Evaluation of the Torque Developed by the Elbow Flexors in Patients with Neuromuscular Diseases

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Abstract
In planning the optimum treatment for patients with neuromuscular diseases (NMD), it is essential to know as much as possible about their functional state. Assessment of the strength of certain muscles is the most direct measure of motor deficiency. In the development of normative data needed for patients with NMD, the use of torque measurements is required. Forty-nine patients (31 men and 18 women, mean age 33 ± 8,9) were included in the study. Five groups of patients, each having one of five different NMDs, were formed. We tested unilaterally the biceps brachii muscle that normally generates the highest torque. For this purpose an electronic brace enabling isometric measurements of torque during elbow flexion was designed. The patients produced 3 maximum voluntary elbow flexions that lasted about 3 s and separated by a pause of about 3 s. Force development was rapid with continuous build-up and isometric. About 15 s later the patients produced the last maximum voluntary elbow flexion, keeping it as stable as possible for a period of 30 s. Patients with mitochondrial myopathy (MM), having the longest mean time to maximum torque (1191.7 ms), elicited the highest mean torque in both short (1.34 Nm) as well as in 30 s-long maximum elbow flexions. Patients with facioscapulohumeral muscular dystrophy (MD-FSH), having a mean time to maximum torque (537.66 ms) about half as short, elicited the lowest mean torque in both the short (0.29 Nm) as well as in 30 s-long maximum elbow flexions. Patients with Becker muscular dystrophy (MD-B), having a mean time to maximum torque (1090.5 ms) about twice as long as patients with MD-FSH, elicited a higher mean torque in both short (0.82 Nm) and 30 s-long elbow flexions. Finally, patients with limb-girdle muscular dystrophy (MD-RM) and spinal muscular atrophy type 3 (SMA3), having a similar mean time to maximum torque (472.39 ms for patients with MD-RM and 505.92 ms for patients with SMA3), also elicited similar torque in both short (0.45 Nm for patients with MD-RM and 0.65 Nm for patients with SMA3) and 30 s-long maximum elbow flexions. The results of the study show that the methodology developed to quantitatively measure the torque developed by elbow flexions in patients with NMD enables the characteristics and natural course of NMD to be more objectively documented. Accordingly, the optimum treatment for patients with NMD could be restored.
Key words: elbow flexors, electronic brace, neuromuscular disease, torque.

Basic Appl Myol 11 (3): 133-137, 2001

The term muscular dystrophy refers to a group of genetic neuromuscular diseases (NMDs) marked by progressive weakness and degeneration of the skeletal, or voluntary muscles, which control movement. However, there is no single disease called muscular dystrophy. The most frequent and therapeutically most complicated of NMD are muscular dystrophies (MD) and spinal muscular atrophies (SMA). The distribution and degree by which muscles or muscle groups are affected, resulting secondary effects, and functional impairment of individual patients differ from one form NMDs to another. The different types of the disease vary in the age at which muscle wasting becomes manifest and in the muscle groups first affected. Differences also occur between patients with the same form of disease. Therefore, patients with NMD should be treated and followed up on an individual basis. Accordingly, it is essential to know as much as possible about a patient's functional state and other abilities especially when planning the optimum treatment for him. Besides, a precise and sensitive quantification of motor deficit may facilitate a better understanding of the natural course of NMD [1-3]. Even though the quantification of NMD has recently become more interesting to investigators, the techniques for measuring neuromuscular deficits remain rather primitive. Large amounts of money are spent annually on clinical investigations whose results are based on inadequately compiled and insensitive assessment protocols [3].

