Determination of muscle fatigue index for strength training in patients with Duchenne dystrophy

Determinação do índice de fadiga muscular para treinamento de força em pacientes com distrofia de Duchenne

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Abstract

Introduction: Muscle weakness is the most prominent impairment in Duchenne muscular dystrophy (DMD) and often involves the loss of functional ability as well as other limitations related to daily living. Thus, there is a need to maintain muscle strength in large muscle groups, such as the femoral quadriceps, which is responsible for diverse functional abilities. However, the load and duration of training for such rehabilitation has proven to be a great unknown, mainly due to the undesired appearance of muscle fatigue, which is a severe factor for the injury of muscle fibers. Objectives: The aim of the present study was to determine a fatigue index by means of surface electromyography (EMG) for the parameterization of muscle strengthening physiotherapy training. Methods: A cross-sectional study (case series) was carried out involving four patients with DMD. Three pairs of surface electrodes were placed on the motor point of the Rectus femoris, Vastus lateralis and Vastus medialis of the dominant limb, maintaining the knee at 60º of flexion. The participants were instructed to perform the extension movement of this joint at four strength levels (100%, 80%, 60% and 40% of maximal voluntary isometric contraction). Results: The slope of the linear regression line was used for the determination of the fatigue index, performed...
by Pearson’s test on the median frequency of each strength level. **Conclusion:** Electromyographic measurements of the strength index for muscle training proved to be a simple accessible assessment method, as well as an extremely valuable tool, allowing the design of a muscle strength training program with an individualized load threshold.

**Keywords:** Duchenne. Fatigue. EMG.

**Introduction**

Duchenne muscular dystrophy (DMD) is characterized by a recessive genetic disorder with a high mutation rate of a gene in the short arm of the X chromosome in a region denominated Xp21 (1). Unless an older brother had previously developed the condition or there is a significant family history of the disease, most infants are not monitored for symptoms. However, in children in whom there has been an early identification because of a family history, the Gowers’ sign (compensatory maneuver when standing up from the ground, in which the patient uses his/her hands to climb up the lower limbs due to a lack of muscle strength in the thighs and hips) may be evident by 15 months of age.

Most children with DMD are not identified until reaching three to five years of age. Beginning at this age, there is notable muscle weakness that selectively affects the proximal muscles before the distal muscles and the lower limbs before the upper limbs (2, 3). When the child begins to stand or walk, he/she tends to fall and the gait is called “anserine”. With the progression of the disease, there is increasing difficulty in walking, which generally becomes impossible between 8 and 12 years of age (4, 5).

The cause of the disease is attributed to the absence of dystrophin, which is a cytoskeletal protein fixed in the sarcolemma of the muscles, the role of which is extremely important to the functioning of muscle fiber, especially during contraction and relaxation (4). Thus, there is disuse of muscle fibers resulting in a reduction in the size of the myofibril and consequent reduction in the transversal area of the fiber as well as lesser strength and reduced muscle endurance, thereby triggering biomechanical disadvantages. Weakness of...
the principal muscles makes the musculature work at a greater percentage of maximal capacity, recruiting less efficient secondary muscles, which increases energy expenditure and leads to fatigue (6-9).

Muscle weakness is the most prominent feature of muscular dystrophy and impedes mobility. This frequently involves a loss of the ability to walk and leads to other limitations to daily living. The usefulness of resistance strength training for such patients has been discussed (10-12). Progressive resistance strength training increases muscle size, strength and endurance in healthy individuals. In muscular dystrophy, however, the situation is not as clear (13). The load and training period for such rehabilitation has proven to be a great unknown thus far, principally due to the appearance of fatigue, which is a severe factor for the injury of muscle fibers in this population. Due to this constant weakness, there is a need to maintain the muscle strength of the large muscle groups, such as the femoral quadriceps muscle, which is responsible for different functional abilities such as walking, climbing up and down stairs and getting up from a chair or bed (14, 15).

Considering the importance of these muscles in activities that affect the independence of patients with DMD, the aim of the present study was to determine a fatigue index by means of surface electromyography (EMG) that can serve as parameterization for physiotherapy training.

**Methodology**

A cross-sectional case series study was carried out at the Physiotherapy Clinic of the Universidade Nove de Julho (São Paulo, Brazil), involving four patients with DMD. Orientation was given to the volunteers regarding the physical activities to be executed during the data collection and the subjects were informed as to the objectives of the study. The volunteers were told that they could remove themselves from the study at any time with no negative repercussions. The subjects read and signed terms of informed consent agreeing to participate. The study received approval from the Ethics Committee of the institution (process n. 133.260/2007).

