



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 60° 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.

Resumo

Introdução: Sabe-se que a fraqueza muscular é o prejuízo mais proeminente na distrofia muscular de Duchenne (DMD), envolvendo frequentemente perda da habilidade funcional e outras restrições relativas à vida diária. Pensando nisso, existe a necessidade de se manter a força muscular de grandes grupos musculares, tais como o quadríceps femoral, responsável por diversas habilidades funcionais; porém, a carga e a periodização de treinamento para tal reabilitação tem se mostrado uma grande incógnita, principalmente pelo aparecimento indesejado da fadiga muscular, fator severo para o acometimento lesional das fibras musculares. **Objetivos:** Este estudo objetivou determinar, por meio da eletromiografia de superfície (EMG), um índice de fadiga que sirva de parametrização para treinamento fisioterapêutico de fortalecimento muscular. **Metodologia:** Participaram deste estudo transversal (série de casos) quatro pacientes com DMD. Três pares de eletrodos de superfície foram colocados sobre o ponto motor dos músculos reto femoral, vasto lateral e vasto medial do membro dominante, mantendo o joelho em flexão de 60°, sendo instruídos a realizar o movimento de extensão desta articulação em quatro níveis de força (100%, 80%, 60% e 40% da contração voluntária máxima isométrica). **Resultados:** Para determinar o índice de fadiga, utilizou-se o ângulo de inclinação para a linha de regressão linear, realizada pelo teste de Pearson da frequência mediana de cada nível de força coletado. **Conclusão:** Medidas eletromiográficas do índice de força para treinamento muscular mostraram-se um método simples e acessível de avaliação, além de se apresentar como uma ferramenta extremamente valiosa, permitindo traçar um programa de treinamento de força muscular com limiar de carga específico individualmente.

Palavras-chave: Duchenne. Fadiga. 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 $\pm 10\%$ 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 60° 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).

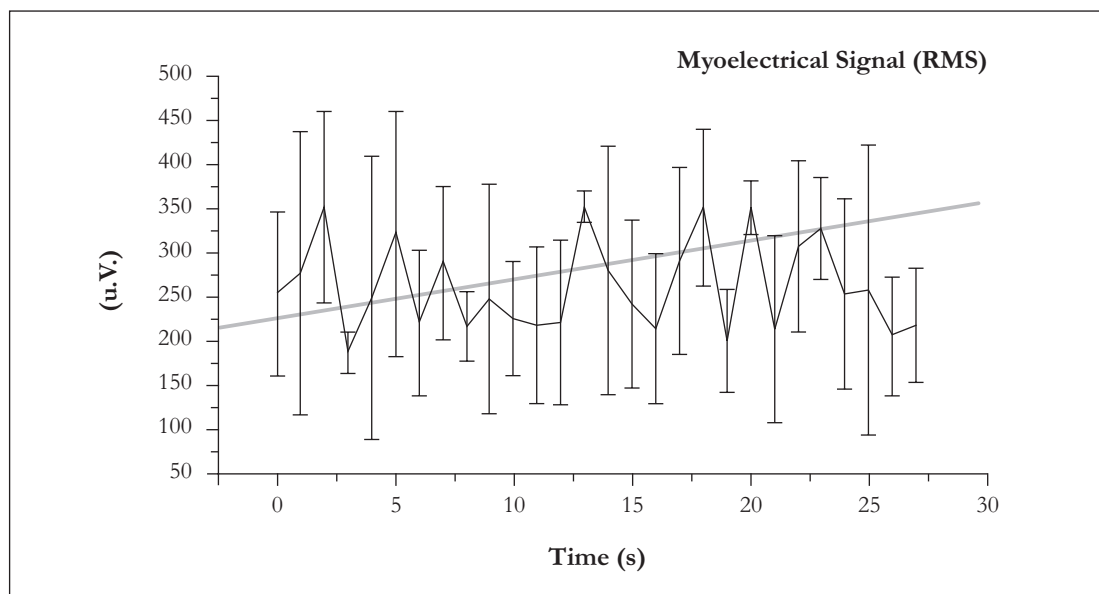


Figure 1 - Alterations in myoelectrical activity (RMS) over time, resisted at 80% of MVIC (*Rectus femoris* of Volunteer 1)

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.

