A BIOMECHAMICAL APPROACH FOR ASSESSMENT OF OVERLOAD ON LUMBAR SPINE: THE EFFECTS OF DIFFERENT DEMOGRAPHIC VARIABLES ON MUSCLE FATIGUE

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SUMMARY

Objectives: To assess low back muscles fatigue and to determine the demographic variables associated to fatigue on these muscles. Methods: The electromyographic (EMG) activity of the right iliocostal (R-IL), left iliocostal (L-IL), right multifidus (R-MU) and left multifidus (L-MU) of 18 volunteers was recorded during submaximal isometric contractions. Root mean square (RMS) and median frequency (MF) values were correlated with isometric endurance time (IET). Positive RMS and negative MF slopes indicated occurrence of muscle fatigue. Multiple regression procedures were performed in order to verify the demographic variables related with the muscle fatigue. Results: Fatigue was identified in all muscles and contraction intensities ($p \leq 0.01$), except for MU-E at 5% in RMS slope analysis. Significant differences were found between the endurance time of 5% and 15% ($p=0.01$), 5% and 20% ($p=0.0002$). Higher levels of fatigue were found bilaterally in the multifidus muscles in the MF slope analysis. The combination of endurance time, age and body mass of the volunteers was identified as the determinant factor for the occurrence of muscle fatigue in the assessed muscles. Conclusions: Interventions designed to treat low back conditions must consider the several factors causing fatigue of muscles in this region.

Keywords: ***Biomechanics; Electromyography; Spine; Muscle fatigue; Low back pain; Clinical protocols.***

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INTRODUCTION

Spinal pathologies constitute a major factor accountable for work withdrawal. More recent data from the National Institute of Social Security (INSS) show that, in 2003, 387,905 job-related accidents were reported, more than 20,341 of which have been associated to the spinal region, and approximately 50% of those accidents have been recorded on INSS files as pain in this body segment[1].

In common, spinal diseases account for changes in its structure and function commonly associated to presence of pain predominantly at lumbar spine[2]. On the other hand, the presence of lumbar pain with no association to other orthopaedic or rheumatic disorders has been increasingly described. Called non-specific lumbar pain, this symptom has been shown to be related to muscular function changes[3,4].

Static and dynamic stability of the spine is responsible for the concurrent action of passive tissues and contractile elements[5,6]. With a compromised spinal muscles function, as a result, for example, of the muscle fatigue, excessive loads are imposed on passive elements of the lumbar spine (intervertebral discs, capsules and ligaments) promoting plastic deformation of these distention-sensitive structures, and, as a result, lumbar pain[7].

For this reason, muscle fatigue behavior (defined as a reduction of the neuromuscular system's ability to generate strength)[8] of spinal muscles has been frequently studied aiming to better understand its correlation with overload on this body segment. In this sense, the electromyographic activity (EMG) assessment on those muscles constitutes a major alternative for understanding the effect of sub-maximal muscle contractions required to perform activities of daily life (ADL), work and sports on muscle fatigue.

Biering-Sorensen[9] proposed a test in which the isometric

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endurance of lumbar muscles is tested by examining the time during which a patient in a ventral decubitus position on a bed is able to keep the torso suspended on a horizontal position by the action of spinal extensor muscles. Results show that men with lumbar pain history but with no report of this symptom at the moment the test is performed presented an average isometric endurance time (IET) of 176 seconds, while men reporting no lumbar pain at the moment of test and no previous history of this symptom presented an average IET of 198 seconds.

Performing further studies using the approach proposed by Biering-Sorensen[9], Kankaanpää et al.[10], Mannion and Dolan[11] or implementing the test with the original way of executing it[7,12], enabled the achievement of similar results, and that, predominantly, evidence a direct correlation between quality of lumbar muscles' isometric endurance and IET. From these results, the researchers suggested that spinal extensor muscles' fatigue may represent a risk factor to lumbar pain development.

However, this procedure is highly dependent on patient's motivation to be valid[11], because it requires a certain strength level to be maintained for as much time as possible. Because of that, the analysis of some EMG parameters, which cannot be voluntarily controlled by patients, has been used to assess the isometric endurance, particularly of the lumbar spine extensor muscles. Another aspect to be considered regarding this test is that, usually, it is performed by using only the trunk mass as endurance parameter[10,11], with the effect of additional loads to trunk mass being often neglected, thus not reproducing the effects of overloads imposed to spine on a day-by-day basis.

