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## Assessment of Low Back Muscle by Surface EMG

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### 1. Introduction

Surface electromyography (EMG) is wide used to analyze back muscle activity. This tool is a non-invasive technique that allows the evaluation of muscle activity. Extensive researches were made to understand the surface EMG techniques and its application to the analysis of low back muscles for classifying healthy subjects and low back pain (LBP) patients, trained and non-trained subjects, subjects under rehabilitation treatments, as well as to access the muscle activity during labor tasks, sports practice or daily life activities.

So, the development of biomechanical tests that enable identifying standards of muscular activity characteristic of a fatigue process, one of the causes for spine muscular-skeletal lesions, which emerges through the task repetitiveness and overload, may be a possibility of preventing lumbar lesions.

The aim of this chapter is to provide a global understand of EMG parameters used to access low back muscle. For this it will be presented some issues that affect the surface EMG for low back muscle as: the reliability of low back muscle EMG; the behavior of low back muscle EMG during isometric contractions by means the analysis of the root mean square (RMS), median frequency (MF) and mean power frequency (MPF); the biomechanical parameter to identify the fatigue threshold known as Electromyographic Fatigue Threshold (EMG<sub>FT</sub>); the used of surface EMG to the assessing low back pain; and the influence of the manual load lifting to the EMG signal in low back muscle.

### 2. Reliability of low back muscle EMG

EMG has been used to study physiological aspects of muscle activity. The reliability of the EMG spectral parameters in low back muscles has been analyzed by different authors (Bouillard et al., 2011, van Dieën & Heijblom, 1996, Dolan et al., 1995, Ng & Richardson, 1996). This reproducibility refers to the consistency in the measurement tool used, where a reproducible method is one that has a small measurement error (Elfving et al., 1999). When evaluating different methods of exercise, the reproducibility of the experiment is very important, and the test/re-test methodology is used to estimate the variability of the measures in repeated tests (Dedering et al., 2000).

Tools commonly used for analysis of reproducibility are the Standard Error of the Measurement (SEM) and the Intra-class Correlation Coefficient (ICC), which appear to be complementary of each other (Elfving et al., 1999). The first can be used to check the size of

the error relative to the size of the changes in the variables analyzed while the second can be used to consider the size of the error related to differences between measures (Keating & Matyas, 1998).

The ICC range from 0.00 to 1.00, where the perfect reliability is 1.00 and the poorest is 0.0. A high ICC reflects a small within-subject variance compared to the between-subjects variance. There are different ways to calculate the ICC depending on the experimental design and the composition of the group being tested (Keating & Matyas, 1998), therefore, we must be careful when comparing it in different groups, and extrapolates it to heterogeneous populations.

Low back muscles EMG parameters are not easily comparable between studies of reproducibility, since the methodology often varies. In several studies (van Dieën & Heijblom, 1996, Dolan et al., 1995, Ng & Richardson, 1996) the number of subjects varies between 4 and 28, mostly males. Also, different locations of electrodes, test positions and levels of muscle contraction are used by different authors in testing low back muscles (Elfving et al., 1999).

The EMG signal is generally obtained in two locations ranging between T10 and L5 vertebrae. The positions of the test usually used are: prone (Mannion & Dolan, 1994, Moffroid, 1993, Ng & Richardson, 1996, Coleman et al., 2011), sitting (Carpenter & Nelson, 1999, van Dieën & Heijblom, 1996, Elfving et al., 2003) and standing (Cardozo & Gonçalves, 2010, Cardozo et al., 2011). The time between test and re-test ranging from 5 to 60 minutes in a comparison intra-day and 1 to 6 days in a comparison of day (Elfving et al., 1999).

Several authors have made studies to verify reliability of surface EMG methods. Spector (1979) found correlation coefficients ranging from 0.73 and 0.97, while Komi & Buskirk (1970) achieved a test-retest reliability of 0.88 for surface electrodes.

Danneels et al. (2002) have reported an excellent within-day ICC for EMG parameters performed at the maximum voluntary contraction (MVC) for both healthy and LBP subjects.

During a sub-maximal protocol Dederling et al. (2000) have shown good reliability for EMG parameters, corroborating with study performed by Fleiss (1986), who also demonstrated good reliability for low back muscles. In his study he found ICCs ranging from 0.443 to 0.727 for the initial MF, and ranging from 0.273 to 0.734 for the MF slope. These better results to the initial values comparing to the slope values is supported by study of Peach et al (1998) performed to analyze back muscle fatigue.

