angle ($P = 0.79$). However, there was main effect of group with the FM group presenting greater posterior tilt than the control group ($P < 0.001$, Fig. 2C).

Table 1
Demographical and clinical characteristics of both fibromyalgia (FM) and control groups.

	FM group (n = 40)	Control group (n = 25)
Age (years)	48.3 (8.8)	47.2 (5.3)
Height (m)	1.58 (0.06)	1.59 (0.07)
Weight (kg)	62.2 (7.7)	64.2 (8.1)
Body Mass Index (kg/m^2)	25.1 (2.3)	26.0 (1.9)
Dominance (right/left)	39/1	25/0
Symptoms duration (months)	96.1 (61.6)	NA
FIQ score	64.4 (13.9)	NA
BDI score	20.8 (11.6)	6.7 (5.4)*
Number of active tender points	17.3 (1.4)	8.7 (3.2)*
Education (school years)	11.3 (3.9)	13.5 (3.9)
Visual Analogue Scale/pain (mm)	46.0 (26.8)	1.4 (1.3)*
Visual Analogue Scale/fatigue (mm)	45.5 (28.2)	1.8 (1.6)*
Systolic blood pressure (mm Hg)	119.0 (12.5)	115.5 (7.07)
Diastolic blood pressure (mm Hg)	78.9 (9.6)	74.7 (6.6)
Heart rate (bpm)	70.8 (7.5)	70.0 (7.3)

Data presented as mean (standard deviation). NA, Not applicable.
* $P < 0.05$.

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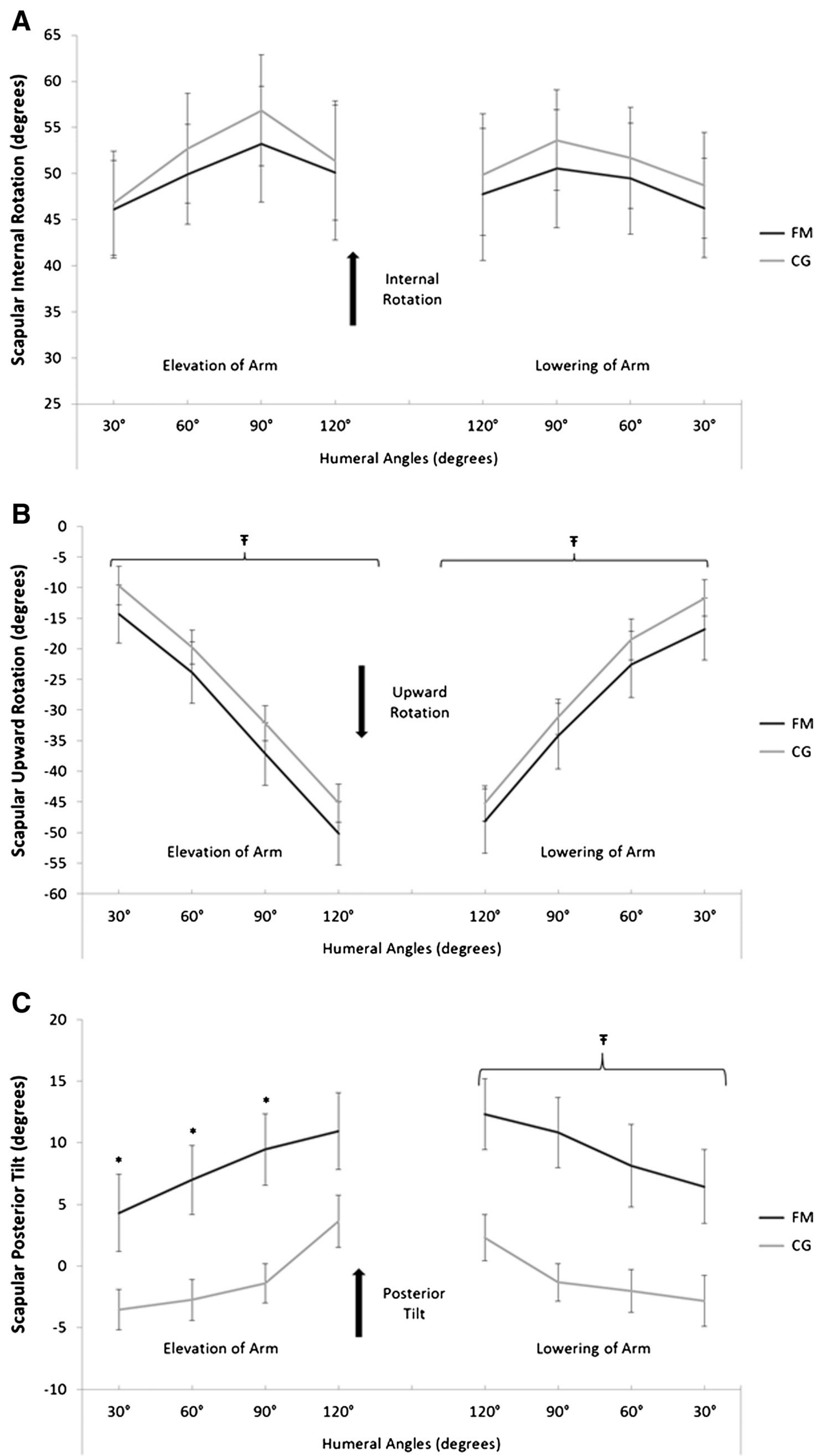