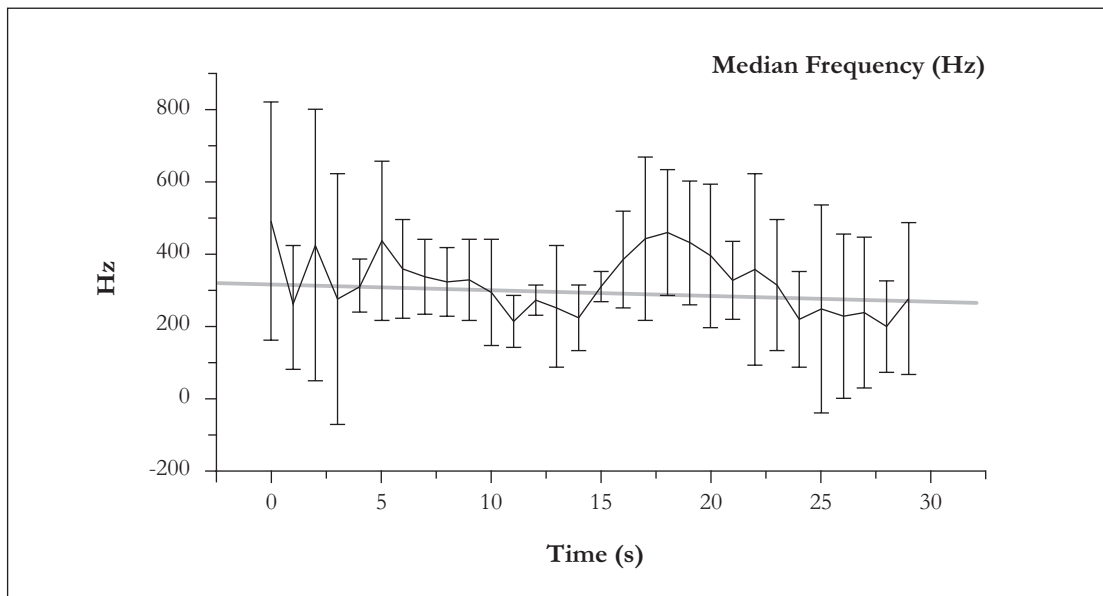


Figure 2 - Alterations in Fmed over time, resisted at 80% of MVIC (*Rectus femoris* of Volunteer 1)

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.