In this context, the objective of the current study was to assess lumbar muscles fatigue during the performance of sub-maximal contractions by means of analysis of parameters related to amplitude and frequency of the EMG signal. The effect of different demographic variables in the studied sample on these muscles' level of fatigue has also been assessed in order to identify the factors determining its occurrence.

MATERIALS AND METHODS

Volunteers

Eighteen healthy male volunteers, with no lumbar pain history for two months previously to the study and with no previous history of specific training applied to lumbar region muscles within a period of one year previous to the study were enrolled.

The studied sample presented the following demographic characteristics: age 21.22±2.13 years, body mass: 70.81±12.13kg, height 175.25±6.30cm and hand dominance: 14 right-handed and 4 left-handed.

All volunteers signed a Free and Informed Consent Form, in compliance with the Resolution 196/96 of the National Health Council, containing information about the tests to which they would be submitted and also assuring their privacy. The present study was approved by the committee on ethics in local research.

Volunteers' Positioning and Equipment

In each phase of the present study, the volunteers were positioned in ventral decubitus on a test bed (Figure 1 A). In a rest position, volunteers' trunks were maintained slightly flexed and supported. Pelvis and lower limbs were fixed to the test bed by means of five safety belts around hips, knees and ankles joints, and also at thigh and leg medial thirds (Figure 1B).

This apparatus enabled to perform the required movement in a stable way, an isometric extension of the trunk with the spine in a neutral position. In order to avoid the occurrence of compensatory movements such as spinal rotation and lateral bent, movement restraints were positioned on scapula and along the trunk (Figure 1C). Those movements are particularly present during exhaustion tests performance, as a consequence of muscle fatigue and the attempt to maintain the position required for the study, and are responsible for EMG activity changes on the assessed muscles.

The spinal isometric extension movement was performed by applying traction to a load cell (Kratos 200kg – Kratos Dinamômetros LTDA. São Paulo, SP) (Figure 1E) perpendicularly attached to test bed's base at one end and to a corset wore by the volunteers (Figure 1D) at the opposite end.

During exhaustion tests, in which the volunteers performed sub-maximal contractions at specific strengths, a digital indicator (Kratos IK 14A – Kratos Dinamômetros LTDA. São Paulo, SP) (Figure 1F) attached to a load cell was also included in this experiment allowing volunteers to control contraction strength.

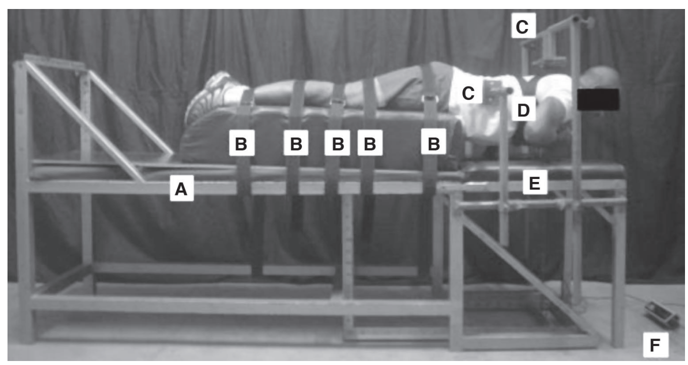

Figure 1 - *Positioning and equipment used for determining maximum load and exhaustion tests. 1A: test table; 1B: safety belts; 1C: movement restraints; 1D: vest; 1E: load cell; 1F: digital display.*

Previously to the tests performance for determining maximum and exhaustion load, the volunteers were invited to the laboratory to get familiar to the environment. On the day maximum load was to be determined, the volunteers made some repeated movements for some seconds intending to become familiar to the correct movement execution and maintenance of a given contraction strength.

The same investigator was responsible for performing all assessments.

Maximum Load Determination

The maximum load for each volunteer was determined by means of the maximum voluntary contraction test (MVCT). In a single day, the volunteers performed three MVCT during five seconds with a five-minute interval between each test. The average for the three MVTC values was determined as the maximum load.

