ABSOLUTE MUSCLE FORCE DETERMINATION

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INTRODUCTION

It is often believed that during maximum voluntary contraction (MVC) humans are able to exert all the muscle force they possess. From our recent findings we can show that this may not necessarily be true. Since muscle force during MVC can still be increased with additional activation of the muscle, a new term - absolute muscle force - was introduced to define this new force level. It is believed that when absolute muscle force is applied, the muscle is activated to its full extent, e.g., when all motor units are activated with their tetanic frequency. A few methods have been suggested to assess the extent of a muscle's activation during MVC. In practice, two methods have been frequently used: method of interpolated twitches (Chapman et al, 1984) in research work and comparison between concentric and eccentric MVC (Buehrle et al, 1981) in professional work. To have a tool that would be easily applicable to all needs (research and professional), a new method of interpolated submaximal electrical stimulation (ES) of muscles has been developed, which gives the possibility to assess the absolute muscle force directly. The aim of this work is to present some data that supports the use of this method.

METHODS

Subjects. Six sport active subjects (age: 24.5 ± 6.6 yrs, height: 181.1 ± 4.0 cm, weight: 74.7 ± 6.7 kg) gave their informed consent and volunteered to participate in the study.

Procedure. Subjects were asked to perform isometric knee extensions at different voluntarily activated torque levels (70%, 85%, and 100% of MVC) and were then transcutaneously electrically stimulated (quadriceps muscle) with equal ES amplitude, set to the individual tolerance threshold. In each condition, two trials were performed in randomized order. Regular rest intervals were inserted to prevent fatigue effects. Four volunteers additionally performed 100% MVC isometric knee extensions with different ES amplitudes (80%, 100%, and 120% of the tolerance threshold). Subjects lay on their backs on the bank with their shanks hanging freely over the bank. The shank was fastened to the metal frame, which was on one side connected to the bank at the knee axis with a help of bearings and on the other side to bank's support via a force transducer. The frame enabled measurement of knee toque with a 45 degree angle at the knee joint. Subjects were fastened with a belt over the hips and with a support under the lumbar spine to prevent pelvis movement.

Electrical stimulation. ES of the quadriceps muscle consisted of 0.8 s long trains delivered at 100 Hz. Single impulse width was 0.3 ms. Three pairs of surface electrodes (5 x 5 cm, Axelgaard Manufacturing, Fallbrook, CA) were used: over vastus lateralis, vastus medialis and rectus femoris muscle. The distal electrode was placed over the distal part of the muscle's belly and the proximal electrode over the motor point areas of the corresponding muscle. A custom made four-channel electrical stimulator was used. To assess the tolerance threshold, for each muscle separately, the amplitude was increased in intervals of 10 mA until discomfort was reported. The previous amplitude was defined as a 100 % ES of the tolerance threshold. The ES amplitude was set while the muscle was voluntarily pre-contracted.

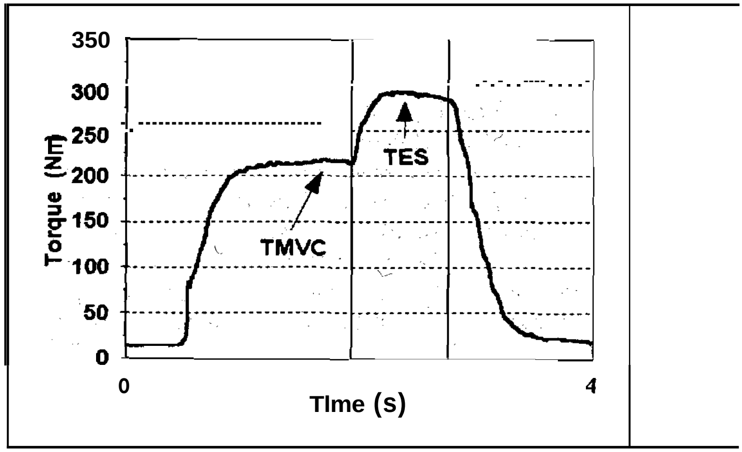

Figure 1. Maximum voluntary knee extension with superimpose ES. Area between vertical bars denotes stimulation period.

Kinetics. Knee torque was calculated from the measured force from the force transducer and then multiplied with the corresponding lever. The force signal was amplified (MES, Maribor, Slovenia), 12 bit AD converted (Burr-Brown, Tucson, AZ) and led to a PC. In parallel it was led also to a voltmeter, which provided the information about the subjects' actual torque level.

Statistics. Maximal torque during ES (TES) and maximal torque before ES (TMVC) were taken from the torque-time curve (Fig. 1). A ratio between TMVC and TES was calculated (RAT=TMVC/TES). From two trials of a single condition the best one was used for further treatment. Oneway analysis of variance was used to assess the statistical significance of differences among the individual experimental conditions.