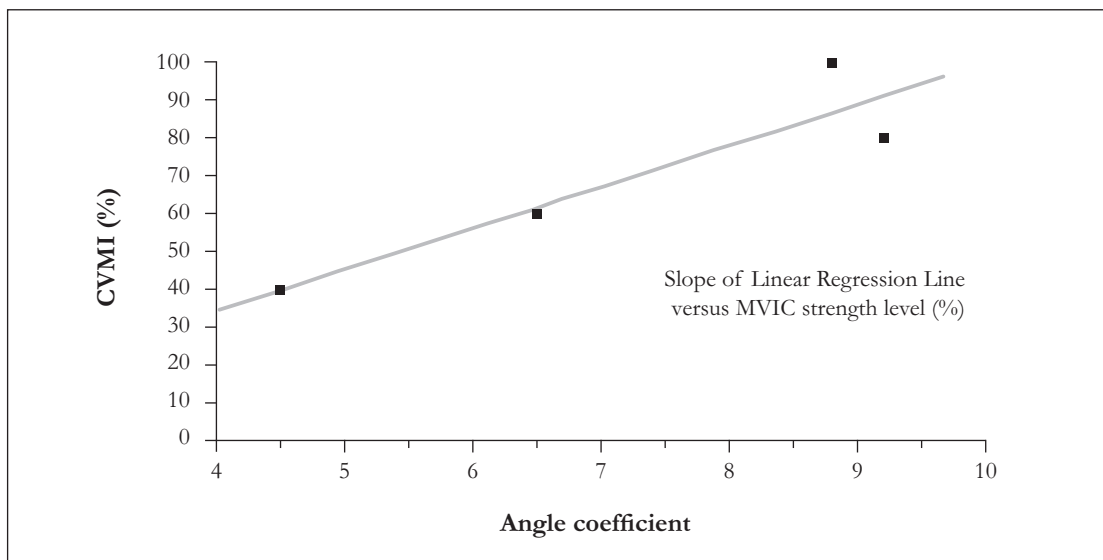


Figure 3 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the *Rectus femoris* of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength 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

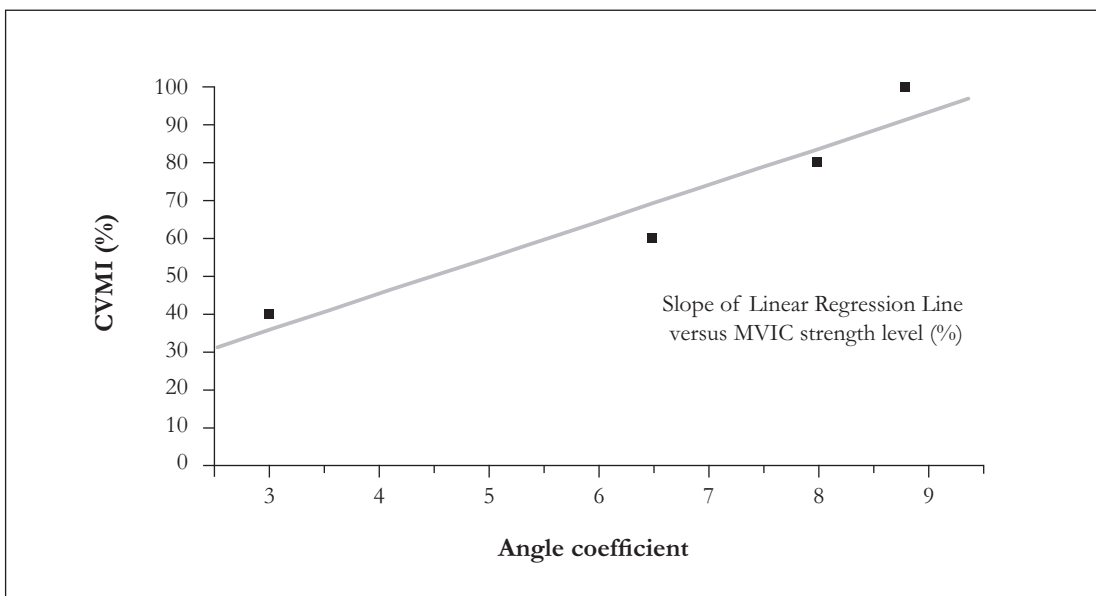


Figure 4 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the *Vastus lateralis* of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength 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