Exhaustion Tests

In four days else, the volunteers performed sub-maximal contractions in strengths corresponding to 5%, 10%, 15%

and 20% of the maximum load, until exhaustion.

Exhaustion was defined as the down movement of the trunk as a result of the inability to maintain an isometric contraction as noticed by the volunteer himself. Tiredness and muscular pain restricted to the lumbar muscles or thigh posterior muscles were the two reasons mentioned by volunteers for stopping the tests. Investigator's identification of a standard deviation above 1 kg on the contraction strength required for each exhaustion test was another criterion for stopping tests.

The duration of exhaustion tests of volunteers or IET was recorded.

Contraction strengths were randomly selected, with one exhaustion test a day being performed, with an interval of at least 24 hours and at most 72 hours between each exhaustion test.

Table 1 shows a summary of the sequence of the tests performed in the current study.

Day	Procedure	Detailing	Assessed Variable
1	Maximum load determination	3 MVCT	Maximum Load
2	Exhaustion test	Contraction Strength 1	IET EMG signal
3	Exhaustion test	Contraction Strength 2	IET EMG signal
4	Exhaustion test	Contraction Strength 3	IET EMG signal
5	Exhaustion test	Contraction Strength 4	IET EMG signal

Table 1 - *Experimental protocol summary.*

Electromyography

During exhaustion tests, the EMG activity of the right iliocostal muscles (IL-R), left iliocostal (IL-L), right multifidus (MU-R) and left multifidus (MU-L) was captured by means of passive bipolar Ag/AgCl electrodes (MEDITRACE 100 – KENDALL. Chicopee, MA) with a capture area of 1 cm positioned perpendicularly to fibers orientation.

The electrodes were positioned at 6 cm of the L2-L3 intervertebral space for IL-R and IL-L muscles, and at 3cm of the L4-L5 intervertebral space for MU-R and MU-L muscles[15] with an inter-electrode distance of 3cm.

In order to reduce the skin-electrode impedance as much as possible, and to assure the quality of captured EMG signal, previously to electrodes positioning, trichotomy, abrasion with fine sandpaper and cleaning of the skin area with alcohol were provided at the electrodes positioning sites and at the ulnar styloid process, where an electrode was placed to act as a reference electrode as well as to assure a good signal quality. At the electrodes positioning site, marks with specific pen were made in order to assure reproducibility of the position during the days in which the study was conducted.

For capturing EMG signals, an electromyographer with a built-in 4-channel biological signals capture module to which cords and electrodes were attached (Lynx – Lynx Tecnologia Eletrônica LTDA. São Paulo, SP), and an analogical-digital (A/D) converser plate with an inlet range of -5 a +5 volts, 10-bit resolution and common rejection mode >70dB (CAD 1026 - Lynx Tecnologia Eletrônica LTDA. São Paulo, SP). For EMG signals, a specific software was also employed (Aqdados 4 – Lynx Tecnologia Eletrônica LTDA. São Paulo, SP), which enabled sampling frequency to be calibrated at 1000Hz. High-pass (10Hz) and low-pass filters have also been employed (500Hz).

Data Analysis

The gross EMG signals have been verified at each collection aiming to determine their quality. At rest, the root mean square (RMS) values for all assessed muscles were fixed set as $<5\mu V$.

By means of specific routines developed in a MATLAB environment (MATLAB 6.5 – MathWorks Inc. Natick, MA), RMS and median frequency (MF) values have been obtained from gross EMG signal from 1-second packages at each 0.5 seconds of the IET.

IET was normalized at 100%, and then RMS and MF values were obtained for each 5% of the normalized time.

Statistical analysis

The statistical analysis was performed by using the following systems: SPSS (SPSS 10.0.1 – SPSS Inc. Chicago, IL), STATISTICA (STATISTICA 4.3 - StatSoft Inc. Tulsa, OK) and BioEstat (BioEstat 2.0 – Manuel Ayres. Brasília, DF).

The normality of assessed data was tested by means of Kolmogorov-Smirnov's, Shapiro-Wilk's and Lilliefors' tests, and due to the results achieved, the parametric analysis was employed.

