KNEE EXTENSOR MUSCLES' TORQUE DURING ISOMETRIC EXERCISES AND RUSSIAN ELECTRICAL STIMULATION FOLLOWING A KNEE LIGAMENT INJURY

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Voluntary isometric exercise (VOL) and neuromuscular electrical stimulation (NMES) are both methods of static muscle strength and girth training. They are applied in strength training programs to healthy muscle as well as for muscle function recovery under certain orthopaedic conditions. Both methods are used to retard muscle atrophy and strength loss resulting from post injury knee immobilization (Eriksson & Häggmark, 1979; Ingemann-Hansen & Halkjær-Kristensen, 1985; Johnson, 1988; Wigerstad-Lossing, Tromby, Jonsson, Morelli, Peterson, & Rentröm, 1988). NMES can elicit twitch or tetanic muscle contractions, determined by current pulse frequency. During tetanic stimulation, the main features of training regimes are:

1) on/off cycle (or duty cycle), made up of the time of contraction plus rest time,
2) the number of contractions and
3) the intensity of contractions (determined by the current amplitude and/or the subject's tolerance).

Keywords: Knee ligament injury, disuse atrophy, isometric exercise, Russian electrical stimulation.

INTRODUCTION

Tetanic NMES is employed as an autonomic method or as a supplement to static (isometric) exercises. VOL and NMES differ in the mechanisms of muscle activation and contraction involved. It has been traditionally assumed that recruitment order during NMES is the reverse of that seen in voluntary contraction. During VOL, motoneurons are activated in an orderly manner, according to Henneman's "size principle": there is a slow twitch (ST), the least fatigable motoneurons are activated first and then, as the intensity of effort increases, there is a fast twitch (FT) and more fatigable motoneurons are recruited. During NMES, the order of contractions is believed to be dependent on the motoneurons' excitation threshold. It seems that NMES recruits the largest, fastest conducting and most fatigable motor units with the lowest intensities, and elicits the smallest, slowest conducting and least fatigable motor units at higher intensities of stimulation (Binder-Macleod, Halden, & Jungles, 1995; Sinacore, Delitto, King, & Rose, 1990). As a result, metabolic differences between NMES and VOL may occur. Another difference is the "central command" mechanism, which means that the voluntary contraction is commanded by the central nervous system, whereas the "artificially" evoked NMES contraction is the effect of local phenomena (Eriksson & Häggmark, 1979; Sinacore, Delitto, King, & Rose, 1990). Moreover, mechanical and spatial differences in motor unit recruitment patterns exist. Electric current elicits the response of muscle fibres in the area of the current flow, whereas voluntary contractions engage the whole muscle mass (Adams, Harris, Woodard, & Dudley, 1993; Ogino et al., 2002). Despite the number of published research papers, especially regarding physiological phenomena, there is still a lack of evidence and agreement when discussing the two methods as training and rehabilitation tools. Both stimulation and isometric exercises are conducted in accordance with various methodologies. Moreover, the applied currents differ in their characteristics (frequency, polarity, and waveform). Still little is known about the methodological aspects and efficacy of isometric exercise and electrical stimulation in muscle disuse atrophy, such as the number of contractions, the duration of each contraction, rest periods, and stimulation parameters. In my study I compared knee extensor muscles' torques measured during stimulated and voluntary contractions. Two well established and popular methods were chosen: Russian electrical stimulation and isometric exercise performed as part of a typical procedure (Babkin & Timtsenko, 1977; Ward & Shkuratova, 2002). The maximal voluntary isometric contraction (MVIC), the maximal electrically evoked contraction (MEEC) and the muscle torques of each contraction during exercise and stimulation sessions were measured. Results were compared to a control group.