Fig. 2. Mean and standard deviation values for scapular internal/external rotation (A), upward/downward rotation (B) and anterior/posterior tilt (C) during arm elevation and lowering at sagittal plane, for both fibromyalgia (FM) and control (CG) groups. Ŧ significant main effect of group. * indicates angles significantly different between groups.

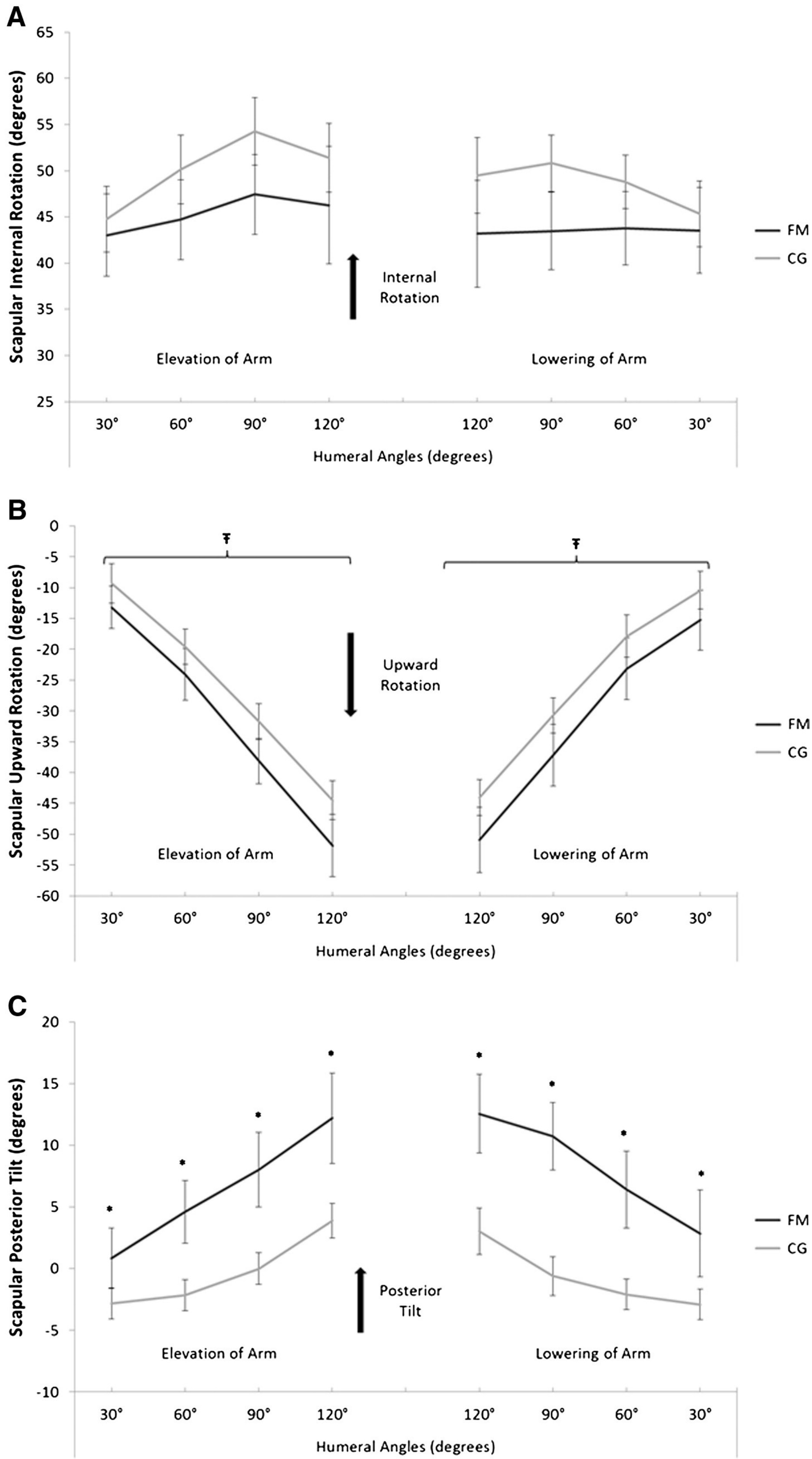

Fig. 3. Mean and standard deviation values for scapular internal/external rotation (A), upward/downward rotation (B) and anterior/posterior tilt (C) during arm elevation and lowering at scapular plane, for both fibromyalgia (FM) and control (CG) groups. Ŧ significant main effect of group. * indicates angles significantly different between groups.

3.2. Scapular plane

For scapular internal rotation, the interaction group × angle was not significant as well as main effect of group for elevation ($P = 0.83$, $P = 0.89$, respectively) and lowering ($P = 0.98$, $P = 0.65$, respectively) of the arm (Fig. 3A).

For scapular upward rotation, the interaction group × angle was not significant for elevation ($P = 0.79$) and lowering ($P = 0.31$) of the arm. Main effect of group showed that the FM group presented greater upward rotation than the control group during elevation ($P < 0.001$) and lowering ($P < 0.001$) of the arm (Fig. 3B).

For scapular posterior tilt, the interaction group × angle was significant for elevation ($P < 0.001$) and lowering ($P < 0.001$) of the arm, with the FM group presenting greater posterior tilt in all humeral angles (Fig. 3C).

Table 2 shows the Numerical Pain Rating Scales for pain during arm movement. FM patients presented greater pain scores for arm elevation at both planes. Table 2 also shows VAS for pain at 4 pain status. The FM group presented greater pain levels at all situations when compared to the control group.