In any case, assessment of muscle strength is the most direct measure of motor deficit [4]. The most frequently used method for assessing muscle strength of certain muscles or muscle groups in NMD patients is manual muscle testing. One major disadvantage of this method is that it is a subjective method of measuring muscle strength and therefore lacks objectivity [5]. In progressive NMD the manual muscle test is applied to determine the distribution of muscular weakness, but does not facilitate a precise evaluation of the disease progress [3, 6-8]. An alternative to the manual muscle testing is a quantitative, instrumented system for assessing muscle strength [5]. For the assessment of muscle strength and its changes in patients with NMD isometric muscle testing with portable, hand-held dynamometers is frequently used [9]. These dynamometers provide real number measurements of muscle strength and are clearly superior for documenting changes in muscle strength in patients with NMD [10]. Since the dimensions of these dynamometers are relatively small they are very suitable for ambulatory use. The results suggest that the hand-held dynamometer can be used as a reliable instrument in measuring the maximum voluntary contraction especially in children with NMD [11, 14]. However, improper stabilization of the dynamometer may result in either a concentric contraction, if the tester provides inadequate resistance, or an excentric contraction, if the tester overcomes the force applied by the subject. Either type of contraction may result in inaccurate measurements [15]. One of the disadvantages of hand-held dynamometers is that they measure force instead of torques [12] and that they usually do not record the measurement results [3]. Although comparison of the force values within a subject over time is clinically practical, the absolute values are not comparable with the results of other individuals. Therefore the development of normative data for patients with NMD is needed and would require the use of torque measurements [12]. Fixed dynamometers have the advantage over hand-held dynamometers because they measure torques and record measurements. However, their disadvantage is that they require a special room and that the equipment is rather expensive [3, 14]. It was reported that the measurements of maximum voluntary contraction in children with Duchenne muscular dystrophy with fixed dynamometers give reliable and valid results. At this time, there is no known treatment that will arrest or reverse the dystrophic process, but medical management can increase mobility, maximise independence in daily activities, and ease discomfort. Therefore, to overcome most of the disadvantages of the aforementioned methods the purpose of the study was to develop a reliable method for isometric measurements of the torque elicited by maximum voluntary elbow flexion in patients with NMD, using a specially designed electronic brace. Our decision to develop the methodology for the torque measurements elicited only by elbow flexors was based on our goal to help the patients with any of five different NMDs in daily activities in which they actively use upper extremities. The data thus obtained could be useful during prescription of orthopedic devices and physiotherapy and appropriate medical management.

Materials and Methods

Patients

Forty-nine patients (31 men and 18 women) ranging from 18 to 54 years of age (mean age 33 ± 8,9 years) were included in the study. 31 of them were still able to walk while 18 were wheelchair-bound. 31 patients have one of the forms of MD and 18 patients have one of the forms of SMA. All patients with five different NMDs were grouped in five corresponding groups. The first group with limb-girdle muscular dystrophy (MD-RM) consisted of 11 patients (mean age 34.6 years); (5 men and 6 women), the second one with Becker muscular dystrophy (MD-B) had 9 patients (mean age 25.7 years); (9 men), the third and largest group with spinal muscular atrophy type 3 (SMA3) had 18 patients (mean age 36 years); (9 men and 9 women), the fourth one with facioscapulohumeral muscular dystrophy (MD-FSH) had 7 patients (mean age 36 years); (5 men and 2 women) and the last, fifth group with Mitochondrial Myopathy (MM) had 4 patients (mean age 30.8); (3 men and a woman). We tested unilaterally only the biceps brachii muscle that normally generates the highest muscle strength. During the measurements the patients received a visual display of force and also loud verbal encouragement in all attempted maximum efforts. Throughout the text the term maximum voluntary elbow flexion denotes the maximum torque produced when a patient received visual force feedback and verbal encouragement and when the subject felt he/she had achieved the maximum effort [16].

Measuring procedure

For muscle strength testing an examination bed (200 cm long, 140 cm wide and 50 cm high), electronic brace, amplifier, and a computer-assisted real-time analog/digital data collection system was used. The patient was asked to lie on a bed on the side not intended to be measured. According to the figure of the patient, an appropriate therapeutic ball was used and situated under the left elbow to support the arm in an almost horizontal plane as shown in Fig. 1.

Fine adjustment was obtained simply by inflating or deflating the ball. In this way the influence of gravity on the results was eliminated. The forearm and the upper arm were then attached to the brace through the two short aluminum foam-padded gutters (5cm in width and 10 cm in diameter) mounted on the shanks of the brace and fastened with two 5cm wide strips (Velcro). An angle between the upper and the lower arms was defined by the brace and was fixated at 70 degrees. To prevent the brace moving away from the forearm and upper arm, the brace was fixed also at the elbow using the third strong strip. Afterwards, the patient was asked to produce 3 maximum voluntary elbow flexions, each lasting about 3 seconds. Maximum voluntary elbow flexions were separated from the subsequent one by a pause that lasted 2 to 3 seconds. The latter interval varied between the subjects and was chosen to minimize any reduction in force due to peripheral muscle fatigue. Torque development in the three elbow flexions had to be fast with continuous build-up, and strictly isometric, reaching the peak force within a few hundred ms. The highest of three measured values was accepted for further statistical analysis. About 15 seconds after preceding maximum voluntary elbow flexions, when the elbow flexors were relaxed, the patient was asked to produce the last maximum voluntary elbow flexion and to keep it as stable as possible for a period of 30 seconds. Namely, it was presumed that maximum voluntary elbow flexion sustained for 30 seconds could elicit appropriate fatigue of biceps brachii muscle in all selected patients having one of five different NMDs.

