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Assessment of neuromuscular activation in individuals with scoliosis using surface electromyography

Avaliação da ativação neuromuscular em indivíduos com escoliose através da eletromiografia de superfície

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Abstract

Objective: The aim of this study was to investigate the potential of surface electromyography (EMG) for assessing neuromuscular efficiency and localized muscle fatigue in the lumbar extensors, in individuals with scoliosis. **Methods:** Twenty individuals participated in this study, divided equally into two groups: (1) Scoliosis Group and (2) Control Group. These subjects underwent a fatigue induction test on their lumbar extensor muscles, consisting of one maximum voluntary isometric contraction (MVIC) followed by a test at 80% of the MVIC effort. Force and EMG signals were collected simultaneously. The EMG signal was processed in the frequency domain by means of fast Fourier transforms using the median frequency; and in the time domain by calculating the root mean square value. The data were analyzed by means of one-way analysis of variance to investigate the differences between the two groups. Paired *t* test was used to investigate the symmetry between the right and left sides. The significance level adopted was 0.05. **Results:** The results showed that the individuals with scoliosis presented: (1) symmetrical neuromuscular activation between the sides; (2) lower neuromuscular efficiency; (3) greater capacity to resist fatigue; and (4) force values 42.6% lower than those of the individuals in the Control Group. **Conclusions:** The results suggest that surface EMG is an effective tool for functional assessments of scoliosis, although the protocol established limited the participation of individuals with scoliosis, from the perspective of neuromuscular efficiency.

Key words: electromyography; fatigue; scoliosis.

Resumo

Objetivo: O objetivo desse estudo foi verificar o potencial da eletromiografia (EMG) de superfície para a avaliação da eficiência neuromuscular e da fadiga muscular localizada dos extensores lombares em indivíduos com escoliose. **Métodos:** Participaram deste estudo 20 indivíduos divididos igualmente em dois grupos, (1) Grupo com Escoliose e (2) Grupo Controle, que foram submetidos a um teste de indução dos músculos extensores lombares a fadiga, o qual constituiu da realização de uma contração voluntária máxima isométrica (CVM), e realização de um teste com esforço a 80% da CVM. Foram coletados simultaneamente sinais de força e eletromiográficos (sinal EMG). O sinal EMG foi processado no domínio da freqüência, utilizando-se a transformada rápida de Fourier (FFT), por meio da mediana da freqüência (MF), e no domínio do tempo, pelo cálculo do valor *root mean square* (RMS). Os dados foram submetidos a uma análise de variância *one-way* para verificar as diferenças entre os dois grupos. Para verificar a simetria entre os lados direito e esquerdo, foi realizado o teste *t* pareado. O nível de significância adotado foi 0,05. **Resultados:** os resultados demonstraram que indivíduos com escoliose apresentaram: (1) simetria de ativação neuromuscular entre os lados; (2) menor eficiência neuromuscular; (3) maior capacidade de resistir a fadiga; e (4) valores de força 42,6% menores que os indivíduos do GC. **Conclusões:** Os resultados sugerem que a EMG de superfície corresponde a um efetivo instrumento de avaliação funcional da escoliose, embora o protocolo estabelecido tenha limitado a participação dos indivíduos com escoliose, do ponto de vista da eficiência neuromuscular.

Palavras-chave: eletromiografia; fadiga; escoliose.

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Introduction

Scoliosis is a complex deformity of the spine, in the three body planes (frontal, sagittal and transversal), in which the main component is abnormal lateral deviation in the frontal plane[1-7]. The frequency of occurrence of scoliosis varies, depending on the population studied, the identification method or the magnitude of curvature, but estimates suggest that the incidence of scoliosis among the general population is around 2 to 4%[8], thus representing around 30% of the incidence of postural deviations[9]. An epidemiological study in the state of Maranhão demonstrated that the incidence of idiopathic scoliosis among male children and adolescents was 3.4% and 7.3%, respectively[10]. Scoliosis is a potentially progressive condition that compromises body posture[5]. Therefore, evaluations investigating structural or functional references will have a decisive role in the intervention in the progression of this deformity.