Another measure of reproducibility of EMG parameters is intra and inter-subject coefficient of variation (CV), where lower values represent greater repeatability (Knutson et al., 1994). The CV reflects the dispersion of data around the mean and it is calculated by the root square of the standard deviation divided by the mean. The high or low values are not considered good or bad. Some degree of variability is necessary to demonstrate reproducibility. A low CV suggests homogeneity of the group, which allows creating a diagnostic or a model that can be compared to other assessments. This is the basis on which the average dynamic electromyography has been considered as a normalization value when studying dynamic events.

Since EMG analysis have been an alternative to check the resistance of low back muscles due to the contraction time, the reproducibility of these measures becomes paramount. According to the studies presented in the current chapter, it is possible to note that during isometric contractions surface EMG can access low back muscles with good reproducibility.

### 3. Low back muscle fatigue during isometric contractions

The possibility of preventing overload-associated lumbar lesions caused by the practice of sports, daily activities and especially at work may come from the development of tests aimed at allowing identifying muscular activities patterns characteristic of a fatigue state, which is one of the evident causes of muscular-skeletal lesions in the spine, once this type of injury is established due to the task repetitiveness and overload.

The EMG spectral analysis is widely used to control the development of the localized muscular fatigue. Fatigue promotes changes on the EMG signal frequencies usually evidenced by the analysis of the MF and MPF (Kumar et al., 1998).

These changes on the spectral values are associated with physiological changes as the waveform of the motor units action potentials affected by alterations on the muscular fibers conduction velocity. This velocity decreases due to changes on the muscular pH that in turn, changes in function of the accumulation of the lactate generated in the muscle (Cardozo & Gonçalves, 2010, DeLuca, 1997). This promotes an increase on the low frequencies and a decrease on the high frequencies making the spectral parameters to change and the MF and MPF parameters to decrease (Figure 1).

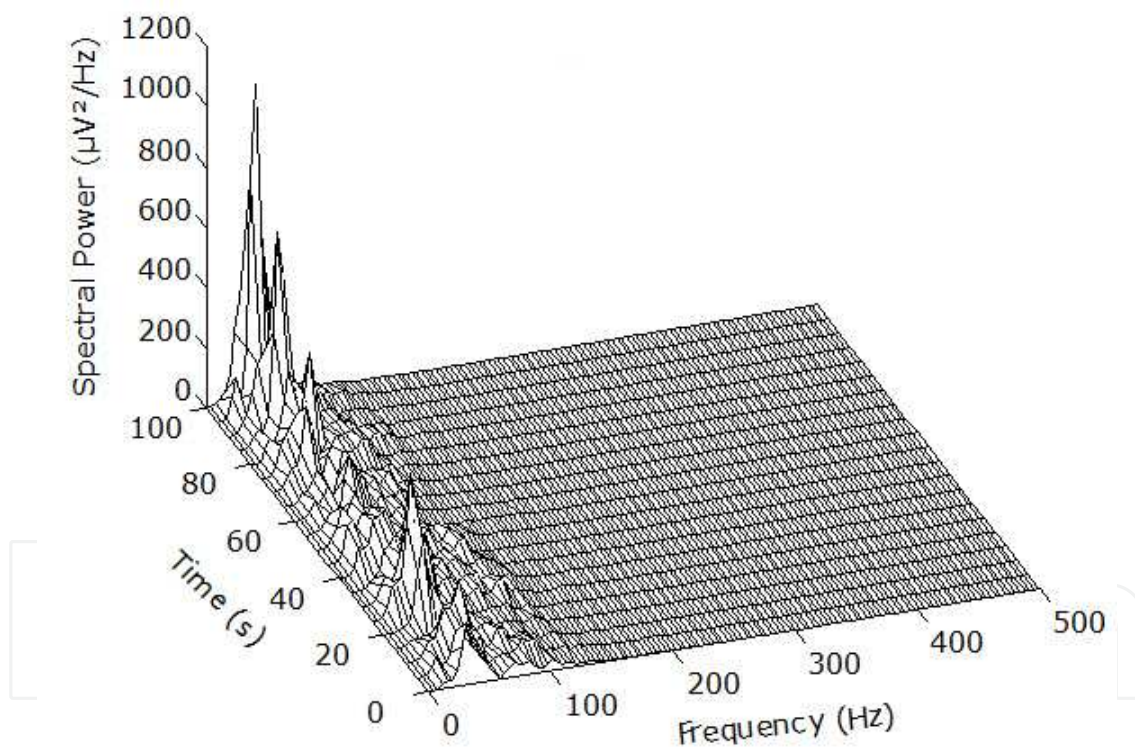


Fig. 1. EMG spectral analysis over time.