Figure 1. Position of a patient with the brace attached on his forearm and the upper arm.

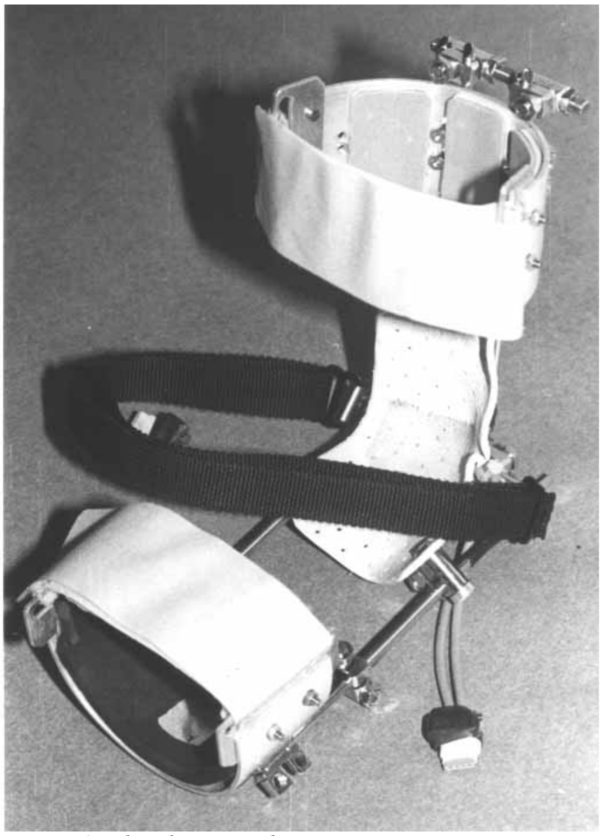

Figure 2. The electronic brace.

Measuring equipment

A force transducer of the electronic brace consisted of a Wheatstone bridge configuration of four semiconductor strain gauges (Celesco, P05-02-500, resistance in ohms: 500.0 ± 0.3%), bonded on two stainless steel bars that were also components of the brace as shown in Fig. 2. The dimensions of the bars to be bent upon the applied torque were defined according to the request of the gauge's manufacturer and our request to a develop transducer that would be sensitive enough in measuring torques elicited by elbow flexors.

The torque produced by the strength of the elbow flexors should elicit elastic deformation of the bars thus resulting as a change in the output voltage, which directly represented an data about the applied mechanical load. The structural characteristic was obtained simply by hanging weights of 100, 200 and 500 g in different combinations on the brace at the level supposed to be acting point of forces when fixed on the arm. The structural characteristic of the brace, not shown in the paper, represented a very linear dependence of the output voltage on the load. The compliance of the brace was about 1.4°/kg. The dynamic behavior of the brace, however, was defined by eliciting mechanical vibration of the brace by striking one shank of the brace with a finger while another shank was clamped in the vice. To eliminate the influence of a gravity, the brace was fixated within the vice in horizontal plane. Fig. 3, represents the dynamic characteristics of the brace whose natural frequency is 12 Hz.

The bridge configuration of the transducer was electrically connected so as to be sensitive only to torque generated by flexing or extending the muscles. Over the nominal range from 0 to 2.5 Nm and at a bridge excitation voltage of 5 V, the sensibility of the transducer was 0.3 mV/Nm. The bridge signal was amplified by a custom designed bridge amplifier with a fixed gain (A = 100). Amplified signals were then fed to a DigiPack 1200 (Axon Instruments) acquisition system and sampled at 10 kHz. Data were stored for reanalysis and all elbow flexions were reviewed off-line to check measurements using high speed data acquisition software (Axon Instruments). From recordings of all forty-nine patients the maxima of a torque of the highest out of three short maximum voluntary elbow flexions and corresponding times to the aforementioned torques were obtained. The time to maximum torque was defined as the time elapsed between onset of the torque development to the maximum of the torque.