A reliable evaluation is the basis for making decisions not only with regard to the treatment, but also for preventing intercurrences[11,12]. Professionals efforts towards obtaining an appropriate evaluation, focus on the fact that it is important to obtain a complete picture of the individual's incapacity and to have criteria for following up the evolution and treatment results[13,14]. Thus, after anamnesis and physical examination, obtaining x-rays is the most important and fundamental step towards measuring the deformity and determining the curvature, with regard to its correction and the potential for progress. However, for most professionals, the basic principal in this process is to diminish the number of x-rays on each individual as much as possible, in order to minimize the costs and the exposure to radioactivity[15].

Scoliosis basically leads to strength imbalance and trunk muscle impairment, such that the muscles on the concave side of the curvature are contracted and the muscles on the convex side are stretched, which characterizes a problem of muscle asymmetry[2]. Traditionally, the muscle imbalances in scoliosis cases are evaluated using muscle function tests. These muscle action analyses are essential to help in elucidating the diagnosis and also to make it possible to prescribe therapeutic exercises[16]. However, muscle function tests are done manually, thus depending on the evaluator's ability, and they are very subjective because they do not quantify the individual's strength level on each side of the trunk[5].

Hence, it can be seen that it would be of interest to objectively evaluate and quantify the muscle imbalances present in individuals with scoliosis, because the results could also provide backing for treatment prescriptions, well as for following up the evolution of this condition. One way of evaluating the trunk muscle strength would be by using dynamometers, which provide the strength level used during a specific movement. In this respect, one study in the literature has reported on an evaluation of adolescents with asymptomatic scoliosis that allowed measurement of asymmetrical effort exerted by the trunk extensors during neuromuscular efficiency and muscle fatigue tests[17], using a triaxial dynamometry and surface electromyography. Despite some inconsistencies, the results suggested that surface electromyography was a useful tool for evaluating the muscle imbalances present in scoliosis cases[17].

For muscle strength to be exerted, there must previously be neuromuscular activation[18]. Surface electromyography (EMG) is a sensitive technique for detecting neuromuscular function that makes it possible to obtain information on neuromuscular activation. Thus, by using this technique, it is possible to monitor the neuromuscular activation of the trunk muscles, both on the concave and on the convex side of a scoliosis case.

Therefore, the objective of this study was to investigate the potential of surface EMG for evaluating neuromuscular efficiency and localized muscle fatigue in the lumbar extensors among individuals with and without scoliosis. Three presuppositions were hypothesized: (1) neuromuscular activation of the iliocostalis lumborum and longissimus muscles is asymmetrical in individuals with scoliosis and symmetrical in normal individuals; (2) individuals with scoliosis demonstrate lower neuromuscular efficiency than do normal individuals; and (3) individuals with scoliosis demonstrate higher rates of localized muscle fatigue than do normal individuals.

Methodology

Sample

Considering that the sample calculation determined a minimum number of 13 individuals, the sample was composed of 20 individuals, divided equally into two groups: scoliosis group (SG) and control group (CG) (Table 1). These individuals were recruited by a physical therapist, by means of anamnesis. To be included in the SG, the scoliosis case had to be confirmed by an up-to-date x-ray examination and the lumbar pain reported by the individuals had to be chronic, with at least one episode during the last three months, but without manifestations during the test. To be included in the CG, the individuals had to have no diagnosis of scoliosis or manifestation of any presence of lumbar pain in the last year. The exclusion criteria for both groups were: previous surgery on the spine, nerve compression symptoms, spondylolisthesis, spinal stenosis, inflammatory diseases and cancer. All

Table 1. Means and standard deviations of age, height and body mass of the individuals with scoliosis (SG) and the control group (CG), and the numbers of individuals with scoliosis having left and right convexity, in which the apices do not exceed a Cobb angle of 20º (classified as grade I scoliosis*).