MATERIAL AND METHODS

26 volunteers (13 females, 13 males), aged 18–28 (with a mean age of 21.92) years, after 21–23 days of knee immobilization following ligament injury, participated in the study. The control group consisted of 65 healthy subjects (32 females, 33 males), aged 20–22 (with a mean of 20.94) years. The subjects had no history of neuromuscular nor cardiovascular disease and no other contraindications. Sedentary persons and competitive sportspeople were excluded – our selection was made using the Halkjær-Kristensen's and the Ingemann-Hansen's scale of physical activity (Ingemann-Hansen & Halkjær-Kristensen, 1985). A selection criterion was also a knee joint range of motion of at least 90°. All participants were informed of the testing procedure, its purpose and the risk factors of the study before giving their informed consent. Characteristics of the subjects are shown in TABLE 1.

TABLE 1
Characteristics of the subjects

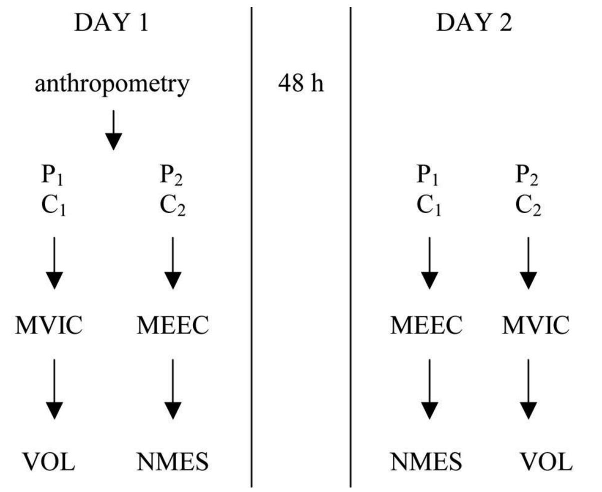
Group		Number of subjects	Age [years]		Height [cm]		Weight [kg]	
			x̄	± SD	x̄	± SD	x̄	± SD
Patients	♀	13	22.31	2.84	166.2	4.21	55.9	5.94
	♂	13	21.54	3.43	178.0	4.24	71.69	5.58
Controls	♀	32	20.88	0.66	166.0	5.57	56.6	5,85
	♂	33	21.00	0.61	177.3	6.11	71.5	7.15

♀ – females; ♂ – males; x̄ – mean value; SD – standard deviation

Isometric exercise (5 seconds of contraction, 10 seconds of rest, 10 repetitions, maximal effort) and NMES ("Russian current" according to Kots, medium frequency, sine wave, 2500 Hz/50 Hz, bipolar (Babkin & Timtsenko, 1977; Ward & Shkuratova, 2002). Sonicator® 992 Plus, Mettler Electronics) of the quadriceps muscle of the dominant extremity in a supine position, with hip and knee flexed to 90°, were performed. For the NMES, two 8 cm × 8 cm flexible carbon electrodes (one circuit) were used. The distal electrode was placed on the skin over the fibres of the vastus medialis muscle, and the second electrode was positioned over the proximal fibres of the vastus lateralis muscle. Tetanic contractions (10 s on/50 s off) were elicited, to the subject's level of tolerance (below pain threshold). Forces were measured with a tensometric force transducer (S2/1000, Hottinger messtechnik), attached to the ankle cuff and the frame anchor. Peak values were recorded.

Each subject performed the trials 1–3 days after the cast immobilisation had been removed. For the sake of full recovery and to avoid any muscular fatigue, there was a rest period of 48 hours between VOL and NMES (Wigerstad-Lossing, Grimby, Jonsson, Morelli, Peterson, & Renström, 1988) and the two sessions were conducted in a random order. For this reason both groups – patients (P) and controls (C) – were divided into two subgroups – P_1 (n = 13), P_2 (n = 13), C_1 (n = 33), and C_2 (n = 33). Before the first trial (VOL or NMES) basic anthropometric measurements (body mass and height) were collected. Then MVIC and MEEC were measured in subgroups P_1, C_1 and P_2, C_2, respectively. The best of three measurements were accepted as MVIC and MEEC. For MVIC and MEEC, forces were measured for both extremities (injured and non injured), whereas exercises and stimulation were conducted using the injured leg. In the control group a dominant leg was chosen. The measurements were performed in the same manner as exercises and stimulation. Fig. 1 describes the design of the study.