But the use of the MF and MPF reflects the global behavior of spectral parameters, and not specific frequencies, which can be important to the analysis of back muscle. With this in mind Dolan et al. (1995) developed an alternative protocol called "Frequency Banding. In their study thirty-five health volunteers pulled upward with constant force on a handlebar attached to the floor while the EMG signal from the erector spinae was recorded at the levels T10 and L3. The power spectra were divided into 10 frequency bands between 5Hz and 300Hz (5-30 Hz, 30-60 Hz, 60-90 Hz etc. up to 300 Hz), as shown in figure 2.

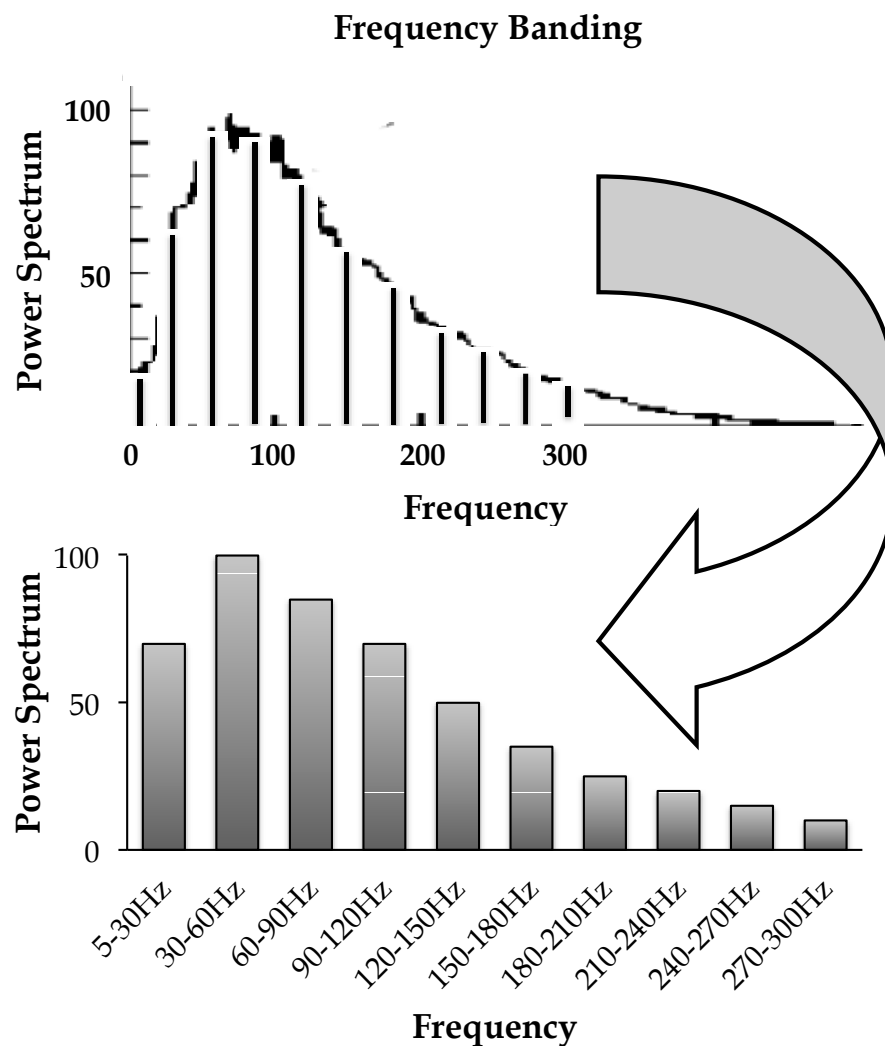


Fig. 2. Frequency Banding technique.

The authors affirm that this range was chosen because preliminary tests showed that most of the signal above 300Hz was noise, and signal below 5Hz was most susceptible to movement artifact. They compared changes in these frequency bands of the EMG power spectrum with changes in MF and total power during sustained isometric contractions of the back muscles and found that changes in the lowest frequency band (5 to 30Hz) were the most reliable index of fatigue. They also found that changes in this band correlated best with the measured endurance time.

More recently Cardozo et al. (2011), using the frequency banding technique, found that the signal in the low frequency part of the EMG power spectrum increases with fatigue in a load-dependent manner. Also, they found that the rate of change in low frequency power may be a useful indicator of fatigue rate or "fatigability" in back muscles and may provide a useful tool for assessing changes in muscle function in patients in response to rehabilitation and muscle training regimes, and that changes in low frequency power are more evident than changes in the MF.

Another methodology aimed at observing the muscular fatigue process through EMG is the RMS value taken as indicative of the muscular activity variation both in the fire rate and in the amplitude, once this value is directly associated to the behavior of the motor units involved.

