Analysis of strength and resistance parameters of the lumbar spinae erector muscles during isometric exercise at different effort levels

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ABSTRACT

The low-back pain has demonstrated to be a common finding among athletes and particularly the overload in the lumbar column resulting from a strength or isometric resistance involvement of muscles of this segment as result of the muscular fatigue has been considered as important etiological factor for its development. In this context, tests used for the training evaluation of the lumbar spinae erector muscles are emphasized. In the present study, the analysis of the strength and isometric resistance parameters was used with the objective of evaluating responses of these muscles during maximal and sub-maximal voluntary isometric contractions (MVIC) in two situations: *with fatigue* and *without fatigue* induced by isometric exercise performed until exhaustion. Nine male healthy volunteers performed MVIC before and after vertebral column extension exercises supporting 5%, 10%, 15% and 20% of the MVIC. In each one of these situations, the electromyographic signal (EMG) of the iliocostalis and multifidus muscles as well as the strength level generated in the MVIC were recorded. Muscular fatigue was identified through the MVIC values decrease verification and median frequency (MF) of the EMG signals obtained after isometric exercise. The results demonstrated that while the strength was able to evidence muscular fatigue, the MF demonstrated in a statistically significant way the iliocostalis and multifidus muscles fatigue, and the multifidus muscles presented a higher muscular fatigue level. Interestingly, loads between 5% and 20% of the MVIC induced the same level of muscular fatigue. Thus, although the strength generated during vertebral column extension after isometric exercise-induced exhaustion remains unchanged, probably due to the action of accessory muscles, the overload on the vertebral column is developed as result of the vertebral column stability involvement resulting from the muscular fatigue identified after isometric exercise.

Key words: Vertebral column. Muscular fatigue. Low-back pain.

INTRODUCTION

In the last years, considerable interest has arisen in the practice of physical exercises as therapeutic resource for low-back pain prevention and treatment, what may be explained by the consistent reports that weakness and low isometric resistance of the lumbar spinae erector muscles are associated with the etiology of the low-back pain[1,2].

A possible explanation for this important relation between strength and isometric resistance of the lumbar spinae erector muscles with the maintenance of the vertebral column functional and physical integrity is that, with muscular fatigue, defined as a reduction on the neuromuscular system to generate strength or to perform work[3], an overload might occur on the passive elements (capsules, ligaments and intervertebral disks) responsible for the vertebral column stability during the execution of specific movement patterns of some sports, resulting in damages to structures sensible to distension, producing pain[4].

Data obtained from a population of young individuals suggest that the incidence of low-back pain is lower in active individuals[5]. In addition, it has also been reported that within a population of athletes, the incidence of low-back pain is higher among elite athletes[6]. From the biomechanical point of view, depending on the type of sport, athletes frequently tend to absorb low-magnitude repetitive loads or high-magnitude unique impacts more frequently when compared with non-athletic active individuals[7]; however, it has been demonstrated that strength and isometric resistance of vertebral muscle of athletes are not significant different when compared with non-athletes[8].

These results demonstrate that possibly the type of sport as well as the frequency and intensity in which it is practiced may be determinant for the development of the low-back pain.

Some studies demonstrated that after a low-back pain episode, a quick atrophy of the lumbar spinae erector muscles occurs, and this atrophy persists even after the symptoms regression[9,10]. With strength and isometric resistance exercises aimed at these muscles, the atrophy is reversible and the low-back pain recurrence is reduced[10].

In this context, the proposal of protocols aimed at evaluating strength and isometric resistance of the spinae erector muscles is emphasized, thus enabling to intervene more precisely in training programs aimed at the prevention or rehabilitation of the low-back pain in athletes.

OBJECTIVES

Considering informations presented above that emphasize the importance of the vertebral muscles fatigue control, the objective of the present study was to verify the possibility of identifying this neuromuscular phenomenon by means of the analysis of strength and isometric resistance parameters obtained from surface electromyography and dynamometry. Additionally, differences related to the fatigability of the lumbar spinae erector muscles found in different vertebral levels as well as the effects of submaximal isometric contractions performed at different effort levels on the fatigue level of these muscles were investigated.

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METHODS

Sample description

Nine healthy volunteers with no muscle-skeletal pathology history in vertebral column and who presented no low-back pain episode in the four weeks previous to the study participated in this one[10]. The demographic characteristics of the sample selected are presented in table 1.