4. Discussion

Results of the present study showed that women with FM present greater scapular upward rotation and scapular posterior tilt during arm elevation and lowering in both sagittal and scapular planes compared to a control group. They also present high pain levels that may significantly affect their quality of life.

Studies have shown that people with shoulder impingement syndrome have increased scapular internal rotation (Hebert et al., 2002), decreased upward rotation (Lin et al., 2005; Ludewig and Cook, 2000) and decreased posterior tilt (Lin et al., 2005; Ludewig and Cook, 2000), which may cause a decrease in the subacromial space leading to extrinsic impingement of the rotator cuff tendons (Ludewig and Reynolds, 2009). FM patients present the opposite scapular motion pattern, with greater upward rotation and posterior tilt.

Scibek et al. (2008) have demonstrated that after reducing pain with a lidocaine injection in patients with full thickness rotator cuff tears, scapula upward rotation decreased during arm elevation, suggesting that increased upward rotation may be compensatory to reduce painful scapular motion during arm elevation. Recently, Wassinger et al. (2013) have reported greater upward rotation in healthy individuals who underwent experimental pain induction, meaning that pain created similar compensatory increase in scapular upward rotation. Shamley et al. (2009) have shown that women after breast cancer surgery present increased scapular posterior tilt. The authors attributed this alteration due to the high pain levels reported by the patients even years after surgery. It is well known that pain is a core feature in FM. In the current study, the alterations in scapular kinematics may also be a compensatory mechanism due to the painful conditions of the FM patients and an attempt to reduce pain during arm elevation.