Fig. 1
Experimental setup, abbreviations explained in the text



DATA ANALYSIS

The subjects were divided by gender for analyzing and comparing the forces of knee extensor muscles between experimental (patient) and control groups. For MVIC and MEEC results, a paired t-test was performed to determine whether the maximal forces were statistically different in patients and controls, as well as between injured and non injured extremities. Significance was determined at the 0.001 and 0.05 levels. Mean values and standard deviations of measured values in subsequent contractions during VOL and NMES as well as percentage values were also computed.

RESULTS

MVIC was lesser than in controls and in the non injured extremity – in females by 222.24 N (50.57%, $p < 0.001$) and 204.54 N (52.64%, $p < 0.001$), in males by 361.04 N (50.08%, $p < 0.001$) and 313.23 N (53.64%, $p < 0.001$), respectively. Similarly, MEEC was lesser in females by 62.79 N (36.45%, $p < 0.05$) and 71.96 N (39.68%, $p < 0.001$), in males by 234.06 N (63.80%, $p < 0.001$) and 112.08 N (46.85%, $p < 0.001$). Contraction forces decreased in subsequent contractions during VOL in both genders. In women, the first contraction's force was 93.20% MVIC (44.3% MVIC of the control group). The tenth contraction (75.19% MVIC, 35.60% MVIC of the control group) was weaker than the first one by 18.01% MVIC. In men, the results are as follows: 91.22% MVIC (42.24% MVIC of the control group) in the first contraction, 85.78% MVIC (39.77% of the control group) in the last contraction. In NMES, subsequent measurements differed less, with no tendency towards a linear decrease. Forces were (change commas to points in the following numerals!) 83.5–89.0% of MEEC (45.7–48.8% MVIC, 21.7–23.1% MVIC of the control group) in women and 69.7–79.8% MEEC (28.4–32.5% MVIC, 13.2–15.1% MVIC of the control group) in men, respectively. Fig. 2 and 3 show the peak force values in subsequent measurements during VOL and NMES in both groups and genders.

DISCUSSION

The inclusion criteria (age, activity level) indicate that factors other than injury and immobilisation had no influence on muscle function and the collected evidence (Booth, Weeden, & Tseng, 1994; Halkjær-Kristensen & Ingemann-Hansen, 1985). MVIC measurements, as a reliable, quantitative method of measuring muscle function (Edwards, Young, Hosking, & Jones, 1977; Morrissey, Brewster, Shields, & Brown, 1985; Wigerstad-Lossing, Grimby, Jonsson, Morelli, Peterson, & Renström, 1988), proved that injury in the subjects and three week immobilisation in the experimental group led to a significant muscle force decrease. There was

Fig. 2
Mean values of peak forces produced during subsequent stimulated contractions (NMES) by male and female patients and controls