TABLE 1
Experimental sample demographic data

Voluntaries	Statistics	Age (years)	BMI (kg/m^2)	Height (cm)	MIVC (N)	Dominance
n = 9	Average	20.4	22.4	175	393.5	Right-handed
	SD	± 1.3	± 3.6	± 0.06	97.9	
	Minimum	19	17.2	167	212.3	
	Maximum	22	27.4	182	552.1	

All volunteers signed a Free Consent Form according to Resolution 196/96 of the Health National Council containing information with regard to tests the volunteers would be submitted to and assuring their privacy. The present study was approved by the local Research Ethics Committee.

Determination of the maximal voluntary isometric contraction (MVIC) and exhaustion test

For the MVIC determination as well as for the exhaustion test, the volunteers were positioned in ventral decubitus on a test table.

The movement to be performed for both tests was the vertebral column isometric extension with a load cell (*Kratos 980 N* – Kratos Dinamômetros Ltda., São Paulo, SP) fixed to a vest used by volunteers as resistance and the test table basis in the other. The load cell was coupled to a digital indicative (*Kratos IK 14A* – Kratos Dinamômetros Ltda., São Paulo, SP), which allowed volunteers to control the intensity of the load pulled out during the exhaustion test.

With the objective of providing higher stability to volunteers, three leather belts were fastened around hip, knees and ankle joints fixing the pelvis and the lower limbs to the test table. In order to avoid possible compensatory movements, movement limiters were positioned on the scapulas and laterally in trunk to control rotation and lateral inclination of the vertebral column, respectively (figure 1).

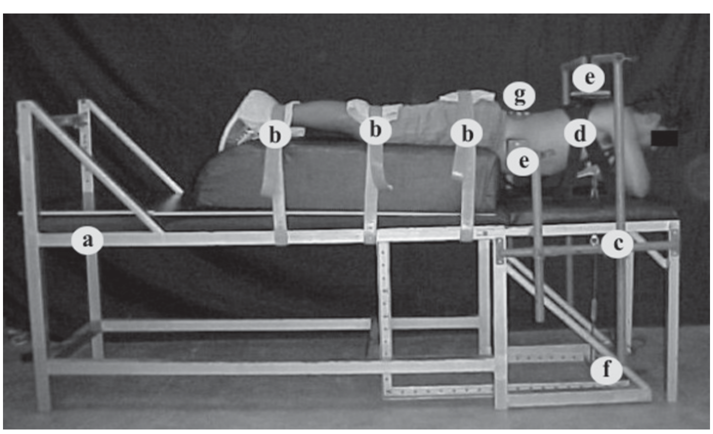

Fig. 1 *– Posture and equipments used for maximal voluntary isometric contraction and exhaustion tests.* ***a:*** *test table;* ***b:*** *leather belts;* ***c:*** *load cell;* ***d:*** *vest;* ***e:*** *movement limiters;* ***f:*** *digital indicative;* ***g:*** *electrodes.*

A MVIC test was initially performed during three days with minimum interval of 24 hours and maximum interval of 48 hours between each day. In each test day, three repetitions were performed with duration of five seconds and interval of five minutes between each contraction. The MVIC of each volunteer was determined by the average of the nine values obtained.

As methodology to induce the fatigue of the spinae erector muscles, the volunteers were submitted to exhaustion test. This test consisted of extension isometric exercise of the vertebral column that was maintained in neutral position. Isometric contractions supported at 5%, 10%, 15% and 20% of the MVIC were performed and randomly distributed in a ratio of two loads a day with minimum and maximum intervals of 24 and 48 hours between each test day, respectively, and with a minimum interval of one hour between each load percentage supported in the same day.

The trunk lowering and the incapacity of maintaining MVIC within a standard deviation of 9.8 newton (N) were the criteria adopted to interrupt exercises.

Electromyography

For receiving of the electromyographic signals (EMG), Ag/AgCl passive bipolar surface electrodes (*Meditrace 100* – Kendall, Chicopee, MA) with receiving area of 1 cm and inter-electrodes distance of 4 cm were used. The electrodes were positioned bilaterally on the iliocostalis muscles at 6 cm from the intervertebral space of L2-L3 and on the multifidus muscles at 3 cm from the intervertebral space of L4-L5[11-13].