Most skeletal muscles respond to fatiguing submaximal contractions with an increase on the EMG signal amplitude (Cardozo & Gonçalves, 2003). However, some studies report that during trunk extension exercises, the back muscles respond differently, as a decrease or no change on the EMG signal (Hermann & Barnes, 2001). It is likely that these contradictions are due to differences of protocols between studies. Studies performed with high load levels have reported decreases on the EMG signal with the fatigue (Hermann & Barnes, 2001), however, other studies involving contractions with low load levels did not presented this decreasing RMS behavior in function of time (van Dieën et al., 1993, Morlock et al., 1997, Ng et al., 1997). Another potential explanation for these conflicting results in back muscles is related with the type of exercise, once these muscles are configured at several directions in the spine (Haldeman, 1999), pure trunk extension exercises may present different results in relation to those using rotation exercises or even combined extension and rotation exercises.

#### 4. Electromyographic fatigue threshold for low back muscle

To evaluate the muscular conditions biomechanically and to obtain an index that allows instructing activities, postures and even exercises to improve the general physical conditions, becomes the main justification to develop a protocol in order to evaluate the development of the fatigue process of back muscle in isometric tasks by means EMG with the objective of obtaining and evaluating a fatigue threshold.

In the fatigue state, differences in EMG activity for agonists' muscles have been suggested (Tesch et al., 1983). Several protocols have been developed for the identification of muscular fatigue, most of them is based in the methodology described by DeVries (1982) that analyze the RMS with the time (Graef et al., 2008, Kendall et al., 2010, Matsumoto et al. 1991, Oliveira et al., 2007, Pavlat et al. 1995, Smith et al., 2007, Viitasalo et al. 1985) at different perceptual of load, allowing to determine the index called Electromyographic Fatigue Threshold ( $EMG_{FT}$ ).

The  $EMG_{FT}$  correspond the higher intensity of load that the subject can maintain without starting the process of neuromuscular fatigue. In this intensity, the EMG activity does not change with the progress of the exercise (Moritani et al. 1993).

To the determination of the  $EMG_{FT}$ , DeVries et al. (1982) proposed a methodology in which the subjects performed an incremental protocol in a cycle-ergometer. The EMG signals were obtained from quadriceps muscle in different loads and, in each load, it was performed a linear regression between the EMG signal and time to obtain the slope (Figure 3-A). After that, a new linear regression was performed between the slope and its corresponding load, been the intercept of the line considered the  $EMG_{FT}$  (Figure 3-B).

Pavlat et al. (1995) adapted the protocol of DeVries et al. (1982) and proposed to determinate the  $EMG_{FT}$ , the use of predictive loads with fixed duration of 1 minute, and 12 consecutives sets of EMG signs with 5 seconds of duration each. This author performed this protocol to avoid the increase of temperature, which can reduce the amplitude of EMG signs.

Housh et al. (1995) utilized the  $EMG_{FT}$  of vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) muscles in the cycle-ergometer during loads from 200 to 400W and concluded that  $EMG_{FT}$  of RF was smaller than VL, suggesting that there is a dissociation in the characteristics of superficial muscles of quadriceps femoris.

About the reproducibility DeVries et al. (1987) verified a correlation of 0,94 between test and re-test. Pavlat et al. (1993) determined the  $EMG_{FT}$  of VL muscle and obtained a correlation of 0,65 between test and re-test. This author also found no differences between values.

Several researchers have attempted to develop testing protocols that allow the evaluation of muscle behavior, but all these protocols were performed for limb muscles. The first study