	Age (years)	Height (cm)	Body mass (kg)	Scoliosis type	
				left	right
SG (n=10)	35 ± 13	170 ± 10	68 ± 14	6	4
CG (n=10)	25 ± 7	174 ± 10	76 ± 13	0	0
Significance	0.029**	0.562	0.229		

* Classification proposed by the Scoliosis Research Society[6,19].

** Significant difference between SG and CG: $p < 0.05$.

individuals signed a consent statement to participate in the study. This study was approved (CEP no. 03/052) by the Research Ethics Committee (Resolution 047/2004) of the Universidade do Vale do Rio dos Sinos in which it was performed, and was thereby deemed to be ethically and methodologically appropriate, in accordance with the precepts of Resolution 196/96 of the National Health Council.

Evaluation protocol

To induce trunk extensor muscle fatigue, the individuals underwent a maximum voluntary isometric contraction (MVIC) test lasting five seconds and, after a two-minute rest period, an isometric contraction test at 80% of MVIC was performed for 35 seconds. The participants were provided with visual feedback of their muscle strength levels, using an oscilloscope (Minipa MO, model 1225, Minipa Electronics, Shanghai). For the fatigue induction test, the subjects were positioned in ventral decubitus on a support, with the armpit, thigh and ankle regions attached to the support using Velcro bands. A 2000N load cell was held in the armpit band, and this was instrumented with strain gauges (Alfa Instrumentos Eletrônicos Ltda, São Paulo) and fixed to the ground. While carrying out this protocol, strength and electromyographic signals were simultaneously recorded.

Signal acquisition

The strength and electromyographic signals were acquired using a 16-channel electromyograph (EMG System do Brasil Ltda, São José dos Campos) and the AqDados software (Lynx Tecnologia Eletrônica Ltda, São Paulo), with a Pentium 200 MHz computer with 64 MB RAM equipped with an A/D converter (EMG System do Brasil Ltda, São José dos Campos). The strength and electromyographic signals were gathered at a sampling rate of 1000 Hz for each channel.

To record the electromyographic sign (EMG signal), pairs of surface electrodes were used (Ag/AgCl; 1 cm diameter; with attachment adhesive) in a bipolar configuration, for each muscle. The electrodes were placed on the muscle belly, at a distance of 2.5 cm from each other[20]. The muscles monitored were the longissimus thoracis (at the same level as the first lumbar vertebra) and the iliocostalis lumborum (at the same level as the fifth lumbar vertebra), both on the right and left sides. The reference electrode was placed at the wrist, on the styloid process of the radius. All the pertinent norms for adequate recording of EMG signals recommended by the International Society of Electrophysiology and Kinesiology[21] were rigorously observed.

Signal processing

To process the strength and EMG signals, the SAD32 data acquisition system was used (version 2.61.07mp version, 2002; www. ufrgs.br/lmm). First, the signs were subjected to digital filtering procedures. For the strength signals, a movable mean low-pass filter was used (with a cutoff frequency of 10 Hz), and for the EMG signals, a high-pass filter was used, with a cutoff frequency of 20 Hz. The EMG signals were processed in the time and frequency domains. For the time domain analysis, the RMS values were calculated in fixed one-second windows (1000 points). For the frequency domain analysis, the median frequency (MF) was calculated in one-second windows (Hamming windowing), from the fast Fourier transform (FFT). The EMG signal was normalized in relation to the highest frequency obtained while performing the protocol[22].

The electromyographic response to the fatigue protocol was evaluated using four localized muscle fatigue indices: (1) the inclination coefficient (α) of the straight line that approximated all 30 values of the median frequency[23] (2) the y-intercept (y) of the straight line that approximated all 30 values of the median frequency[23] (3) the inclination coefficient (β) of the straight line that approximated only the first and last value of the median frequency[24] and (4) the y-intercept (y') of the line that approximated only the first and last value of the median frequency[24].