In order to avoid possible interferences on EMG signals receiving, trichotomy, abrasion with thin sandpaper and skin cleaning with alcohol were performed previously to the electrode placement at the level of the muscles studied as well as in the right wrist region, site where a ground wire was placed with the objective of acting as reference electrode and of assuring signal quality.

The EMG signals acquisition was performed by means of a electromyograph equipped with four-channel biological signals acquisition modulus (*Lynx* – Lynx Tecnologia Eletrônica Ltda., São Paulo, SP) to which the electrodes were connected. The gain was calibrated in 1,000 times, the high-pass filter in 10 Hz, the low-pass filter in 500 Hz and common-mode rejection of 80 dB. The analogical/digital signals conversion was performed through a analogical/digital plate (A/D) with inlet range from –5 to + 5 volts, resolution of 10 bits and sampling frequency of 1000 Hz (*CAD* 1026 – Lynx Tecnologia Ltda., São Paulo, SP). A specific software (*Aqdados* 4 – Lynx Tecnologia Eletrônica Ltda. São Paulo, SP) was also used in the EMG data acquisition.

In rest, studied muscles' EMG activity was held in < 5 μV.

Muscular fatigue identification

The muscular fatigue was identified by verifying the decrease on the values corresponding to MVIC and MF of each individual, both obtained previously to the performance of the exhaustion test (Initial MF = IMF/Initial MVIC = IMVIC) and after the end of the same test (Final MF = FMF/Final MVIC = FMVIC).

A five-minute interval was established between IMVIC and the exhaustion test in order for the IMVIC not to influence the exhaustion test, while the FMVIC was performed shortly after the exhaustion test with the objective of not allowing the voluntary's recovery.

The MF values obtained from the first (MF1) and from the last (MF2) collections performed in the exhaustion test in each load percentage were evaluated with the objective of verifying the effect of submaximal contractions on the behavior of the EMG parameter.

Statistical analysis

All MVIC and MF values were obtained from collections with duration of five seconds and analyzed through specific routines developed in MATLAB environment.

For comparison purposes between values of IMVIC-FMVIC/IMF-FMF-MF2, the Student's *t* test for dependent samples was used.

With the objective of verifying possible differences on variables related to MF obtained from different vertebral levels evaluated as well as for the comparison between muscles found in right and left sides of the vertebral column (laterality effect), the Student's *t* test for independent samples was used.

In order to identify possible differences in the behavior of variables related to MF as result of the load intensity pulled out during exhaustion test, the analysis of variance (ANOVA) was performed separately from initial and final values of this variable. This same statistical test was also used in order to compare initial and final MVIC values obtained before and after each exhaustion test, respectively.

In all statistical analyses performed, the significance level adopted was of $p < 0.05$.

RESULTS

The average value and standard deviation of the MVIC used as reference for the attainment of submaximal loads used in the exhaustion test was of 398.07 ± 94.37 N. When the strength values obtained before and after exhaustion test were compared, no statistically significant differences were revealed ($p > 0.05$), although strength has decreased in all load percentages. The comparison between IMVIC obtained previously to the performance of each exhaustion test as well as the comparison between FMVIC obtained after each exhaustion test also revealed no difference statistically significant ($p > 0.05$).

With regard to the EMG variables, when MF was analyzed, the muscular fatigue was identified significantly in all muscles evaluated ($p < 0.05$), thus emphasizing a decrease on FMF values in relation to IMF as well as MF2 values in relation to MF1 (figure 2).