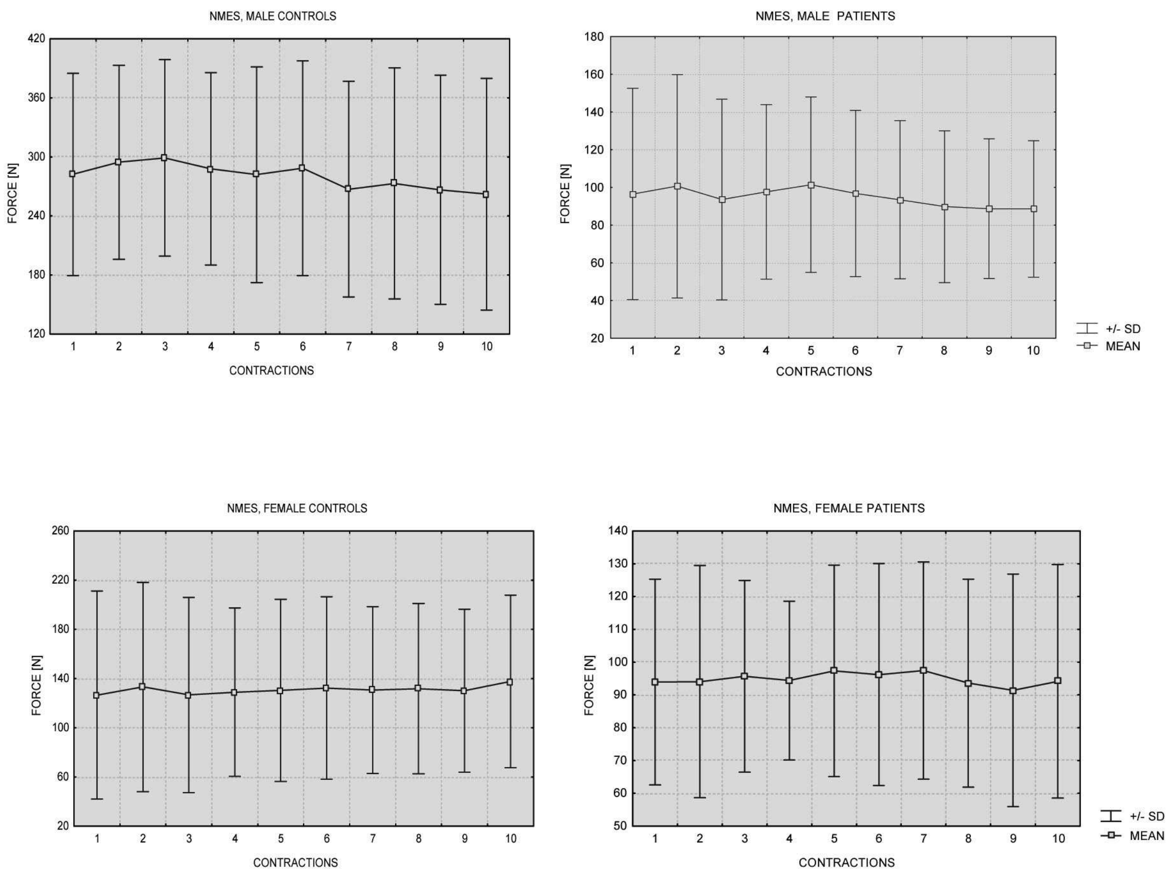
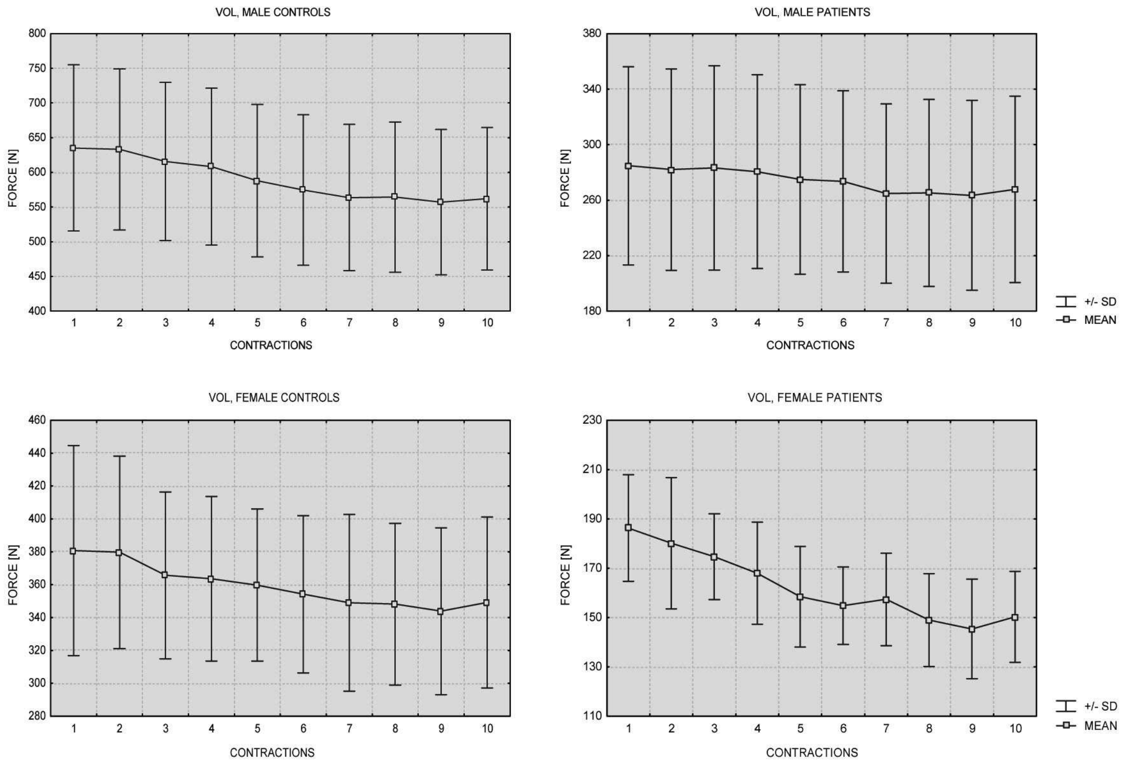