Results

Records of elbow flexion measurements in a group of patients with MD-RM, containing three short maximum elbow flexions each lasting about 3 seconds, separated by 2 to 3 seconds and maximum voluntary elbow flexions maintained for a period of 30 seconds, showed that the mean time to maximum torque is 472.39 ms while the mean torque of the greatest, short maximum elbow flexions is 0.45 Nm. Records of the group of patients with MD-B showed that the mean time to maximum torque is twice as long as in a patient with MD-RM and is 1090.5 s while the mean torque of 0.82 Nm is almost twice as great. Moreover, a record of an arbitrarily chosen patient from the group with SMA3 is shown in Fig.

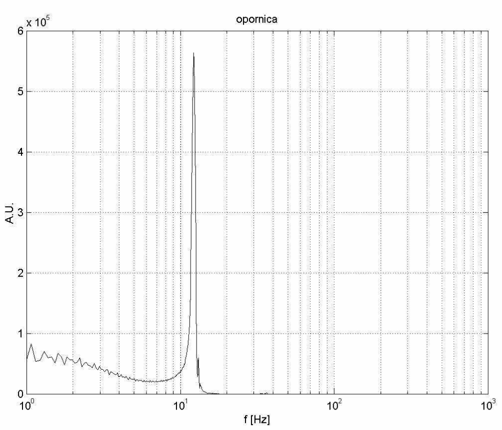

Figure 3. Dynamic characteristics of the brace.

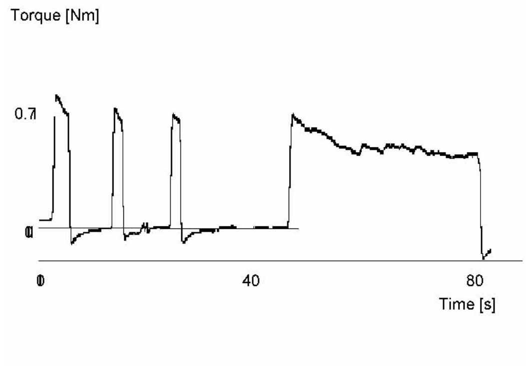

Figure 4. A record of torque measurement in the patient, arbitrarily chosen from the group of patients with SMA3 (spinal muscular atrophy Type 3).

4. In this patient the time to maximum torque is slightly longer than in the patient with MD-RM at 505.92 ms while the maximum torque is slightly higher at 0.67 Nm. Similarly, records of all patients of the group with SMA3 showed that the mean time to maximum torque is also slightly longer than in the patient with MD-RM and is 517.7 ms while the mean maximum torque is 0.65 Nm.

Records of patients of the group with D-FSH showed that the mean time to maximum torque of 537.66 ms is longer than in the patient with MD-RM and the torque of 0.29 Nm is much lower. Finally, records of the patients of the group with MM showed that the mean time to maximum torque of 1191.7 ms is much longer than in the patient with MD-RM and also the torque of 1.34 Nm is much higher.

Discussion

This work showed that the method developed for isometric measurement of the torque elicited by maximum voluntary elbow flexion in patients with NMD, using a specially designed electronic brace, provides accurate and reliable data. It was also shown that the method enables an evaluation of the pattern of recruitment fibers in the biceps brachii muscle, which was the muscle of prime interest in our study. As could be seen from the recordings, the patients with MM, with the longest mean time to maximum torque, were able to elicit the highest mean torque of both short maximum voluntary elbow flexions as well as 30 s-long maximum voluntary elbow flexions. In contrast, the patients with MD-FSH and an almost twice as short mean time to maximum torque were able to elicit the lowest mean torque of both short maximum voluntary elbow flexions as well as 30 s-long maximum voluntary elbow flexions. The group of patients with MD-B with a mean time to maximum torque almost twice as long as the group with MD-FSH was able to elicit a much higher mean torque of both short and 30 s-long elbow flexions. Moreover, the group of patients with MD-RM and SMA3 with a similar mean time to maximum torque were also able to elicit a similar torque of both short and 30 s-long elbow flexions. The results of the study show that developed methodology could enable a more objective documentation of both the characteristics and the natural course of NMD for the majority of patients with this disease. Consequently, the more adequate treatment for patients with NMD could be restored. It is widely believed that "static" voluntary contractions are relatively isometric, although definitive evidence is lacking. Such contractions are unlikely to be truly isometric "in vivo" because of the following factors: Tendon stretch, movement of other parts of the body involved in "stabilization" of the relevant joint, and compliance within the joint. Accordingly, in the present study, there was significant shoulder movement during attempted maximum elbow flexions resulting in small changes in length of the elbow flexion muscle fibers, accounting for some of the variation in voluntary torque at high voluntary strengths [16]. Additionally, in our study the measurements at low strengths are not purely isometrical since at low strengths the brace mechanically acts on muscle and subcutaneous fat tissues thus also measuring some adaptation of the tissues. However, at higher strengths the brace was more adapted and the measurement became more isometrical. Since the results provide the data enabling quantification of motor deficit in patients with NMD they are applicable in evaluating the results of different therapeutic trials in NMD patients. Since any lengthening of an active muscle can lead to a sustained increase in structural force, possibly contributing to the non-linearity in the region of large voluntary torques, our effort will be made to minimize shoulder movement [16].