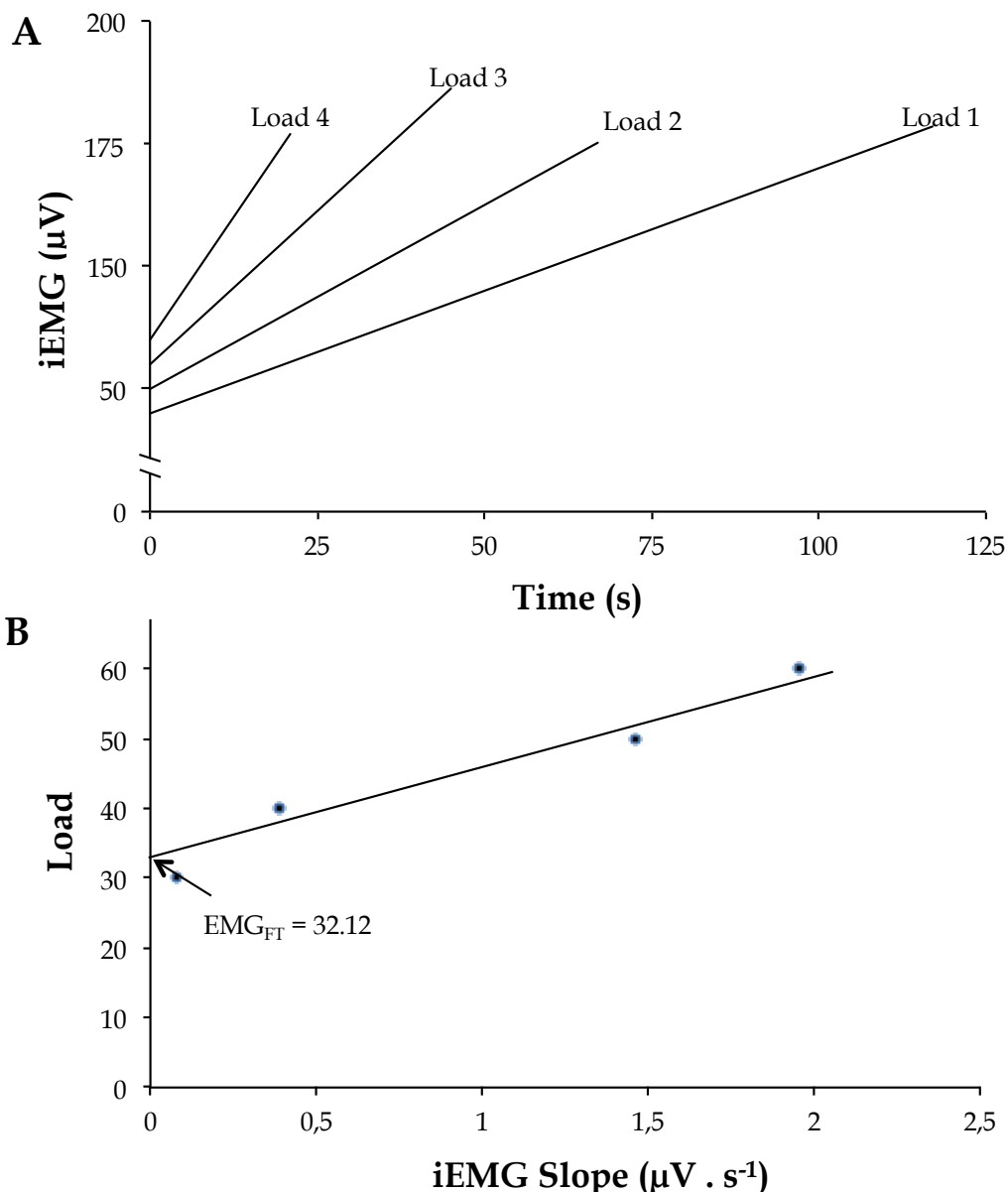


Fig. 3. Determination of the Electromyographic Fatigue Threshold ( $EMG_{FT}$ ) by DeVries et al. (1982) protocol. A: linear regression between the EMG signal and time to obtain the slope; B: linear regression performed between the slope and its corresponding load (the intercept of the line is considered the  $EMG_{FT}$ ).

developed to identify the  $EMG_{FT}$  for back muscle was accomplished by Cardozo & Gonçalves (2003). Based on the protocol proposed by DeVries *et al.* (1982), they developed a specific protocol for the determination of the  $EMG_{FT}$ , particularly for the erector spinae muscles and observed that the attainment of this index is possible for low back muscles.

But, these protocols were performed by means of the signal amplitude, but the changes on the RMS values as the fatigue process develops are related to mechanical-physiological alterations in the muscle with the increase on the fire rate and the recruitment of new motor units (Gonçalves, 1998). Also, to the determination of the  $EMG_{FT}$  it is necessary a linear positive behavior of the RMS values in function of time. In studies involving fatiguing tests for back muscle not always it is observed this kind of behavior. Several studies have found

linear negative behavior of the RMS with the fatigue process development (Cardozo & Gonçalves, 2003), and others have found non-linear behavior of the RMS in function of time (Clark et al., 2003), what would make impossible the  $EMG_{FT}$  identification by this parameter. However, the changes on the MF values are related to physiological changes as the wave shape of the action potential of motor units affected by alterations on the conduction velocity of muscular fibers.

With this in mind Hendrix et al. (2009) found that the  $EMG_{FT}$  can also be obtained by spectral parameters of the EMG signal, using an adopted protocol based on DeVries work (Figure 4).