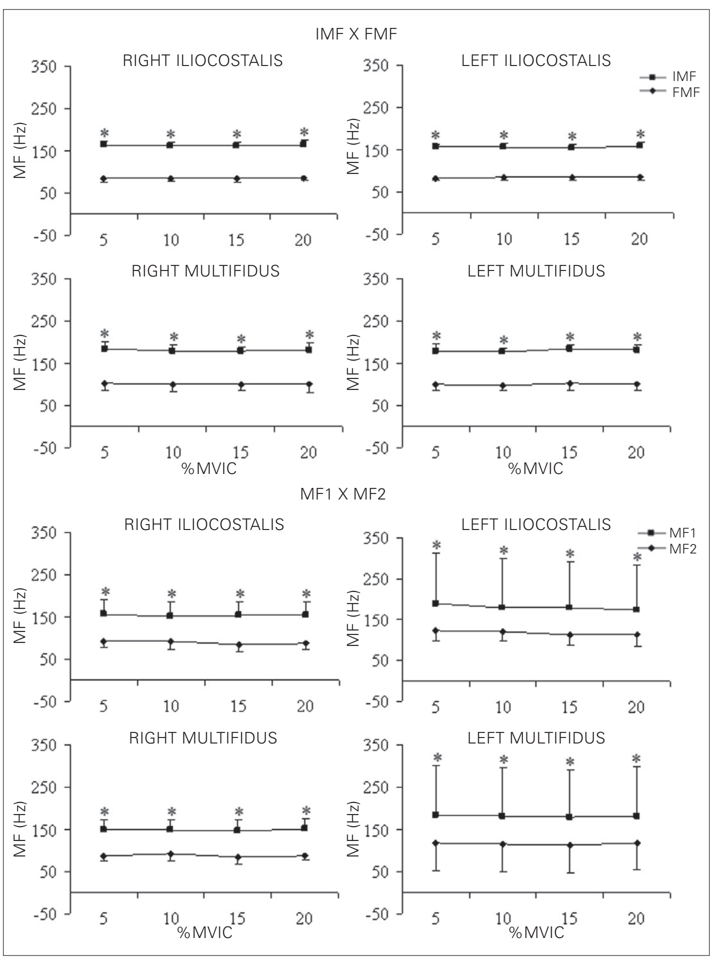

***Fig. 2** – Comparison between MF average values obtained in the beginning (IMF) and end (FMF) and between the first (MF1) and last (MF2) EMG signals acquisitions during vertebral column extension isometric exercises performed until exhaustion at 5%, 10%, 15% and 20% of the MVIC.*
** Significant difference in relation to FMF and MF2 ($p < 0.05$).*

The comparison of values corresponding to IMF, FMF, MF1 and MF2 obtained in relation to different load percentages revealed no statistically significant difference ($p > 0.05$), demonstrating that the load intensity did not influence variables related to MF.

Interestingly, in the comparison of the different vertebral levels behavior, statistically significant differences between iliocostalis and multifidus muscles were predominantly observed bilaterally ($p < 0.05$) only when the variable analyzed was MF1 (figure 3).

With regard to the laterality, the comparison between muscles found at the right and left sides of the vertebral column revealed no differences statistically significant regardless the variable analyzed ($p > 0.05$).

DISCUSSION

The test used in the present work was originally applied evaluating the isometric resistance time only (IRT), defined as the maximum time a given load can be supported during an isometric exercise[14]. This variable has demonstrated to be related with the occurrence of low-back pain[14,15], once the IRT of volunteers with low-back pain has demonstrated to be significantly lower when compared with healthy volunteers[2,16,17].

Other variable related with the etiology of the low-back disorders is the muscular strength. De Vries[18] reported that when a muscle is not found in fatigue situation, the MVIC measurement by means of traction in each load cell is unquestionably related with its basic physical capacity, while in fatigue situations, a reduction on the MVIC values obtained after exhaustion test in relation to values obtained before the test is observed.

However, the use of mechanical parameters such as IRT and MVIC may result in false interpretations with regard to the muscular fatigue, especially the spinae erector muscles, once the MVIC represents a measurement of the traction force on the load cell promoted by a set of muscles that act as accessories for the performance of that movement, and thus, it is possible that the load transfer between muscles[19,21] is a factor that makes the observation of significant differences between MVIC initial and final values difficult.

Other observation that may be performed with regard to the use of this type of methodology lies in the fact that mechanical variables such as strength, represented in the present study by the MVIC values obtained before and after exhaustion test, undergo influence from subjective factors such as motivation, concentration, fear and pain.

On the other hand, the use of neuromuscular variables such as MF for the muscular fatigue identification presents the advantage that these variables cannot be voluntarily altered in this type of study, thus resulting in more reliable evaluation of the muscular function, what may be corroborated by the decrease on their values after exhaustion test. This MF values decrease as result of the muscular fatigue may be related with the type of muscular fibre recruited in the muscles evaluated during the exercises. Roy *et al.*[22] suggested that the decrease on MF could be explained by the fact of smaller-size muscular fibres are recruited in higher load intensities or in fatigue situations. These observations were consistent with results obtained from autopsies and histological analyses that report that type II muscular fibres, which present lower diameter in vertebral muscles, are recruited at last according to the recruitment principle, and also as result of the type I fibres fatigue initially recruited[23,24]. These fibres are innervated through smaller motor neurons resulting in lower conduction velocity and hence in a deviation of the EMG signal frequency spectrum towards low frequencies, what indicates muscular fatigue.