Table 2
Pain scores for both fibromyalgia (FM) and control groups.

	FM group ($n = 40$)	Control group ($n = 25$)
Arm elevation at sagittal plane[a]	5.25 (2.81)	0.52 (1.00)*
Arm elevation at scapular plane[a]	5.13 (2.89)	0.36 (0.70)*
Pain at rest (mm)[b]	59.9 (28.6)	1.2 (4.4)*
Pain at movement (mm)[b]	60.7 (22.9)	2.0 (4.8)*
Greatest pain level/previous week (mm)[b]	71.3 (24.8)	4.6 (10.0)*
Lowest pain level/previous week (mm)[b]	45.6 (26.1)	0.9 (2.8)*

Data presented as mean (standard deviation).
[a] Pain measured with the Numerical Pain Rating Scale.
[b] Pain measured with the Visual Analogue Scale.
* $P < 0.001$.

In the resting position, the FM group had greater scapular upward rotation and posterior tilt than the control group. This initial position may have contributed to the differences found between groups during elevation and lowering of the arm. However, the difference in the resting position might be an adaptation to the chronic and constant pain status in the FM patients.

One of the most important physical therapy resources for FM treatment is exercise (Clauw, 2014). There are systematic reviews that show aerobic exercise having a positive effect on pain, fatigue, health-related quality of life and physical fitness (Brosseau et al., 2008; Häuser et al., 2010). Our results show that FM patients present altered scapular kinematics. Hence, strengthening and motor control exercises for scapular muscles, especially the serratus anterior and lower trapezius, may be beneficial to reduce pain and improve shoulder function in FM patients. Stretching or relaxation techniques for the upper trapezius may also be effective. It is very important to take into account the pain level when prescribing the exercises not to exacerbate it.

This study has some limitations. Only the dominant side was evaluated. Alterations in scapular kinematics may be more prominent in the non-dominant side as it is believed that preferred use of the dominant hand can result in mechanical changes in the muscle (Adam et al, 1998). Hence, scapular muscular control could be affected by the dominance. Another limitation is that scapular muscle activity was not measured. Knowing how shoulder muscles are being activated in this population can better contribute to explain the kinematics alterations and also to prescribe more specific exercises. Further research should address these issues. In addition, the FM patients were not screened for shoulder pathology. Future studies should use magnetic resonance imaging to check for integrity of shoulder structures.

5. Conclusion

Women with FM present greater scapular upward rotation and posterior tilt in the resting position and during arm elevation and lowering of the arm in sagittal and scapular planes. These alterations may be a compensatory mechanism to reduce pain during arm movement.

Conflict of interest statement

The authors declare no conflict of interests.

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References

Adam, A., De Luca, C.J., Erim, Z., 1998. Hand dominance and motor unit firing behavior. J. Neurophysiol. 80, 1373–1382.
Alburquerque-Sendín, F., Camargo, P.R., Vieira, A., Salvini, T.F., 2013. Bilateral myofascial trigger points and pressure pain thresholds in the shoulder muscles in patients with unilateral shoulder impingement syndrome: a blinded, controlled study. Clin. J. Pain 29 (6), 478–486.
Auvinet, B., Bileckot, R., Alix, A.S., Chaleil, D., Barrey, E., 2006. Gait disorders in patients with fibromyalgia. Joint Bone Spine 73 (5), 543–546.
Bachasson, D., Guinot, M., Wuyam, B., Favre-Juvin, A., Millet, G.Y., Levy, P., Verges, S., 2013. Neuromuscular fatigue and exercise capacity in fibromyalgia syndrome. Arthritis Care Res. 65 (3), 432–440.
Bengtsson, A., 2002. The muscle in fibromyalgia. Rheumatology 41, 721–724.
Brosseau, L., Wells, G.A., Tugwell, P., et al., 2008. Ottawa panel evidence-based clinical practice guidelines for aerobic fitness exercises in the management of fibromyalgia: part 1. Phys. Ther. 88 (7), 857–871.
Burckhardt, C.S., Clark, S.R., Bennett, R.M., 1991. The Fibromyalgia Impact Questionnaire: development and validation. J. Rheumatol. 18 (5), 728–733.

