KNEE JOINT TORQUE MEASUREMENTS BEFORE, DURING AND AFTER TRAINING WITH ELECTRICAL STIMULATION

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The aim of this study was to investigate the influence of an eight-week Electrical Stimulation (ES) training program on the knee joint torque of the knee joint extensor muscles of six test persons (three trained hobby sportsmen 'T ES' and three untrained test persons 'UT ES'). ES sessions were carried out with simultaneous maximum voluntary isometric contraction five times weekly. A control group of six test persons (three 'T NoES' and three 'UT NoES') completed the same training program without ES. Every two weeks measurements on a dynamometer were done before, during and after training sessions. The averaged strength increase of the 'UT ES'-group amounted to 9.5% and of the 'T ES'-group to 5.7% at the knee joint flexion angle of 60°. The 'UT NoES'-group achieved 9.1% at the same knee joint flexion angle.

KEY WORDS: electrical stimulation, knee joint dynamometer, knee joint torque

INTRODUCTION: The physiological experiments of Galvani who made frog muscles contract with the aid of contact current around 1791 are generally known. However in the year of 420 before Christ Hippocrates already treated asthma with electrical strokes (ES!) of the torpedo-fish. Functional Electrical Stimulation (FES) has been employed with spinal cord injury subjects for a long time. Kern (1995) reports on clinical and physiological effects of eight months FES of the m. quadriceps femoris on 16 paraplegic patients. After eight months of FES training muscle perfusion was augmented by 80% and the muscle fibre diameters showed an average increase of 50%.

In recent years attempts have been increased to also use ES in training of healthy test persons (sportsmen). Studies were conducted about ES for weight lifting (Delitto et al.,1989), for basketball players (Maffiuletti et al., 2000), for swimming (Pichon et al., 1995), for cycling (Theriault et al., 1996) and in the explosive strength training (Witt & Voß, 1996). ES training proved to be effective in all these studies. Very different strength increases of between 0 % and 44 % were reported (Currrier & Mann, 1983; Laughman et al., 1983; Selkowitz, 1985). In Austrian high-performance sports ES is used in skiing for strength training. In rowing it is used only for regeneration, because the coach doubts the effectiveness of strength training with ES. These doubts inspired us to investigate whether or not strength increase is attainable by training with ES. Tests were done on untrained and trained test persons.

METHODS: Twelve healthy persons (two female and ten male, average age 22.4 years) who never had trained with ES before were randomly assigned to the ES group or the control (NoES-) group. Both legs were trained in this study. Surface electrodes (rectangular self adhesive electrodes, 50 mm x 50 mm and 100 mm x 50 mm) were placed above the motor points of the m. quadriceps (fig. 1). The muscle was stimulated by a commercial stimulation unit (Compex Sport). The stimulation data are shown in table 1. The leg was fixed at a knee joint flexion angle of approximately 90°. Both training periods I and II (tab. 1) lasted three weeks and the training period III 2 weeks.

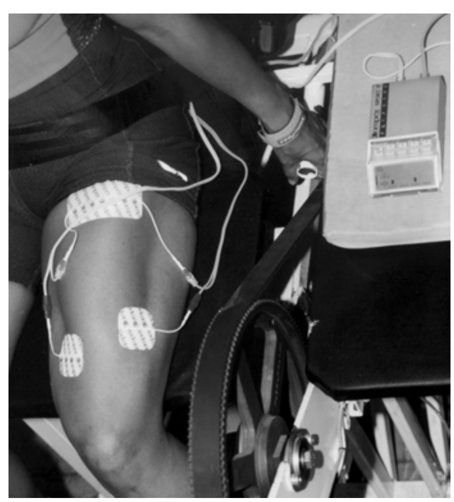

Fig. 1 - Surface-electrodes and stimulation unit.

At first the test person warmed up his m. quadriceps voluntarily and then the muscle was warmed up for five minutes with ES (low impulse frequency and amplitude). The amplitudes of the stimulation currents (for warming up, strength training and regeneration) were chosen by the test persons themselves depending on their pain sensitivity. The strength training, that lasted between 20 and 25 minutes depending on training period, followed. The test persons had to contract the m. quadriceps isometrically (at a knee joint flexion angle of 90°) with maximal force while being stimulated. The training cycle was completed by the regeneration part which helped the test persons to cool down. The control group had to train, after warming up for 20 – 25 minutes, with maximal voluntary isometric contraction at the same knee joint flexion angle.