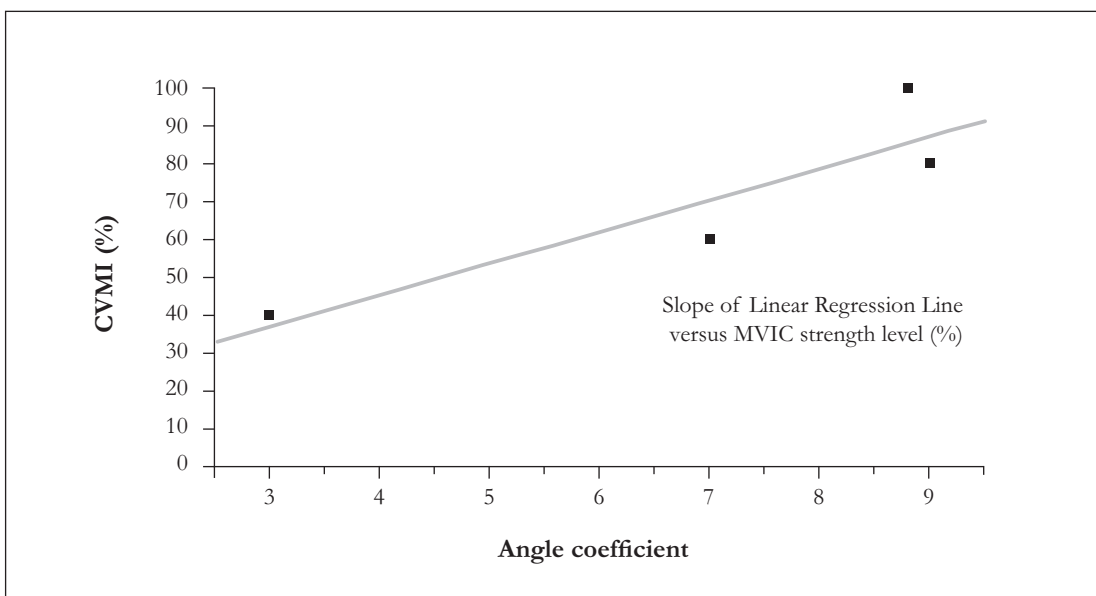


Figure 5 - Slope of linear regression line (determined by Pearson’s test) for median frequency of each strength level measured for the *Vastus medialis* of Volunteer 1 (abscissa axis) crossed with respective strength levels (ordinate axis). The linear regression line obtained by the slope of each strength 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 is 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

1. Caromano FA, Kuga LS, Passarella J, Sá CSC. Efeitos fisiológicos da sessão de hidroterapia em crianças portadoras de Distrofia Muscular de Duchenne. *Fisioter Pesq.* 1998;5(1):49-55.
2. Ratel S, Duché P, Williams CA. Muscle fatigue during high intensity exercise in children. *Sports Med.* 2006;36(12):1031-65.
3. Heydemann A, McNally E. No more muscle fatigue. *J Clin Invest.* 2009;119(3):448-50.
4. Emery AEH. Duchenne muscular dystrophy. London: Oxford; 1993.
5. Leitão RA, Leitão AVN, Lancellotti CLP. Distrofias musculares. In: Lianza S. *Medicina de reabilitação.* 3a ed. Rio de Janeiro: Guanabara Koogan, 2001. p. 381-93.
6. Moura RCF, Cunha MCB, Monteiro AP. Orientações fisioterapêuticas motoras para pacientes portadores de distrofia muscular de Duchenne, na fase I. *Fisioterapia Brasil.* 2002;3(1):46-52.
7. Kilmer DD, Aitkens S. Doenças neuromusculares. In: Frontera WR, Dawson DM, Slovik DM. *Exercício físico e reabilitação.* Porto Alegre: Artmed; 2001. p. 235-44.
8. Ratel S, Duché P, Williams CA. Nitric oxide deficiency determines global chromatin changes in Duchenne muscular dystrophy. *Sports Med.* 2006;36(12):1031-65.
9. Caromano FA. Características do portador de Distrofia Muscular de Duchenne. *Arq Ciências Saúde UNIPAR.* 1999;3(3):211-18.
10. Gualano B, Artioli GG, Poortmans JR, Lancha Junior AH. Exploring the therapeutic role of creatine supplementation. *Amino Acids.* 2010;38(1):31-44.