Burckhardt, C.S., O'Reilly, C.O., Wiens, A.N., Clark, S.R., Campbell, S.M., Bennett, R.M., 1994. Assessing depression in fibromyalgia patients. Arthritis Care Res. 7, 35–39.

Camargo, P.R., Zanca, G.G., Okino, P.S., Russo, T.L., Michener, L.A., 2014. Scapular kinematics and muscle performance in a single case of Parsonage–Turner. Man. Ther. 19 (1), 77–81.

Clauw, D.J., 2014. Fibromyalgia: a clinical review. JAMA 311 (15), 1547–1555.

Furlanetto, L.M., Mendlowicz, M.V., Bueno, J.R., 2005. The validity of the Beck Depression Inventory—Short Form as a screening and diagnostic instrument for moderate and severe depression in medical inpatients. J. Affect. Disord. 86, 87–91.

Gerdle, B., Grönlund, C., Karlsson, S.J., Holtermann, A., Roeleveld, K., 2010. Altered neuromuscular control mechanisms of the trapezius muscle in fibromyalgia. BMC Musculoskelet. Disord. 11, 42.

Haik, M.N., Alburquerque-Sendín, F., Camargo, P.R., 2014a. Reliability and minimal detectable change of 3-dimensional scapular orientation in individuals with and without shoulder impingement. J. Orthop. Sports Phys. Ther. 44 (5), 341–349.

Haik, M.N., Alburquerque-Sendín, F., Silva, C.Z., Siqueira-Junior, A.L., Ribeiro, I.L., Camargo, P.R., 2014b. Scapular kinematics pre and post thoracic thrust manipulation in individuals with and without shoulder impingement symptoms: a randomized controlled study. J. Orthop. Sports Phys. Ther. http://dx.doi.org/10.2519/jospt.2014.4760. (accepted for publication, Epub ahead of print).

Häuser, W., Klose, P., Langhorst, J., Moradi, B., Steinbach, M., Schiltenwolf, M., Busch, A., 2010. Efficacy of different types of aerobic exercise in fibromyalgia syndrome: a systematic review and meta-analysis of randomised controlled trials. Arthritis Res. Ther. 12 (3), R79.

Hebert, L.J., Moffet, H., McFadyen, B.J., Dionne, C.E., 2002. Scapular behavior in shoulder impingement syndrome. Arch. Phys. Med. Rehabil. 83, 60–69.

Heredia-Jiménez, J.M., Aparicio-García-Molina, V.A., Porres-Foulquie, J.M., Delgado-Fernández, M., Soto-Hermoso, V.M., 2009. Spatial–temporal parameters of gait in women with fibromyalgia. Clin. Rheumatol. 28, 595–598.

Lin, J.J., Hanten, W.P., Olson, S.L., Roddey, T.S., Soto-Quijano, D.A., Lim, H.K., et al., 2005. Functional activity characteristics of individuals with shoulder dysfunctions. J. Electromyogr. Kinesiol. 15, 576–586.

Ludewig, P.M., Cook, T.M., 2000. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys. Ther. 80, 276–291.

Ludewig, P.M., Reynolds, J.F., 2009. The association of scapular kinematics and glenohumeral joints pathologies. J. Orthop. Sports Phys. Ther. 39 (2), 90–104.

Marques, A.P., Santos, A.M.B., Assumpção, A., Matsutani, L.A., Lage, L.V., Pereira, C.A.B., 2006. Validation of the Brazilian version of the Fibromyalgia Impact Questionnaire (FIQ). Rev. Bras. Reumatol. 46 (1), 24–31.

Mease, P., 2005. Fibromyalgia syndrome: review of clinical presentation, pathogenesis, outcome measures, and treatment. J. Rheumatol. Suppl. 75, 6–21.