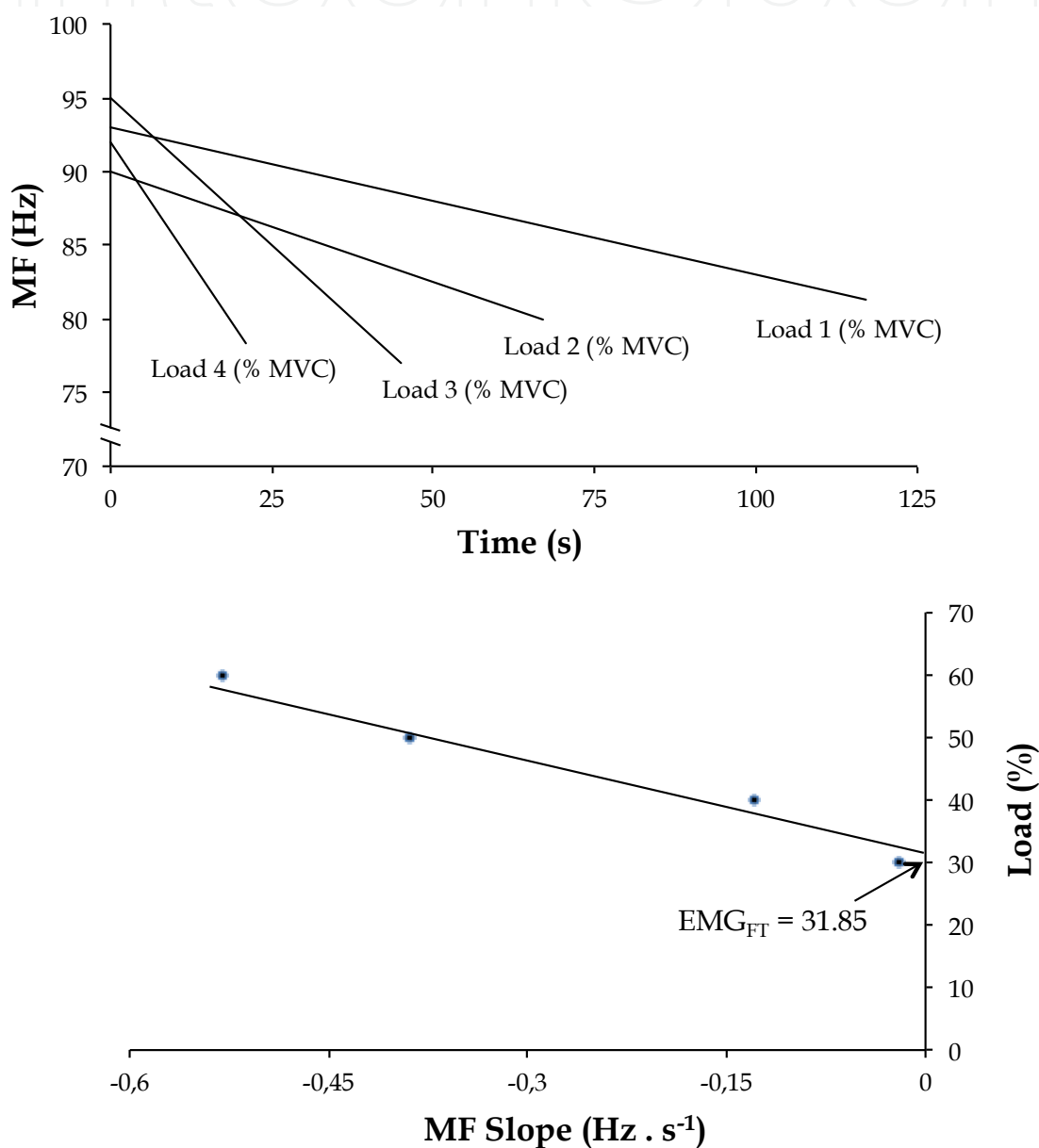


Fig. 4. Determination of the Electromyographic Fatigue Threshold ( $EMG_{FT}$ ) by Hendrix et al. (2009) protocol.

Even the  $EMG_{FT}$  has been wide used over years, its usefulness is still discussed. Recently Bouillard et al. (2011) found an inability to detect an  $EMG_{FT}$  by means the RMS values in



most of the subjects. To achieve this threshold the author established three criteria: (i) significant positive linear regression between load and slope, (ii) a coefficient of determination greater than 0.85, and (iii) a standard error for the  $EMG_{FT}$  below 5% of MVC. Their results show the possibility to determine the  $EMG_{FT}$  in only nine of the 37 subjects by means the RMS values. The  $EMG_{FT}$  by means the MF values allowed the determination of 27 out of the 37 subjects, but with a weak reproducibility, concluding that the  $EMG_{FT}$  is not a valid tool to assess muscle function.

So, more studies must be performed to understand the significance of this parameter and its application to access low back muscle by means surface EMG.

## 5. EMG in assessing low back pain

LBP causes an socio-economic impact promoting many day lost in work. It is a multifaceted problem and because of this nature the extend contribution in causation of the problems is not ascertainable. Most are the factors that has relation with de LBP: history of back pain, psychological and work related factors, heavy physical work, prolonged sitting, lifting, trunk rotation, pushing/pulling, vibrations and factors genetic, muscle strength, physical fitness and one of the most important related to musculoskeletal disorders is the fatigue due the repetition of movement or intensity of work.