The EMG signal acquisition system consisted of a load cell (SV-100 model) with a nominal capacity of 100 kg, made with anodized aluminum, with a sensitivity of ± 10% and three pairs of active, bipolar, differential electrodes for capturing the electrical activity of the muscles. The signal was pre-amplified in the differential electrode with a ten-fold gain, with a common rejection of 80 dB and sampling frequency of 2.000 Hz. The components of the signal acquisition system were connected to a signal conditioner module, in which the analogue signals were filtered in a 10 Hz to 1.000 Hz band-pass filter and amplified again with a 100-fold gain, achieving a final gain of 1000. The three pairs of surface electrodes were placed on the motor point of the Rectus femoris (RF), Vastus lateralis (VL) and Vastus medialis (VM), muscles of the dominant limb following the longitudinal direction of the muscle fibers (fixed inwardly to the skin by double-faced adhesive tape, with another piece of adhesive tape used outwardly, thereby providing better fixation of the electrodes) (16, 17).

The patients were positioned sitting in a chair, maintaining the knee joint a 60º of flexion and were instructed to perform extension of this joint at four strength levels (100%, 80%, 60% and 40% of maximal voluntary isometric contraction – MVIC) sustained for thirty seconds, with a three-minute rest period between each strength level. The same procedure was repeated twice, for a total of three series (18).

The median frequency (Fmed) of the power spectrum and signal amplitude (given in root mean square (RMS)) was used for the analysis of muscle fatigue. The slope of the linear regression line was used for the determination of the fatigue index, using Pearson’s test for the median frequency of each strength level (100%, 80%, 60% and 40% of MVIC), which when plotted (abscissa axis) with respective strength levels (ordinate axis), provides a linear regression line, which, upon crossing the ordinate axis (percentage of load), demonstrates the fatigue index for the muscle analyzed. The Excel™ (Microsoft) and Matlab™ v. 6.0 (Mathworks) programs were used for the statistical treatment and the Matlab™ v. 6.0 (Mathworks) and Origin™ v. 6.0 Professional (Microcal Software) programs were used for the mathematical treatment.
Results

An important limitation of our study was the sample number. The initial sample had 13 patients, from which nine were excluded, resulting in just four patients. Four patients were excluded for presenting severe postural deviations associated with DMD; one patient was excluded for presenting hearing alteration; and four patients were excluded for their absence in the scheduled dates for data collection and evaluation. Another limitation found wasn’t using a control group, that because the musculoskeletal and functional characteristics can not be compared.

In order to exemplify and simplify the visualization of the results obtained in the present study, only the data on the Rectus femoris muscle of volunteer 1 are used, which is sufficient for the understanding of how these data were analyzed. Another point that should be stressed is that the entire analysis of the data was performed as intra-subject analysis, since biological individuality – which is the primary principle of physical training – does not permit inter-subject analysis.

Fatigue and Range of the Myoelectrical Signal

Figure 1 displays the EMG signal of the Rectus femoris (mean curve with respective standard deviation representative of three contractions performed by volunteer 1), given as RMS. Based on the linear regression line, there was an initial increase in values, thereby demonstrating the need of the Rectus femoris to recruit a greater number of motor units in order to maintain the strength level stipulated for the data collection (80% of MVIC).

![Figure 1](image.png)

**Figure 1** - Alterations in myoelectrical activity (RMS) over time, resisted at 80% of MVIC (Rectus femoris of Volunteer 1)

Fatigue and Fmed

Figure 2 presents the mean curve and standard deviation of the representative Fmed of three contractions of the Rectus femoris performed by volunteer 1 and shows the linear regression line determined by Pearson’s test in the time domain. The initial Fmed values underwent a decline during the sustaining of muscle contraction, which demonstrates the appearance of muscle fatigue.
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Muscle fatigue index

The coefficients of the angle of the slope of the linear regression line (determined by Pearson’s test) for the median frequency of the four strength levels (100%, 80%, 60% and 40% of MVIC) of the RF, VL and VM muscles in volunteer 1 are displayed in Figures 3, 4 and 5, respectively.

Figure 2 - Alterations in Fmed over time, resisted at 80% of MVIC (Rectus femoris of Volunteer 1)

Figure 3 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the Rectus femoris of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength level (100, 80, 60, 40% of MVIC) establishes a new linear regression line, which crosses the ordinate axis (percentage of strength level), demonstrating the fatigue index for the muscle analyzed.
Figure 4 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the *Vastus lateralis* of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength level (100, 80, 60, 40% of MVIC) establishes a new linear regression line, which crosses the ordinate axis (percentage of strength level), demonstrating the fatigue index for the muscle analyzed.

Figure 5 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the *Vastus medialis* of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength level (100, 80, 60, 40% of MVIC) establishes a new linear regression line, which crosses the ordinate axis (percentage of strength level), demonstrating the fatigue index for the muscle analyzed.
The muscle fatigue values obtained from the new regression line were 35% of MVIC for the Rectus femoris, 30% of MVIC for the Vastus lateralis and 32% of MVIC for the Vastus medialis. Thus, the muscle fatigue index for the femoral quadriceps muscle of volunteer 1 was 32.33 ± 2.51 of MVIC. For the other volunteers analyzed in the present study, the muscle fatigue index for the femoral quadriceps muscle was 43.54±3.25 of MVIC in volunteer 2, 25.12±7.45 of MVIC in volunteer 3 and 56.87±5.42 of MVIC in volunteer 4.