The statistical analysis was performed by using the RMS and MF values obtained from normalized time.

The linear regression of those values as a function of the normalized time enabled to obtain a trend slope which allowed identifying and quantifying muscle fatigue. Muscle fatigue was characterized by identifying positive slope values for RMS analysis and negative slope values for MF analysis. This statistical procedure was conducted for all assessed muscles at each contraction strengths used.

Multiple regression procedures were performed to identify determinant factors (IET, age, or body mass) of assessed muscles fatigue (r^2).

Potential differences among IETs and also among the fatigue levels induced by different contraction strengths were examined by means of simple variance analysis (ANOVA).

Comparisons among fatigue levels of IL-R *vs* MU-R, IL-L *vs* MU-L muscles at each contraction strength have been performed by using the t-test for independent samples, enabling to check for differences of fatigue ability of muscles at different vertebral levels.

For all statistical analysis, the significance level adopted was $p \leq 0.05$.

RESULTS

The mean maximum load value was 46.63±12.05kg, and the mean values for IET were 102.83±23.02, 89.06±22.90, 79.72±20.94 and 71.44±20.17 for contraction strengths corresponding to 5%, 10%, 15% e 20% of the maximum load, respectively, with significant differences being identified for 5% compared to 15% ($p=0.01$) and 20% ($p=0.0002$).

The RMS and MF slopes are shown on table 2. The comparison between RMS slopes achieved from different contraction strengths did not show significant differences for IL-R ($p=0.60$), MU-R ($p=0.68$), IL-L ($p=0.66$) and MU-L ($p=0.32$) muscles. The comparison between MF slopes obtained from different contraction strengths showed no significant differences for IL-R (p=0.55), MU-R (p=0.61), IL-L (p=0.79) and MU-EL (p=0.58) muscles as well.

Slope	% Maximum Load	IL-R	MU-R	IL-L	MU-L
RMS (μV/time)	5	0.29*	0.11*	0.29*	0.02
	10	0.35*	0.19*	0.32*	0.14*
	15	0.44*	0.24*	0.41*	0.19*
	20	0.42*	0.22*	0.37*	0.24*
FM (Hz/time)	5	-0.20*	-0.52*	-0.18*	-0.44*
	10	-0.23*	-0.49*	-0.23*	-0.42*
	15	-0.19*	-0.46*	-0.24*	-0.40*
	20	-0.18*	-0.44*	0.26*	-0.38*

Table 2 – *Slopes resulting from RMS and MF values linear regression. *p≤0.01*

The results of multiple regressions are summarized on Tables 3 and 4.

The model employing the association between volunteers' IET, age and body mass was the one showing the strongest influence over fatigue ability of iliocostal muscles.

For IL-R muscle, this model accounted for approximately 15% of the increase identified on RMS values during exhaustion tests, except for contraction strength corresponding to 20%, in which, although this has been the most contributing model for muscle fatigue, its share was quite small when compared to other contraction strengths. At IL-L muscle, this model accounted for, at least, 10% of the muscle fatigue, reaching to over 25% of the contraction strength corresponding to 5%.

When taken separately, the influence of each variable on IL-R and IL-L muscles fatigue has shown to be multiple and predominantly negligible ($r^2 < 0.10$).

On multifidus muscles, the model combining the three variables assessed in this study was also the one showing the strongest influence on muscle fatigue.

On MU-R muscle, this model accounted for almost 30% of the EMG signal range in contraction at 5% and for 17% in contraction at 15% of the maximum load. In other contraction strengths, although this was the most important model for muscle fatigue to occur, its share was below 10%. On MU-L muscle, this model accounted for, in average, almost 15% of the EMG signal range, except for contraction at 15%, where the model accounted for less than 10% of muscle fatigue.

The analysis of the individual influence of each assessed variable has shown to be negligible, except for the age variable, which, with MU-R muscle contractions at 5% and 15% has shown to influence EMG signal variation in 13% and 15%, respectively.

The results achieved from multiple regression procedures to identify determining factors for MF slopes showed to be similar to the ones achieved with the analysis of the RMS slopes.