Table 1 Stimulation Data

training period	warm up	strength training	impulse frequency	contraction time	relaxation time	regeneration	total time
	(min)	(min)	(Hz)	(s)	(s)	(min)	(min)
I	5	20	83	4	23	10	35
II	5	22	90	4	27	10	37
III	5	25	96	4	31	10	40

The measurements of the knee joint torque during contraction of the knee joint extensor (m. quadriceps) were performed on a dynamometer, that had been developed at our institute (Angeli, 2000). For the calculation of the active knee joint torque two measuring steps were necessary. First the test person's shank was moved passively (i.e., without muscle contraction) by the dynamometer and the passive knee joint torque was measured (step one). This value includes gravity forces and mass moment of inertia of the lower extremity (plus that of the measuring arm), passive muscle forces and loss of power due to friction. Secondly the test person was requested to extend the knee joint with maximum force at a fixed knee joint flexion angle of 110° (0° knee joint flexion angle equals fully extended lower extremity). This isometric contraction (between 0 ms and 1800 ms in fig. 2) allows the muscle to be prepared for the following concentric contraction. The isometric and concentric contractions are referred to as step two. These steps are performed at the knee joint angular velocities of 15°/s, 30°/s (fig. 2 and fig. 3), 60°/s, 90°/s, 120°/s and 180°/s. The test person tries to accelerate the measuring arm during the concentric movement as hard as possible. The active knee joint torque is calculated as the measured knee joint torque (step two) minus the passive knee joint torque (step one). For example: To hold the leg at the knee joint

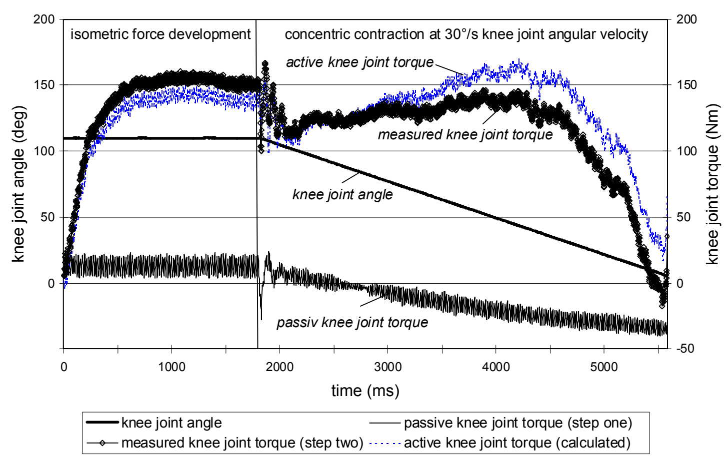

Fig. 2 - Results of knee joint torque measurements and knee joint flexion angle as a function of time of one cycle on one test person time at 30°/s knee joint angular velocity.

flexion angle of 5° the m. quadriceps must overcome the weight of the shank and foot and the passive torque of the antagonist muscles (hamstrings, m. gastrocnemius and others) which means that it is actually performing a higher force than measured. The knee joint angle course as a function of time is depicted in figure 2. Additionally isometric measurements were done at 30°, 60° and 90° knee joint flexion angles.

RESULTS AND DISCUSSION: Figure 3 depicts the knee joint torque increase for the 'UT ES'-group measured at the angular velocity of 30°/s. After 8 weeks of training the torque of the isometric contraction at the start angle of 110° was 27% higher than before training. This enormous strength increase can be explained by the fact that these tests persons almost never contracted their m. quadriceps maximally. A strength increase would have also been accomplished by the training effect of the six measurement cycles alone without the actual training. The lower the knee joint flexion angle was, the smaller the strength increase was.

Due to the small number of test persons and the deviation of their daily conditions the measurement results varied. The force velocity relation diagrams (fig. 4 - 6) were therefore smoothed. This was done by averaging the values of both legs of two consecutive measurement cycles and depicting the results in one curve (for example O in fig. 4 – 6). The force velocity relation values of the untrained test persons are shown in figure 4 ('UT ES') and figure 5 ('UT NoES') for the knee joint flexion angle of 60°. The comparison of the results was surprising. After eight weeks of training 9.5 ± 6.4% strength increase was measured for the 'UT ES'-group and

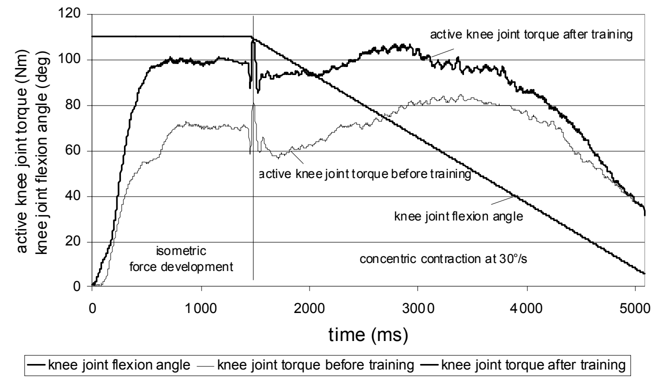

Fig. 3 - Active knee joint torque before and after training and knee flexion angle as function of time at 30°/s knee joint angular velocity.