To evaluate the neuromuscular efficiency, a linear regression analysis was done on 30 points of the curve of RMS value versus contraction time (30 seconds) to obtain a straight-line equation (equation 1) for each muscle. For inclusion in the study, the determination coefficient obtained from the linear regression had to be greater than or equal to 0.5.

$$y = \varphi \cdot x + b \qquad \text{Equation 1}$$

where:
φ= inclination coefficient of the straight line
b= y-intercept value

The inclination coefficient (φ) was considered to be an index for the neuromuscular efficiency. Since the protocol required the strength to be constantly maintained at 80% of the strength obtained in the MVIC, steeper inclinations in the curve of RMS versus time represented lower neuromuscular efficiency. To evaluate the activation asymmetry between the right and left sides of the trunk, the four localized muscle fatigue indices and the neuromuscular efficiency index were used.

Statistical treatment

For the statistical treatment, the normality of the data (Shapiro-Wilk test) and homogeneity of the variance (Wilk's Lambda test) were first verified and confirmed. One-way ANOVA was performed to investigate the differences between the two groups (scoliosis and control) regarding body mass, age, height, strength values from the MVIC, muscle fatigue indices and neuromuscular efficiency indices. To investigate the symmetry between the right and left sides, the paired Student's t test was used. The significance level used was 0.05.

Results

The results showed that the SG individuals demonstrated significantly lower strength values (p= 0.009) than the CG individuals did, such that the SG showed a mean strength of 416 ± 29 N, while the CG demonstrated values of 718 ± 14 N.

Comparing the localized muscle fatigue indices, significant differences between the SG and CG were only shown for the right longissimus muscle, for three of the four studied fatigue indices (Table 2). These results indicate that the individuals in the SG showed lower fatigue indices for the right longissimus muscle (Figure 1), probably due to lower strength shown in the MVIC and, consequently, while the fatigue protocol was being conducted. The other muscles (left longissimus, right iliocostalis and left iliocostalis) did not differ significantly between the SG and CG groups, for any of the four localized muscle fatigue indices.

Comparing the neuromuscular efficiency indices, significant differences between the SG and CG were shown for the longissimus and iliocostalis muscles, but only on the right side for both groups (Table 1). The SG individuals demonstrated greater muscle activation while the fatigue protocol was being conducted on the right longissimus and right iliocostalis muscles, i.e., to maintain the same strength level, they showed a steeper straight-line inclination, with positive inclination coefficients (φ), thus indicating lower neuromuscular efficiency (Figure 2). The neuromuscular efficiency indices for the longissimus and iliocostalis muscles on the left side, did not differ significantly between the SG and CG.

Symmetry comparisons between the right and left sides of the trunk, using the fatigue and neuromuscular efficiency indices, did not demonstrate any significant differences between the two sides, for any of the four muscles, for either the SG or the CG. This result indicates that the neuromuscular activation level was similar for both sides, as was the fatigue level shown by the muscles, independent of the group to which the individual belonged.

Discussion

The purpose of this study was to investigate the potential for using surface EMG to evaluate the neuromuscular efficiency and localized muscle fatigue of the lumbar extensors among individuals with scoliosis. The results showed that the individuals in the SG group presented significantly lower strength values than did the individuals in the CG.

Table 2. Mean and standard deviation values of the neuromuscular efficiency indices (φ) and localized muscle fatigue indices (α, y, β, y'), and p values obtained via ANOVA, comparing the scoliosis and control groups (RL: right longissimus; RI: right iliocostalis).