11. Bobo JK, Kenneson A, Kolor K, Brown MA. Adherence to american academy of pediatrics recommendations for cardiac care among female carriers of duchenne and becker muscular dystrophy. *Pediatrics*. 2009;123(3):e471-5.
12. Lindeman E, Spaans F, Reulen J, Leffers P, Drukker J. Surface EMG of proximal leg muscles in neuromuscular patients and in healthy controls. Relations to force and fatigue. *J Electromyogr Kinesiol*. 1999;9(5):299-307.
13. MacCartney N, Moroz D, Garner SH, McComas AJ. The effects of strength training in patients with select neuromuscular disorders. *Med Sci Sports Exerc*. 1988;20(4):362-8.
14. Weidner NJ. Developing an interdisciplinary palliative care plan for the patient with muscular dystrophy. *Pediatr Ann*. 2005;34(7):546-52.
15. Lindeman E, Spaans F, Reulen J, Leffers P, Drukker J. Quadriceps strenght and timed motor performances in myotonic dystrophy, Charcot-Marie-Tooth disease, and healthy subjects. *Clin Rehabil*. 1998;12(2):127-35.
16. Corrêa FI, Tessarolo A, Melo AS, Corrêa JCF, Sampaio LMM, Costa MS, et al. Avaliação do ácido láctico em indivíduos portadores de hemiparesia em decorrência de AVE após utilização de FES para fortalecimento muscular. *Rev Fisioter Pesq*. 2009;16:122-6.
17. Corrêa JCF, Rocco CCM, Andrade D, Oliveira CS, Corrêa FI. Functional implication of gait after left or right-sided stroke. *Electromyog Clin Neurophysiol*. 2008;48:323-7.
18. Corrêa JCF, Rocco CCM, Andrade D, Corrêa FI. Electromyographic and neuromuscular analysis in patients with post-polio syndrome. *Electromyog Clin Neurophysiol*. 2008;48:329-33.
19. Natterlund B, Ahlstrom G. Activities of daily living and quality of life in persons with dystrophy muscular. *J Rehab Med*. 2001;33(5):206-11.
20. Svein ML, Jeppesen TD, Hauerslev S, Køber L, Krag TO, Vissing J. Endurance training improves fitness and strength in patients with Becker muscular dystrophy. *Brain*. 2008;131(11):2824-31.
21. Lindeman E, Leffers P, Spaans F, Drukker J, Reulen J, Kerckhoffs M et al. Strenght training in patients with Myotonic dystrophy and hereditary motor and sensory neuropathy: a randomized clinical trial. *Arch Phys Med Rehabil*. 1995;76(7):612-20.
22. Ansved T. Muscle training in muscular dystrophies. *Acta Physiol Scand*. 2001;171(3):359-66.
23. Vignos PJ. Physical models of rehabilitation in neuromuscular disease. *Muscle Nerve*. 1983;6(5):323-38.
24. Milner-Brow HS, Miller GR. Muscle strengthening through high-resistance weight training in patients with neuromuscular disorders. *Arch Phys Med Rehabil*. 1988;69(1):14-9.
25. Milner-Brow HS, Miller GR. Muscle strengthening through electric stimulation combined with low-resistance weights in patients with neuromuscular disorders. *Arch Phys Med Rehabil*. 1988;69(1):20-4.
26. Allen DG. Skeletal muscle function: role of ionic changes in fatigue, damage and disease. *Clin Exp Pharmacol Physiol*. 2004;31(8):485-93.
27. Rose KJ, Burns J, Wheeler DM. Interventions for increasing ankle range of motion in patients with neuromuscular disease. *Cochrane Database Syst Rev*. 2010;17(2):CD006973.
28. Davidson ZE, Truby H. A review of nutrition in Duchenne muscular dystrophy. *J Hum Nutr Diet*. 2009;22(5):383-93.

29. Okafor UA, Akinbo SR, Sokunbi OG. Comparison of electrical stimulation and conventional physiotherapy in functional rehabilitation in Erb's palsy. Nig Q J Hosp Med. 2008;18(4):202-5.
30. Dolhem R. The history of electrostimulation in rehabilitation medicine. Ann Readapt Med Phys. 2008;51(6):427-31.

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