An additional explanation for the MF decline is the metabolites accumulation and the change on the ions concentration along the muscular fibre membrane responsible for the muscular fibre depolarization and hence its contraction, resulting in decreased conduc-

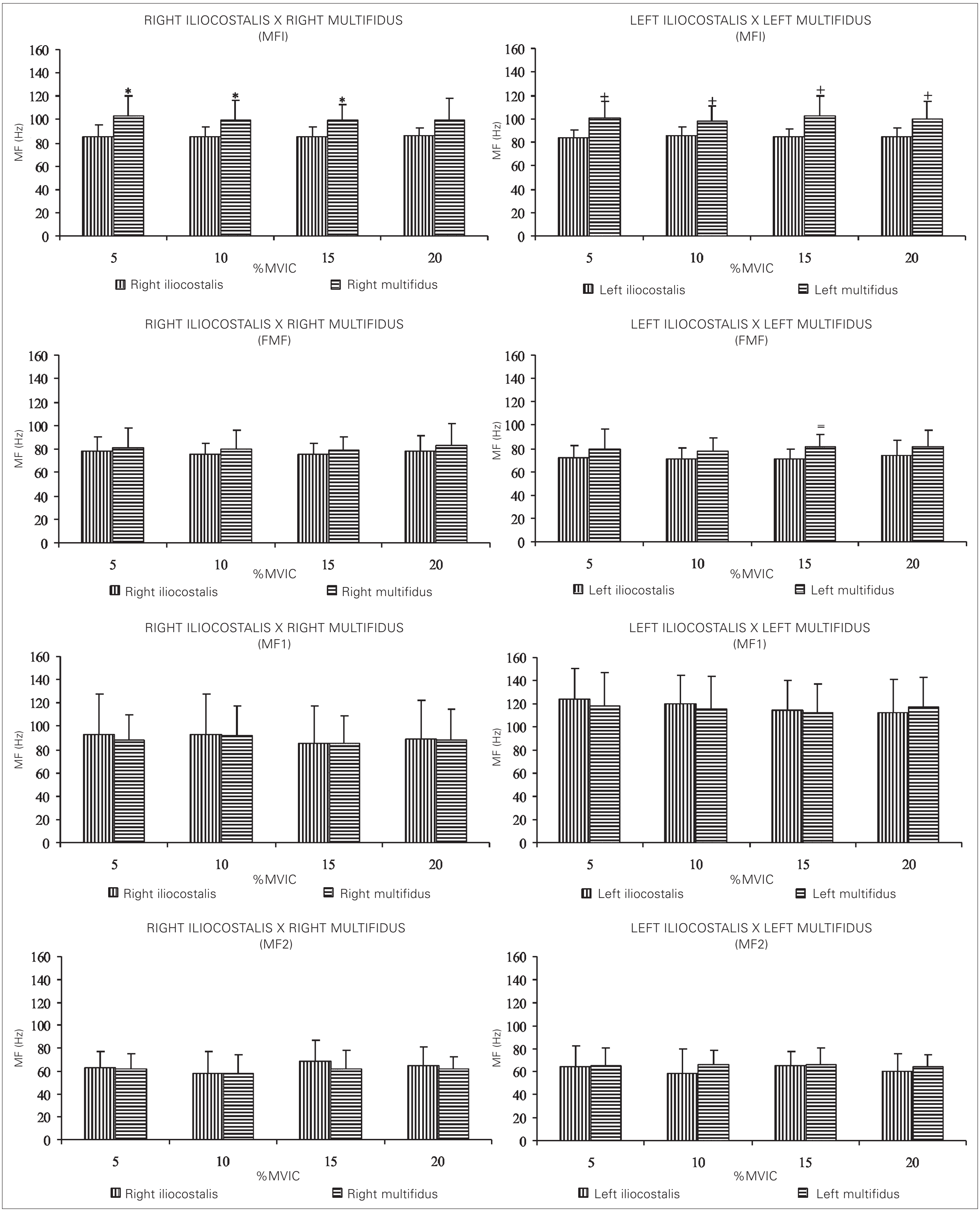

***Fig. 3** – 'Comparison between iliocostalis and homolateral multifidus muscles considering MF values (IMF, FMF, MF1 and MF2) obtained from vertebral column extension isometric exercises performed until exhaustion at 5%, 10%, 15% and 20% of the MVIC*
** right iliocostalis in relation to right multifidus.*
+ left iliocostalis in relation to left multifidus.
= left iliocostalis in relation to left multifidus.
Significant difference ($p < 0.05$).

tion velocity of the action potential along the muscular fibre membrane[25]. The isometric contraction, especially the MVIC, are important causal factors for these physiological fibre alterations, once this type of contraction induces the occlusion of capillaries responsible for both nutrition and metabolites removal[26].

The IMVIC and IMF values with no statistically significant difference when compared in relation to the different load percentages for exhaustion tests may be interpreted as a guaranty that the muscles were found in a same condition before these tests, what allows one to assert that the intervals established between the test days as well as between tests performed within the same day were suitable.

Unlike results obtained in most studies, in which the fact that with the increased MVIC percentage resulted in decrease on the MF values as result of the type II[22,27] fibres recruitment was verified, in the present study no effect of the load intensity on MF1 and MF2 was observed, suggesting that these muscles, in the current experimental conditions, present an activation pattern regardless the load intensity. This result is particularly interesting, once it suggests that the reproduction of this test with the objective of evaluating the basic physical capacities of the spinae erector muscles in athletes or the effect of a training or rehabilitation program in this population may be performed with an unique load percentage.

According to Van Dieën[28], the vertebral muscles are composed of several fascicles that act synergically during the most diverse movements that can be performed by this segment. Whenever an extension effort of the vertebral column is constantly maintained during fatiguing task, a load distribution between these synergist muscles occur. This load distribution between spinae erector muscles and the fact that some muscles are more fatigable than others[19,22,29] recommend the acquisition of the EMG signals from a higher number of sites with the objective of obtaining a more reliable behavior measurement of the different vertebral muscles[19,22]. In the search for reliability and validity of biomechanical protocols and EMG indexes, this highly synergic nature of the vertebral muscles definitely needs to be considered.