RESULTS

Actual preset mean MVC levels were 73 % and 83 % for the proposed 70 % and 85 % of MVC, respectively. In all subjects the interpolated ES elicited an additional force growth, over the actual voluntary level. Results showed that in the first experiment (constant ES amplitude) TES was not following TMVC, since the changes in TES were much smaller (6.8% between 73 % and 100 % of MVC) than in TMVC (26.7 %) (Fig. 2). TES differences were also statistically non-significant. Because of this discrepancy, mean RAT values were changing from 66.6 % at 73 % MVC to 84.6 % at 100 % MVC. To examine the effect of different ES amplitudes on absolute force, three different ES amplitudes were used in the second experiment (constant voluntary activation level). However, they again exhibited statistically non-significant differences in TES (Fig. 3). Mean RAT values were 84.1 %, 84.3 %, and 83.4 % for 80 %, 100 %, and 120 % of ES amplitude, respectively, and were not statistically significant. The pearson correlation coefficient between TES at 80 % and 100 % amplitude of ES was 0.985.

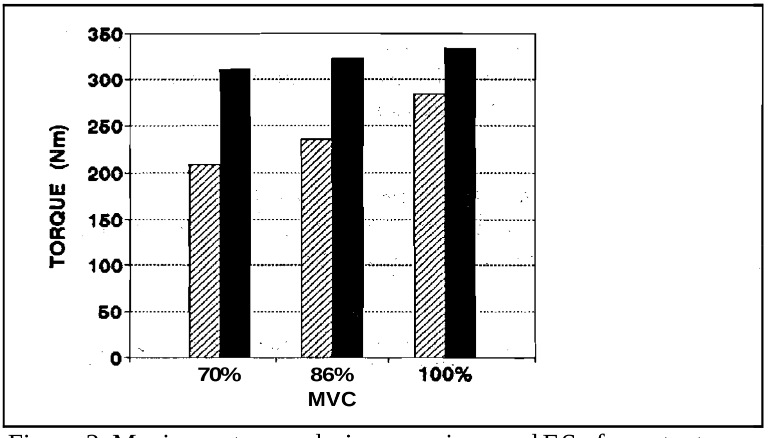

Figure 2. Maximum torque during superimposed ES of constant amplitude at different voluntary activation levels (denoted at abscissa as % of MVC). Stripped bar - TMVC, solid bar - TES. n=6.

DISCUSSION

There is no doubt that superimposed ES enabled greater knee torque than that exhibited with MVC. No direct evidence exists to show that TES represents a real muscle's maximum capability to exert force. Some indirect evidence is given by showing the relative independence of TES of different ES amplitudes at 100 % MVC (Fig. 3), which might suggest that all muscle's force potential was used during ES. The expectation that TES, obtained at lower voluntary activation levels, will reach, or at least come

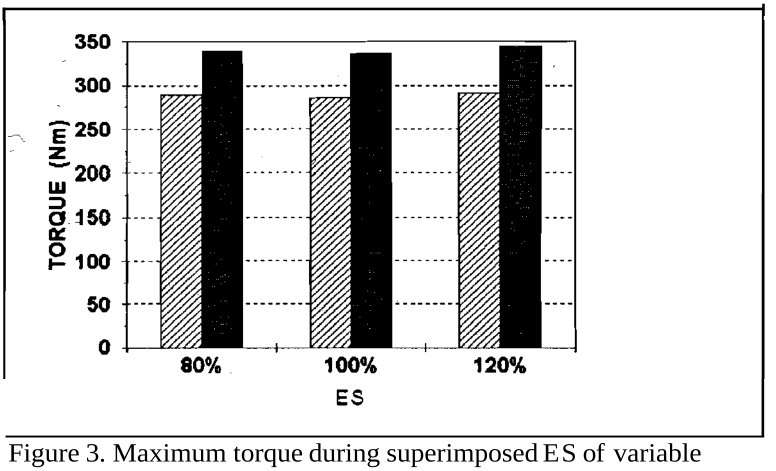

Figure 3. Maximum torque during superimposed ES of variable amplitude at MVC. Abscissa denotes relative ES amplitude in accord to tolerance threshold. Stripped bar - TMVC, solid bar -TES. n= 4.

near to the absolute torque (TES at 100 % MVC), was confirmed. This makes it possible to state that absolute torque is relatively independent of TMVC at a given mode of ES, although not enough to perform the absolute torque measurements without regarding TMVC. It seems important, from a practical point of view, that submaximal ES (80% of tolerance threshold) is sufficient to obtain maximal TES. Pain, which may often be connected to the use of ES, is in this way excluded. Submaximal ES amplitudes ensure reliable absolute torque determination by producing a stable TES, because in a quite broad range of ES amplitudes. the same TES level was obtained. These results represent a firm base for a possible use of this method for the assessment of the extent of a muscle's activation during MVC. Since ES can be easily applied to diverse muscles, or their combination, at different tasks (Strass et al, 1991; Strojnik et al. 1993), a broad field of its exploitation appears. Because of the substantial torque improvements in comparison to MVC, superimposed ES can be used to study a single muscle and/or muscle group sensitiveness to movement, especially in single joint or single limb designs. It may not be appropriate for use in complex movements.

CONCLUSIONS

It was concluded that superimposed ES during MVC can be an efficient tool for the determination of a muscle's absolute force, although some more direct evidence about complete muscle's activation would be appreciated.

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