	Scoliosis Group	Control Group	Significance
RMS φ RL	1.08 ± 1.4	-0.002 ± 0.5	0.034*
RMS φ RI	0.81 ± 1.2	-0.006 ± 0.4	0.044*
MF α RL	-0.54 ± 0.1	-1.04 ± 0.3	0.000*
MF y RL	114.3 ± 11.7	114.9 ± 13.4	0.238
MF β RL	-0.56 ± 0.4	-1.35 ± 0.3	0.000*
MF y' RL	100.4 ± 10.7	112.6 ± 15.1	0.050*

* Significant differences between SG and CG: p< 0.05.

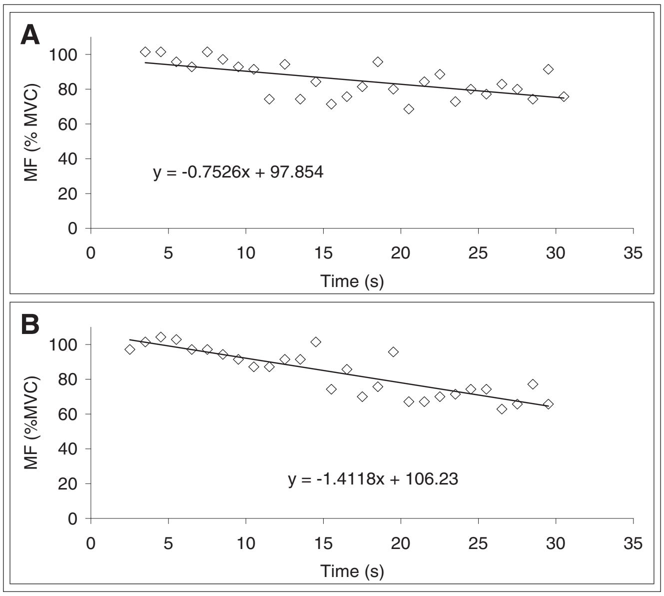

Figure 1. Behavior of the median frequency (MF) of the right longissimus muscle from two representative individuals during the fatigue test: (a) from the scoliosis group and (b) from the control group.

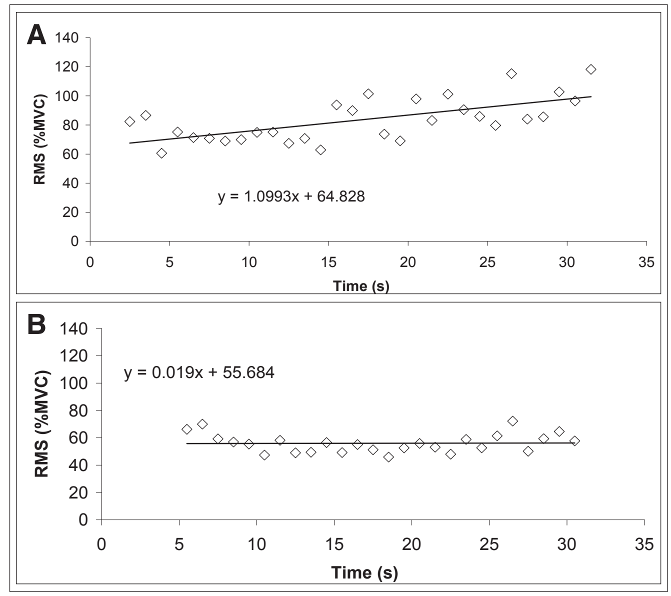

Figure 2. Behavior of the RMS value of the right longissimus muscle from two representative individuals during the fatigue test: (a) from the scoliosis group and (b) from the control group.

One possible explanation for this result is that the SG individuals had lumbar pain and, for this reason, they might have not used their maximum strength during the MVIC. It has been reported that individuals with pain tend to put a pain protection mechanism into action, which stops them from attaining maximum effort with the muscles in question[25, 26]. Therefore, pain has an important role in body protection, because the changes in motor recruitment in an individual who suffers from pain may be due to some type of strategic control that the nervous system performs through a specific neural route[27]. The effects of this neural mechanism suggest that there is a reduction in agonist activation and an increase in antagonist activation[27].