In order to create a methodology that could be used to evaluate isometric resistance of low back muscles, as well as to analyze disorders of the lumbar spine, Biering-Sorensen (1984) proposed a test called "Sorensen Test."

In this test the subjects are positioned prone on a test table where the legs are fixed by belts and the arms are folded across the chest touching the contralateral shoulder. In this position, subjects were instructed to keep the trunk in a horizontal position and parallel to the ground by means of isometric contractions held until exhaustion (Figure 5).

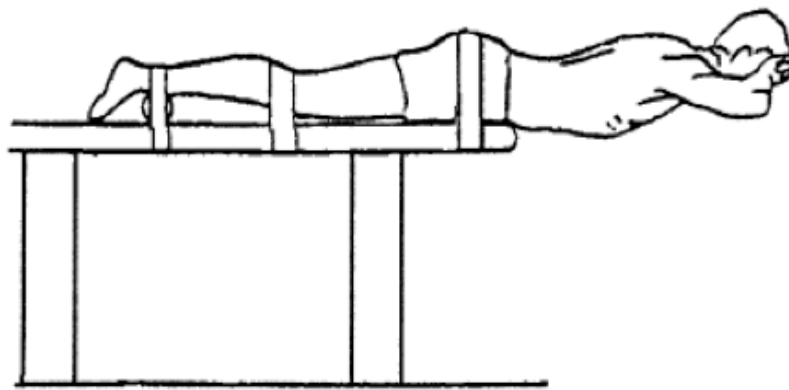


Fig. 5. Sorensen Test.

The isometric endurance time (IRT), defined as the time to maintain the proposed approach to exhaustion, was recorded. The results showed that men with a history of LBP, but without the presence of this symptom at the time of testing, had an IRT average of 176 seconds, while men without the presence of LBP at the time of the test and no history of this symptom had an IRT average of 198 seconds.

This test is considered safe for both healthy people and for people with LBP (Alaranta et al., 1995, Biering-Sorensen, 1984, Moffroid, 1997, Peltonen et al., 1998), whereas perform maximal contractions may not be safe for this second group (Moffroid et al., 1993).

Luoto et al. (1995) also showed that subjects with IRT less than 58 seconds are three times more likely to develop LBP after one year follow-up than men with IRT greater than 104.

Other studies using the approach proposed by Biering-Sorensen (1984) (Kankaanpää et al., 1998, Mannion & Dolan, 1994, Sparto et al. 1997) or by deploying the test relation to the original form of execution (Seidel et al., 1987), were able to produce similar results. From these results, researchers began to suggest that fatigue of low back muscles might represent a risk factor for the development of LBP.

However, the analysis only the IRT is a procedure that is highly dependent on the subjects' motivation for its validity (Mannion & Dolan, 1994), because it requires a certain level of strength to maintain the exercise for as long as possible. For this reason, EMG analysis of certain parameters, such as the decline in MF and MPF, and their initial values, which cannot be voluntarily controlled by subjects, have been used to assess the isometric strength of low back muscles.

The observation of the MF behavior may yet have clinical applications as those reported in the study of Ng & Richardson (1996) and Roy et al. (1995), who performed an EMG spectral analysis of the back muscles in patients with LBP during the rehabilitation, where the results were analyzed in order to determine if the EMG procedures are capable of: (i) distinguishing patients with LBP from normal individuals; (ii) to control changes on the muscular function after rehabilitation from lumbar lesion. One concluded that the procedures adopted allowed distinguishing patients with LBP from healthy individuals and those subjects presented decreased fatigability after rehabilitation, according to the EMG spectral analysis. Therefore, this procedure may be useful in the LBP rehabilitation process.

Furthermore, when comparing EMG parameters with spinal mobility and trunk strength from athletes with LBP, Klein et al. (1991) found that the recovery of the EMG is better than the others parameters, showing its usefulness to evaluate training and rehabilitation programs.

Some authors have found that the greater is the load the lower is the spectral value (Dedering et al. 2002; Mannion & Dolan, 1996). These authors explain this behavior by the fact that to sustain high loads it is necessary to the recruitment of type II muscle fibers, which in the lumbar muscles, unlike appendicular muscles, have a smaller diameter than type I fibers (Mannion & Dolan, 1996; Roy et al., 1989). With this smaller diameter fiber that has a lower conduction velocity, thus contributing to the reduction in MF values when increasing the initial charge level. Therefore this variable can even identify the muscle fiber composition (Biedermann et al., 1991).