Discussion

The present study sought to demonstrate the muscle fatigue index through the Fmed and amplitude of the electromyographic signal (given in RMS) during MVIC of the Rectus femoris, Vastus medialis and Vastus lateralis of patients with DMD. This proposal came about from the need to understand the fatigue process in individuals with DMD in order to obtain more reliable orientation regarding muscle strengthening work without the occurrence of fatigue and consequent reversion of rehabilitation.

In a study carried involving 77 patients with muscular dystrophy, Natterlund (19) reports that muscle weakness is the main difficulty stemming from the disease, as it impedes mobility, thereby leading to a consequent loss in the ability to walk and perform activities of daily living. Sveen et al. (20) carried out endurance training on 11 patients with Becker’s muscular dystrophy for 12 weeks, involving muscle biopsies, echocardiography (ECG) and the determination of creatine kinase (CK) enzyme levels; they authors report that training may be harmful to muscle integrity, even though they found an approximately 11% improvement in the ECG signal, no increase in the CK enzyme and a 13 to 40% increase in strength. Thus, the findings of the present study represent a very useful tool for combating fatigue in patients with muscular dystrophy, as it is possible to quantify the load that leads to weakness processes (muscle fatigue index) and design a better muscle strengthening training program, thereby providing patients with a better quality of life through enhanced independence.

Lindeman (21) also agrees that the reduction in strength is the most prominent impairment in muscular dystrophy and stresses that the literature offers no clear, specific answers regarding the efficacy of strength training. According to Ansved (22), progressive-resistance strength training increases muscle size and strength in healthy individuals. Regarding muscular dystrophy, there are reports of a moderate increase in strength without additional apparent morphological harm. Vignos (23) and Ansved (22) have the same opinion that the increase in strength in limited in individuals with muscular dystrophy, but is possible when carefully supervised. With the present study, we offer a new option for muscle strength training by means of a quantitative assessment.

It is well known that strengthening is indicated in cases of muscle weakness. With muscular dystrophy, however, one factor cannot be forgotten, namely, the fatigue imposed by muscle strengthening programs. Thus, training is an unknown, as an overestimated strengthening program could lead to fatigue and consequent irreversible muscle injury in patients with DMD. On the other hand, an underestimated training protocol would merely lead to a limited increase in strength after several weeks of training.

In the present study, we were able to quantify the fatigue index, which allowed designing an individualized muscle strengthening program based on the adequate load threshold of each patient. This allowed obtaining a more significant increase in strength without the appearance of injury. Milner-Brow and Miller (24) performed sub-maximal isokinetic exercises on four patients with DMD in the initial phase and concluded that such exercises do not have negative effects on muscle function and furnish a mild increase in strength. In another study, Milner-Brow and Miller (25) obtained more significant quantitative data with muscle training using electrostimulation combined with light loads, demonstrating that electrostimulation with load is recommendable for patients with mild to moderate muscle weakness. The authors of a number of studies (10, 19, 25-28) concerned themselves with gain in muscle strength, but made no attempts to assess how much load could be administered with these patients, making such studies subjective. A different load was adapted.
to each patient, with no parameters for assessing the ideal load and we do not know whether the increase in strength was due to the load or electrostimulation (29, 30).

Mccartney (13) published a study questioning the efficacy of muscle training in patients with muscular dystrophy. The author reports that results regarding increases in muscle strength in neuromuscular diseases are subjective and limited improvement potential is expected in investigations involving patients with DMD. We disagree with this, for we believe that gains in strength have been limited because the evaluation has not been quantitative, but rather merely subjective, thereby underestimating an adequate training load. Limitations are expected due to the disease, but the increase in strength could be optimized if the assessment were more objective and precise. Therefore, the assessment protocol described in the present study proved to be an extremely valuable tool, allowing the design of a more objective strengthening program for patients with DMD after determining the adequate load to be applied without harm to the patient.

Conclusion

The electromyographic measurement of the muscle fatigue index for muscle strength training is a simple, accessible assessment method. Based on the results demonstrated in the present study, the method proved extremely reliable and effective in determining the muscle fatigue index. This assessment protocol constitutes an extremely valuable tool, allowing the design of an individualized muscle strength training program based on the specific load threshold of each patient.

However, more studies are needed to verify the reliability within and between examiners, as well as the applicability of the development of an individualized program of muscular strength training based on the threshold of specific load of each patient.

References


Received: 08/05/2009
Received: 05/08/2009

Approved: 04/14/2010
Aprovado: 14/04/2010

Reviewed: 06/22/2010
Revisado: 22/06/2010