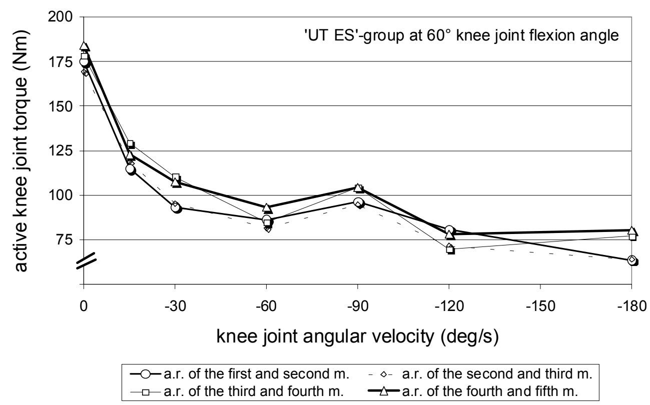

Fig. 4 - Averaged results (a.r.) of the different measurements (m.) of the 'UT ES'-group at the knee joint angle of 60°. For details see text.

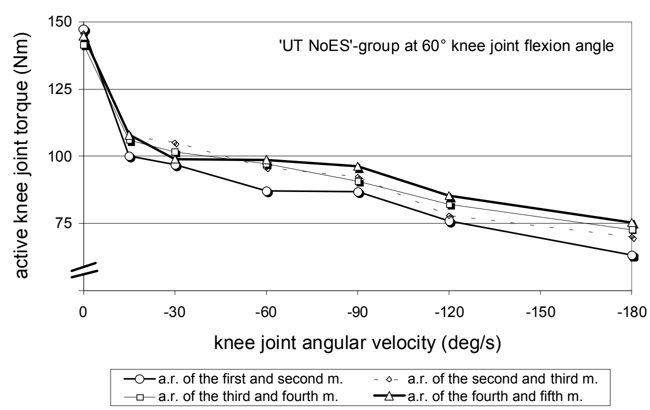

Fig. 5 - Averaged results (a.r.) of the different measurements (m.) of the 'UT NoES'-group at the knee joint angle 60°

9.1 ± 5.5% for the 'UT NoES'-group. All test persons who had trained with ES complained about strong muscle aches that were stronger than after training without ES. These aches also persisted longer than usual. The ES group probably chose smaller stimulation intensities and stimulated fewer motor units. This could be the reason for low values of the averaged results of the second and third measurements of the 'T ES'-group (Fig. 6). The first two measurements at the knee joint angular velocity of 60°/s in Figure 5 are deviations and therefore the averaged strength increase for the control group rose. It was no surprise that the strength increase of the untrained test persons achieved by this training was higher than that of the hobby sportsmen. The 'T ES'-group achieved 5.7 ± 3.3% strength increase at the knee joint flexion angle of 60° (fig. 6). The 'T NoES'-group achieved almost no strength increase (0.1 ± 3.5%) without ES. This surprising result of the control group might have come about because of lack of motivation. Moreover, one of the test persons complained about muscle aches caused by strain.

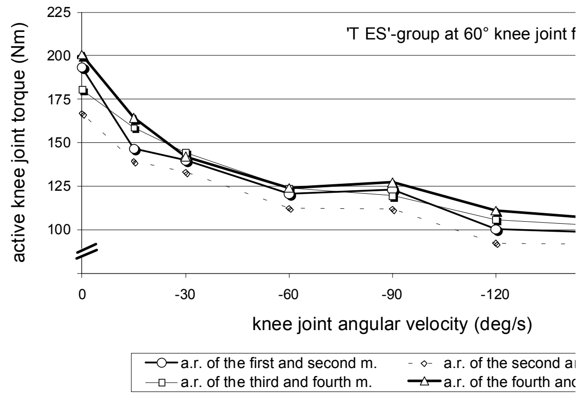

Fig. 6 - Averaged results (a.r.) of the different measurements (m.) of the 'T ES'-group at the knee angle 60°.

CONCLUSION: It was surprising that such a great strength increase could be measured with the untrained test persons without ES. With top athletes the strength increase is smaller than with hobby sportsmen. If ES training is able to improve strength increase for top athletes, we will investigate in the near future.

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