Also, higher initial value for MF is related to higher concentration of type I fibers and lower values are associated with higher concentrations of type II fibers. People with LBP may develop atrophy of type II fibers in the muscles of the spine and consequently have a higher concentration of type I fibers.

So, EMG parameters seems to be related to muscle composition and might be useful to measure muscle ability in a noninvasively way.

## **6. Low back muscle EMG during manual load lifting**

The act of load lifting is included in many movements that we do during the day and we perform many times automatically and unconscious of necessities mechanisms to lift this load or to maintain it.

This continued load lifting has brought one important percentage of all LBP result from bad mechanics and postural habits and the majority of LBP is localized at level L4/L5 and L5/S1. This fact can be justified because the occupational activities are designed to meet occupational demands and not to optimize biological compatibility (Kumar, et al., 2001).

Chaffin & Anderson (1984) claim that NIOSH (The National Institute for Occupational Safety and Health) found that rates of muscle-skeletal injuries, even though the number of injuries per hour/men in the work and rate of severity, and the numbers of hours lost due to injuries per hour/men at work increased when: heavy and dense objects were lifted from the ground, with high rates of lifting, position of load relationship with the body and duration of activity. These can promote a significant increase of injuries risk and fatigue for some people if they aren't carefully trained for the tasks of lifting.

The load lifting causes a great lost time in industrial injuries and high stress in the muscle skeletal system (Frievalds et al., 1984). Many of industrial accidents cause injuries in the lumbar column. The LBP has been the most common cause of work absenteeism and also a significant factor in functional disability and is the most common cause of activity limitation among people in many countries, having a general agreement that mechanical stresses to spine is related to the development of degenerative disc disease and this problem is significant yet.

During the manual load lifting many variables interfere in this action and can influence in its efficiency such as: (i) joint posture before and after the load lift (Kumar & Garand, 1992); (ii) the magnitude of the mechanical load (Chaffin & Park, 1973); (iii) the type of contractions used where dynamic strengths are significantly lower than isometric strengths (Kumar & Garand, 1992); and (iv) the maximal capability of any individual varies with posture (Kumar & Garand, 1992).

An important factor that interferes in an EMG activity during load lift is the velocity of execution and a significant difference between static and dynamic strength has been also reported by MacGill & Norman (1985) and Kumar (1994).

The muscle activity during the load lifting has been correlated between posture of trunk (Kumar et al., 1996), distance of load of body (Cook & Neumann, 1987), the velocity of lifting (Winters & Woo, 1990), different plans (Seroussi & Pope, 1987), high of handles (Andersson et al., 1975), and the initial position of load (Gracovetsky, 1988),

Studies about accessories to help the load lifting and to protect the worker have been interests particularly about the use of pelvic belt. The experience in the use of this accessory associate at kind of breath can modify the activity of rectus abdominis, obliquos extern abdominis and erectors spinae during load lifting (Udo & Yoshinaga, 1997) as well as increasing the intra-abdominal pressure (Lander et al., 1992). In sports as the squat, when a belt is used, the movements were faster than without the use of it, however, the EMG activity of the erector spinae and obliquos externus muscles decrease with the use of the belt.

Many occupational activities have been realized repetitively and employ many muscles. Asymmetric motions are very frequently and muscles can also be differently loaded promoting differences amounts of fatigue and the rate with which they fatigue may also be different (Kumar et al., 2001).

Several researchers have attempted to develop testing protocols that allow for the evaluation of muscle behavior in this extremely demanding activity.

The literature contains several proposals for test protocols, some of which include the use of manual load lifting accessories such as pelvic belts, which have been found to reduce EMG activity but to interfere little in the development of the fatigue process (Gauglitz et al., 2003).

## 7. Conclusion

This chapter presented the basic concepts of surface EMG techniques and its application to the assessment of low back muscle. It was shown that the surface EMG has a good reliability in its parameters, and is a good tool to access muscle fatigue. We can also note that it is possible to obtain an index to verify the fatigue state, by means the  $EMG_{FT}$ , as well to identify LPB noninvasively.

## 8. Acknowledgment

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## **Applications of EMG in Clinical and Sports Medicine**

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This second of two volumes on EMG (Electromyography) covers a wide range of clinical applications, as a complement to the methods discussed in volume 1. Topics range from gait and vibration analysis, through posture and falls prevention, to biofeedback in the treatment of neurologic swallowing impairment. The volume includes sections on back care, sports and performance medicine, gynecology/urology and orofacial function. Authors describe the procedures for their experimental studies with detailed and clear illustrations and references to the literature. The limitations of SEMG measures and methods for careful analysis are discussed. This broad compilation of articles discussing the use of EMG in both clinical and research applications demonstrates the utility of the method as a tool in a wide variety of disciplines and clinical fields.

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