Acknowledgements

This work was financed by the following research grants: J2-3415 from the Ministry of Education, Science and Sport, Ljubljana, Republic of Slovenia, and HPRN-CT-2000-00030 from the European Commission.

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References

[1] Allen GM, McKenzie DK, Gandevia SC: Twitch interpolation of the elbow flexor muscles at high forces. *Muscle & Nerve* 1999; 21 (3): 318-328.

[2] Andres PL, Skerry LM, Munsat TL: Measurement of strength in neuromuscular diseases, in Munsat TL (ed): *Quantification of neurologic deficit*. Boston, Mass., Butterworth-Heinemann, 1989, pp 87-100.

[3] Bäckman E: Methods for measurement of muscle function. Methodological aspects, reference values for children, and clinical applications. *Scand J Rehabil Med* 1988; Suppl. 20: 9-95.

[4] Beck M, Giess R, Würffel W, Magnus T, Ochs G, Toyka KV: Comparison of maximal voluntary isometric contraction and Drachman's hand-held dynamometry in evaluating patients with amyotrophic lateral sclerosis. *Muscle & Nerve* 1999; 22: 1265-1270.

[5] Bohannon RW: Testing isometric limb muscle strength with dynamometers. *Crit Rev Phys Rehabil Med* 1990; 2: 75-86.

[6] Brooke MH, Griggs RC, Mendell JR, Fenichel GM, Shumate JB, Pellegrino RJ: Clinical trial in Duchenne dystrophy. I. The design of the protocol. *Muscle & Nerve* 1981; 4: 186-197.

[7] Brussock CM, Haley SM, Munsat TL, Bernhardt DB: Measurement of isometric force in children with and without Duchenne's muscular dystrophy. *Phys Ther* 1992; 72: 105-14.

[8] Edwards RHT, Hyde S: Methods of measuring muscle strength and fatigue. *Physiotherap* 1977; 63: 51-55.

[9] Fowler WM, Gardner GW: Quantitative strength measurements in muscular dystrophy. *Physical Medicine and Rehabilitation* 1967; 48 (12): 629-644.

[10] Hyde SA, Scott OM, Goddard CM: The myometer: the development of a clinical tool. *Physiotherap* 1983; 69: 424.

[11] Kendall F, McCreary E: Muscle testing and function, 3rd ed. Baltimore, Md: Williams & Wilkins, 1983.

[12] Koch BM, Simenson RL: Upper extremity strength and function in children with spinal muscular atrophy Type II. *Arch Phys Med Rehabil* 1992; 73: 241-252.

[13] Rideau YM: Outlines of muscular dystrophy. In Poitiers France: Faculté de Médecine, SEREM Edition, 1978, p 61.

[14] Scott OM, Hyde SA, Goddard C, Dubowitz V: Quantitation of muscle function in children: a prospective study in Duchenne muscular dystrophy. *Muscle & Nerve* 1982; 5: 291-301.

[15] Stuberg WA, Metcalf WK: Reliability of quantitative muscle testing in healthy children and in children with Duchenne muscular dystrophy using a hand-held dynamometer. *Phys Ther* 1988; 68: 977-82.

[16] Wadsworth CT, Krishnan R, Sear M, Harrold J, Nielsen DH: Intrarater reliability of manual muscle testing and hand-held dynametric muscle testing. *Physical Therapy* 1987; 67: 1342-1347.