In the present study, this aspect was considered and hence two vertebral levels were evaluated. Differences with regard to the fatigability of the muscles evaluated were observed bilaterally only when the IMF of the iliocostalis and multifidus muscles were compared. It has been demonstrated that vertebral muscles found in lower vertebral levels present prevalence of type II fibres (less resistant to fatigue)[30,31]. These findings corroborated results obtained in the present study, in which the multifidus muscle presented higher fatigue level. Analyzing FMF, seldom were the differences found in both muscles, especially characterizing the fatigue development of the multifidus muscle in function of the contraction time.

However, with regard to the laterality, the comparison between muscles found in the right and left sides of the vertebral column revealed no statistically significant differences, allowing inferring that the dominance presented no effect on the fatigability of spinae erector muscles, unlike what was found by Merletti *et al.*[32], who mentioned that vertebral muscles found at the opposite side of the dominance present higher fatigue resistance as result of the training voluntarily imposed at the cost of the daily life activities (DLA) preferentially performed with the upper dominant limb. It may also be inferred that the present test station enabled the control of compensatory vertebral column movements, thus inducing a symmetric action of the spine erector muscles.

A detail specially interesting was the report of the occurrence of pain localized in thigh posterior muscles during isometric exercises performed until exhaustion. This information, already described in literature[33], demonstrates the important role the hip extensor muscles play in aiding indirectly the spine erector muscles in stabilizing the lumbar column and in the prevention of pain in this vertebral segment[34].

CONCLUSIONS

By means of the results obtained in the present study, it is possible to conclude that the training protocol employed allows the muscular fatigue induction and identification with regard to the spectral characteristics of the muscles evaluated as the different responses of the spinae erector muscles found at different vertebral levels in the lumbar column were emphasized. This fact contributes for decisions of training or rehabilitation protocols involving isometric contractions of the spinae erector muscles to consider a differentiated overload in the several lumbar column segments due to their characteristics in terms of resistance.

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