On IL-R and IL-L muscles, the correlation between IET, age and body mass has been shown to contribute with 10%-30% to muscle fatigue, with such contribution being always greater than the one identified by the analysis of each individual variable.

On multifidus muscles, this model explained predominantly more than half MF decrease as a function of time.

On MU-R muscle, 52% of muscle fatigue could be explained by this model on contractions at 5% and 10% of maximum load, and 41% and 55% of muscle fatigue can be explained by this model on contractions at 15% and 20% of the maximum load, respectively. On MU-L muscle, the correlation between IET, age and body mass accounted for 41%, 58%, 52% and 30% of the MF range as a function of time on contractions at 5%, 10%, 15% and 20% of the maximum load, respectively.

Slope	Model	r^2 5%	10%	15%	20%
RMS		IL-R			
	IET	0.03	0.16	0.07	0.04
	Age	0.05	0.05	0.12	0.02
	Body Mass	0.003	0.01	0.01	0.0003
	IET + Age + Body Mass	0.14	0.17	0.16	0.07
		MU-R			
	IET	0.04	0.02	0.04	0.002
	Age	0.13	0.02	0.15	0.07
	Body Mass	0.08	0.003	0.0003	0.00001
	IET + Age + Body Mass	0.29	0.03	0.17	0.08
		IL-L			
	IET	0.04	0.07	0.03	0.05
	Age	0.23	0.005	0.13	0.10
	Body Mass	0.02	0.06	0.07	0.003
	IET + Age + Body Mass	0.26	0.11	0.16	0.16
		MU-L			
	IET	0.08	0.04	0.003	0.008
	Age	0.03	0.06	0.04	0.05
	Body Mass	0.00006	0.01	0.001	0.11
	IET + Age + Body Mass	0.13	0.12	0.04	0.14

Table 3 – *IET, age and body mass as determinant factors for RMS slope values.*

Similarly to iliocostal muscles, the individual contribution of each assessed variable for multifidus muscles fatigue was less significant than the contribution of the model combining all variables.

Comparisons concerned to fatigue levels of IL-R *vs* MU-R and IL-L *vs* MU-L muscles at each contraction strength showed significant differences when RMS slopes of IL-R vs. MU-R muscles were compared on contractions at 10% and of the IL-L vs. MU-L muscles on contractions at 5% of the maximum load, while comparisons between MF slopes showed significant bilateral differences between IL and MU muscles on the four contraction strengths (Table 5).

DISCUSSION

In the present study, the average IET of the contraction strength corresponding to 5% of the maximum load was close to the value proposed by Luoto et al.[13] as an indicative parameter of an individual's likelihood to develop lumbar pain.

According to the authors, volunteers (men or women) with IET below 58 seconds are three times more likely to develop lumbar pain after a follow-up period of one year than men with IET above 104 seconds and women with IET above 110 seconds.

Considering that in the study by Luoto et al.[13] the same test was performed, however using a contraction strength enough

R^2					
Slope	Model	IL-R			
		5%	10%	15%	20%
MF	IET	0.004	0.07	0.09	0.03
	Age	0.02	0.002	0.003	0.04
	Body Mass	0.11	0.01	0.01	0.009
	IET + Age + Body Mass	0.20	0.10	0.15	0.08
		MU-R			
	IET	0.41	0.15	0.10	0.33
	Age	0.05	0.05	0.05	0.05
	Body Mass	0.02	0.21	0.21	0.21
	IET + Age + Body Mass	0.52	0.52	0.41	0.55
		IL-L			
	IET	0.008	0.13	0.07	0.21
	Age	0.07	0.03	0.06	0.01
	Body Mass	0.0004	0.06	0.03	0.11
	IET + Age + Body Mass	0.09	0.30	0.21	0.26
		MU-L			
	IET	0.41	0.04	0.36	0.01
	Age	0.0001	0.12	0.007	0.17
	Body Mass	0.11	0.27	0.19	0.06
	IET + Age + Body Mass	0.41	0.58	0.52	0.30