Fig. 3
Mean values of peak forces produced during subsequent voluntary contractions (VOL) by male and female patients and controls



no force loss in the healthy extremity. The ratio of body mass and quadriceps force was 73.76% in women and 88.93% in men, which is in accordance with normal values, according to Edwards et al. (1977). There are no such normal values for MEEC and such measurements are not common. However, values ranging from 37.72% MVIC to 54.75% MVIC (Binder-Macleod, Halden, & Jungles, 1995; Duchateau & Hainaut, 1988; Eriksson & Häggmark, 1979; Lorentzo, Elmqvist, & Sjostrom, 1989; Morrissey, Brewster, Shields, & Brown, 1985). Stimulation was conducted to the level of tolerance, and the contractions were subjectively maximal. It suggests that NMES does not engage the whole muscle, but only motoneurons in the current flow area, which is in accordance with other authors (Adams, Harris, Woodard, & Dudley, 1993; Ogino et al., 2002). We observed no force decrease in subsequent stimulated contractions, in contrast to voluntary exercises. This finding supports Kots's claims of the role of long rest periods between stimulated contractions to avoid fatigue.

CONCLUSIONS

1. Three weeks' post injury knee immobilization leads to a significant quadriceps force decrease.
2. Russian electrical stimulation elicits superficial motoneurons.
3. Isometric exercises of ten strenuous 5 second contractions with 10 second rest periods are more fatiguing than 10/50 second stimulated contractions.

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TORZE KOLENNÍCH EXTENZOROVÝCH SVALŮ BĚHEM IZOMETRICKÝCH CVIČENÍ A RUSKÁ ELEKTRICKÁ STIMULACE PO ZRANĚNÍ KOLENNÍCH VAZŮ

(Souhrn anglického textu)

Dobrovolné izometrické cvičení (VOL) i neuromuskulární elektrická stimulace (NMES) jsou metody rozvoje statické svalové síly. Používají se v programech pro rozvoj síly u zdravých svalů a také pro zotavování svalové funkce za určitých ortopedických podmínek. Obě metody se používají pro zpomalování svalové atrofie a ztráty síly v důsledku imobilizace kolena po zranění (Eriksson & Häggmark, 1979; Ingemann-Hansen & Halkjær-Kristensen, 1985; Johnson, 1988; Wigerstad-Lossing, Tromby, Jonsson, Morelli, Peterson, & Rentröm, 1988). NMES může vyvolat záškuby nebo tetanické svalové kontrakce, a to v závislosti na frekvenci proudových impulsů. Během tetanické stimulace jsou hlavními rysy nácvikových režimů:

1) cyklus zapnutí/vypnutí (pracovní cyklus), tvořený dobou kontrakce a dobou uvolnění,
2) počet kontrakcí a
3) intenzita kontrakcí (dána proudovou amplitudou nebo tolerancí subjektu).

Klíčová slova: zranění kolenních vazů, atrofie z nečinnosti, izometrické cvičení, ruská elektrická stimulace.

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