Some studies have presumed that, when people with pain perform an MVIC test, they attain submaximal effort because of their own pain situation, and that this has an influence on the fatigue test result when based on a protocol of, for example, 80% MVIC[28]. The results from the present study go along with that supposition, since the individuals in the SG presented strength values 42.6% lower than those of the CG, probably because they did not exert their maximum strength during the MVIC.

It has been documented that, in muscle fatigue situations like those occurring during sustained contractions, there is an increase in RMS and a decrease in MF of the EMG signal[23,24]. Thus, while performing muscle fatigue protocols, it is common to observe spectral compression towards the lower frequencies, thereby decreasing the MF. The reduction in MF that occurs because of decreased conduction velocity of the muscle fiber action potential has been accepted by many researchers as an indicator for the muscle fatigue that occurs during sustained isometric contraction[20,21,23,29]. The results from the present study showed this behavior, such that the SG reported significantly lower muscle fatigue indices and therefore a straight line sloping less steeply, thereby demonstrating greater capacity to resist fatigue than did the individuals in the CG (Figure 1). Initially, it had been speculated that individuals with scoliosis would show a steeper slope on the MF straight line and would be more susceptible to muscle fatigue than would be the individuals of the CG. The results showed an inverted relationship between fatigue and scoliosis, i.e., the right longissimus muscle, representing the concave side of the individuals' curvature (contracted musculature), did not show early manifestations of muscle fatigue, as measured using fatigue indices. It can be understood that this result was influenced by the non-attainment of maximum strength during the MVIC, since the fatigue test depends on this result.

The results regarding neuromuscular efficiency showed significant differences between the SG and CG, on the right side, for both the longissimus and the iliocostalis muscles. In other words, the individuals with scoliosis showed lower neuromuscular efficiency indices and therefore greater neuromuscular activation on the concave side. These results partially corroborate previous studies[17,30] that suggested that, among individuals with scoliosis, the trunk muscles on both the convex side and the concave side produce greater electrical activation than is seen among healthy individuals without scoliosis.

Since muscles cause movements and maintain tonus, they can be considered to produce skeletal deformities in situations of imbalance. In other words, situations of imbalance of the back muscles may be the causal factor for scoliosis[31]. For some authors, paravertebral muscles having increased electrical signals on the convex side of the curve indicate that the convex side is stronger than the concave side. For other authors, it would be just the opposite, i.e., the electrical signals correspond to weak muscles that respond to the stimuli with all of their fibers and consequently produce stronger signals[31]. Although there have been references in the literature to electrical activation asymmetry among individuals with scoliosis, independent of which side (concave or convex) is stronger, the results from the present study do not sustain any of these findings. One possible explanation for these results could be that the isometric contraction of the trunk extensors performed during the fatigue test, as proposed in the present study, does not ensure that the muscle effort is symmetrical and therefore the activation would also not be symmetrical. Therefore, one explanation for why the results did not indicate the asymmetries may relate to the fatigue protocol itself, not only because it was dependent on the MVIC (which, as already mentioned, did not correspond to the individuals' maximum effort), but also because the trunk extension movement required in the protocol was not done unilaterally. Therefore, it may have been more appropriate to make unilateral demands on the trunk extensors, as required in the Klapp exercises, thereby avoiding compensatory situations during the exertions of the fatigue test. These points constitute a limitation of the present study, in which the evaluation protocol was based on a situation that perhaps is not possible for individuals with scoliosis.

Conclusion

The results demonstrated that the individuals with scoliosis demonstrated lower neuromuscular efficiency and strength values 42.6% lower than among the individuals in the control group. The results also showed that individuals with scoliosis showed neuromuscular activation symmetry between the right and left sides of the trunk and lower localized muscle fatigue indices, thus contradicting the presuppositions previously established. The results suggest that surface EMG is an effective tool for functional assessments of scoliosis, from the point of view of neuromuscular efficiency, although the protocol established limited the participation of individuals with scoliosis.

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