Table 4 – *IET, age and body mass as determinant factors for MF slope values.*

Variable	% Maximum Load	IL-R vs MU-R	IL-L vs MU-L
RMS slope	5	0.29 *vs* 0.11	0.29 *vs* 0.04†
	10	0.35 *vs* 0.19*	0.32 *vs* 0.14
	15	0.44 *vs* 0.24	0.41 *vs* 0.19
	20	0.42 *vs* 0.22	0.37 *vs* 0.24
MF slope	5	-0.21 *vs* -0.52†	-0.18 *vs* -0.44†
	10	-0.24 *vs* -0.49†	-0.23 *vs* -0.42†
	15	-0.19 *vs* -0.46†	-0.23 *vs* -0.39†
	20	-0.18 *vs* -0.44†	-0.23 *vs* -0.37*

Table 5 – *Comparison between Pearson's correlation coefficient of lumbar muscles. *p≤0.05 †p≤0.01*

only to sustain trunk's mass, we can estimate in the present study that performing the proposed test with this contraction strength would result in a similar IET, and thus within the average of normative data indicating a lower potential to develop lumbar pain.

The experimental protocol suggested in this study showed to be efficient for assessing lumbar muscles fatigue, clearly evidencing increased RMS values and decreased MF values as a function of time.

However, the level of fatigue induced by contractions between 5% and 20% of the maximum load showed to be similar, indicating that the effects of overloads imposed by contractions at these strengths are potentially the same, and, for this reason, they deserve the same level of attention when considered for different daily life activities.

The increase of RMS values is associated to the recruitment of new muscle fibers with a larger activation range, as well as to the synchronization of the activation of previously recruited muscle fibers[7], while the decrease of MF values as a function of time has been shown to result from a reduced conveyance speed of the action potential along muscle fiber membrane as a consequence of the accumulation of metabolic byproducts, such as lactate and extra cellular K^+[10,12].

The analysis of determining factors for RMS and MF values behavior as a function of time suggest that lumbar muscles fatigue is essentially multifactorial. Especially on multifidus muscles, the association of different demographic variables assessed constituted the most important factor for muscle fatigue, contributing with almost 1/3 to muscle fatigue identified by means of RMS slopes and explaining more than half of the muscle fatigue identified by means of MF slopes.

On the other hand, on iliocostal muscles, the association of the three variables, which have also conjunctively showed to be the most important factor for muscle fatigue, contributed to as low as 23% when RMS slopes were assessed, and as low as 11% when MF slopes were assessed, indicating that, for these muscles, some other factor not identified in this study could have been determinant for muscle fatigue development.

Similar results were found by Kankaanpää et al.[10], who showed that the demographic characteristics of the volunteers more importantly influenced the fatigue of muscles at lower levels and closer to the lumbar spine ($r^2 \geq 0.60$).

The results of both studies point out to the existence of a stronger influence of demographic characteristics of the volunteers (age and body mass) as well as of parameters related to test execution (IET) on multifidus muscles. This finding can be explained by anatomical characteristics of these muscles and their biomechanical repercussions. According to MacIntosh e Bogduk[14], multifidus muscles fixation on spinous processes of the lumbar vertebrae favor the development of an effective lever arm for lumbar spine isometric extension, thus justifying the critical role of these muscles in this segment stabilization and, consequently, the stronger influence of the factors mentioned above on multifidus muscles fatigue.

This information was supported when a comparison of the fatigue levels between iliocostal and multifidus muscles was performed. This analysis showed MF slope values and, thus, higher levels of iliocostal muscles fatigue, bilaterally. This difference has been attributed to the prevalence of fibers with low resistance to fatigue (type-II fibers) on multifidus muscles[15].

The present study aimed to better understand the influence of isometric contraction on lumbar spine overload. The identification of a reliable test protocol to assess the isometric endurance of lumbar muscles and the possibility to find determinant factors to its execution, provide important information for an appropriate diagnosis, and, especially, for preventing and developing optimal rehabilitation programs for lumbar spine dysfunctions.

CONCLUSIONS

The protocol proposed herein has shown to be efficient for identifying muscle fatigue as well as for assessing more specific aspects related to the levels of fatigue induced by submaximal contractions at different strengths and fatigueability of lumbar muscles located at different vertebral levels.

Regarding volunteers' demographic variables, the association of IET, age and body mass were shown to be determinant for muscle fatigue to occur.

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