Mitchell, C., Adebajo, A., Hay, E., Carr, A., 2005. Shoulder pain: diagnosis and management in primary care. BMJ 331 (7525), 1124–1128.

Muto, L., Mango, P., Sauer, J., Yuan, S., Sousa, A., Marques, A., 2014. Postural control and balance self-efficacy in women with fibromyalgia. Are there differences? Eur. J. Phys. Rehabil. Med. (Apr 23, Epub ahead of print).

Nielens, H., Boisset, V., Masquelier, E., 2000. Fitness and perceived exertion in patients with fibromyalgia syndrome. Clin. J. Pain 16, 209–213.

Panton, L.B., Kingsley, J.D., Toole, T., Cress, M.E., Abboud, G., Sirithienthad, P., Mathis, R., McMillan, V., 2006. A comparison of physical functional performance and strength in women with fibromyalgia, age- and weight-matched controls, and older women who are healthy. Phys. Ther. 86, 1479–1488.

Phadke, V., Camargo, P.R., Ludewig, P.M., 2009. Scapular and rotator cuff muscle activity during arm elevation: a review of normal function and alterations with shoulder impingement. Braz. J. Phys. Ther. 13, 1–9.

Pierrynowski, M.R., Tiidus, P.M., Galea, V., 2005. Women with fibromyalgia walk with an altered muscle synergy. Gait Posture 22, 210–218.

Queiroz, L.P., 2013. Worldwide epidemiology of fibromyalgia. Curr. Pain Headache Rep. 17, 356.

Roy, J.S., Moffet, H., Mcfadyen, B.J., Macdermid, J.C., 2010. The kinematics of upper extremity reaching: a reliability study on people with and without shoulder impingement syndrome. Sports Med. Arthrosc. Rehabil. Ther. Technol. 2, 8–19.

Scibek, J.S., Mell, A.G., Downie, B.K., Carpenter, J.E., Hughes, R.E., 2008. Shoulder kinematics in patients with full-thickness rotator cuff tears after a subacromial injection. J. Shoulder Elbow Surg. 17, 172–181.

Shamley, D., Srinaganathan, R., Oskrochi, R., Lascurain-Aguirrebeña, I., Sugden, E., 2009. Three-dimensional scapulothoracic motion following treatment for breast cancer. Breast Cancer Res. Treat. 118 (2), 315–322.

Shang, Y., Gurley, K., Symons, B., Long, D., Srikuea, R., Crofford, L.J., Peterson, C.A., Yu, G., 2012. Noninvasive optical characterization of muscle blood flow, oxygenation, and metabolism in women with fibromyalgia. Arthritis Res. Ther. 14 (6), R236.

Sprott, H., Salemi, S., Gay, R.E., Bradley, L.A., Alarcón, G.S., Oh, S.J., Michel, B.A., Gay, S., 2004. Increased DNA fragmentation and ultrastructural changes in fibromyalgic muscle fibres. Ann. Rheum. Dis. 63, 245–251.

Vandenberghe, A., Levin, O., De Schutter, J., Swinnen, S., Jonkers, I., 2010. Three-dimensional reaching tasks: effect of reaching height and width on upper limb kinematics and muscle activity. Gait Posture 32 (4), 500–507.

Wassinger, C.A., Sole, G., Osborne, H., 2013. Clinical measurement of scapular upward rotation in response to acute subacromial pain. J. Orthop. Sports Phys. Ther. 43 (4), 199–203.

Wolfe, F., Smythe, H.A., Yunus, M.B., et al., 1990. The American College of Rheumatology 1990 criteria for the classification of fibromyalgia. Report of the multicenter criteria committee. Arthritis Rheum. 33, 160–172.

Wolfe, F., Clauw, D.J., Fitzcharles, M.A., et al., 2010. The American College of Rheumatology preliminary diagnostic criteria for fibromyalgia and measurement of symptom severity. Arthritis Care Res. 62 (5), 600–610.

Wu, G., Van Der Helm, F.C.T., Veeger, H.E.J., et al., 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion — part II: shoulder, elbow, wrist and hand. J. Biomech. 38, 981–992.

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