DEPENDENCE OF MUSCLE TORQUE OF ANKLE PLANTAR AND DORSAL FLEXORS ON DIFFERENT ANKLE ANGLES

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ABSTRACT

Research background and hypothesis. There is much research information about the relationship between the knee joint angle and the quadriceps muscle torque (Mohamed et al., 2002), but still we lack evidence about the relationship between ankle angle and calf muscle torque.

Research aim. The purpose of this research was to establish the dependence of maximal voluntary contraction (MVC) and electrical stimulation (ES)-evoked torque and calf muscle electrical activity (EMG) on different ankle plantar and dorsal flexion angles. We hypothesized that the calf muscle MVC and ES-evoked torque as well as muscle EMG amplitude would increase with increasing muscle length (i. . increasing ankle angle).

Research methods. The subjects in the research were ten non-trained men. Calf plantar and dorsal flexors muscle ES and MVC torque were tested at eight different ankle angles (–25°; –15°; –5°; 0°; 15°; 25°; 35°; 45°) which were chosen in randomized sequence. The tibialis anterior, soleus, gastrocnemius lateralis and medialis muscle EMG were measured during muscle MVC.

Research results. The results showed that the highest ES-evoked and MVC developed torque of plantar flexion muscles was at –25° ankle angle (149.1 ± 31.6 N·m and 207.8 ± 38.1 N·m, respectively), while the highest dorsal flexion MVC muscle torque was at 25° ankle angle (47.2 ± 8.1 N·m). However, dorsal flexion muscle MVC torque increased with the muscle length only until 25° ankle angle.

Discussion and conclusions. Plantar flexion muscle electrical stimulation evoked and plantar / dorsal flexion muscle maximal voluntary contraction torques are highest at that ankle angle where muscle length is the longest.

Keywords: maximal voluntary contraction, electrical stimulation, EMG.

INTRODUCTION

In scientific literature, biomechanics of lower limb musculoskeletal system has been widely considered. Data on the biomechanical peculiarities of lower extremities can be used not only for improving performance in sports, but also for injury prevention and rehabilitation. Muscular torque is the result of the applied force and the lever arm multiplication (Arnold et al., 2009), which magnitude depends on muscle length (i. e. angular position), contraction mode, angular velocity (Babault et al., 2003; Skurvydas et al., 2008) and central nervous system activation (Desbrosses et al., 2006).

It has been found that changing the joint angle the length of muscle changes as well, which affects the maximal muscle torque (Thomas et al., 1987; Babault et al., 2003; Skurvydas et al., 2008; Arnold et al., 2009). O. Mohamed and co-authors

(2002) performed hamstring muscle length and force dependence research and direct correlation was found between muscle length and maximal voluntary muscle torque.

It is well known that the electrical stimulation (ES)-induced muscle force depends on the amount of stimulation frequency and voltage. ES-induced thigh muscle torques as well as maximal voluntary contraction (MVC) torque depend on muscle length. When thigh muscles are at longest length, they evoke higher torque (De Ruiter et al., 2004). However, Creswell and co-authors (1995) found an opposite muscle length and ES-evoked calf muscle torque dependence. They established that, when the knee angle flexion increased from 60° to 180°, the ES-induced muscle torque of the gastrocnemius decreased. Thus, the maximum gastrocnemius muscle length did not evoke maximal muscle torque (Creswell et al., 1995). The tibialis anterior muscle torque evoked by ES in a different joint angle has not been widely studied.

Muscle electrical activity (EMG) reflects the muscle motor unit potential (Arampatzis et al., 2006). When high muscle forces are at work, they include a large amount of motor units (Thomas et al., 1987). References provide contradictory muscle activity data at different joint angles (Babault et al., 2003). Some scientists state that the activity of a muscle does not change performing an isometric movement (Thomas et al., 1987; Gandevia, McKenzie, 1988; Bigland-Ritchie et al., 1992), others claim that the activity changes at different angles (Marsh et al., 1981; Cresswell et al., 1995; Kasprisin, Grabiner, 2000; Arampatzis et al., 2006). Therefore, it is important to assess the muscle EMG and the muscle length dependence on isometric muscle work.

There is a lack of information about the relationship between muscle lengths at different ankle angles and electrically as well as voluntarily evoked calf muscle torque.

Therefore the purpose of this study was to evaluate ankle plantar and dorsal flexors muscle torque dependence on the different ankle angles.

RESEARCH METHODS

Subjects. Ten healthy non-trained male subjects volunteered to participate in the study (height 181.8 ± 4.2 cm; body mass 80.4 ± 5.3 kg; age 24.5 ± 1.5 years; means ± SE). All the experimental procedures were performed in accordance with the Declaration of Helsinki and all the subjects gave written informed consents to participate in the study.

Protocol. The details of the experiment were explained to the participants before testing. The participants were checked if they could tolerate ES at different ankle angles with the stimulation voltage from 30 to 120 V, 24 hours before the experiment (Fig. 1). On the day of the experiment the subjects performed a 5-min warm-up at 80–100 r.p.m. with a 60–100 W resistance on an Ergo–Fit ergometer. The experiment started from the calf muscles ES at different ankle angles. After the ES procedure (5–10 min), the subjects performed dorsal and plantar flexion MVC at eight different ankle angles (Fig. 1). At each angle the subjects were allowed to develop two trials of 5 seconds MVC with a 30 s pause between each trial and 60 s pause between the angles. Visual feedback of torque output was provided to the subjects on a computer screen during each trial. EMG was measured during MVC testing.

Measurement of electrical stimulation-evoked torque. A high-voltage stimulator (MG 440, Medicor, Budapest, Hungary) was used to deliver electrical stimuli to the muscles performing plantar flexion and dorsal flexion through skin surface electrodes. Two stimulation electrodes (4 × 4 cm) were placed on the proximal and distal part of the anterior tibialis muscle. Other two electrodes were

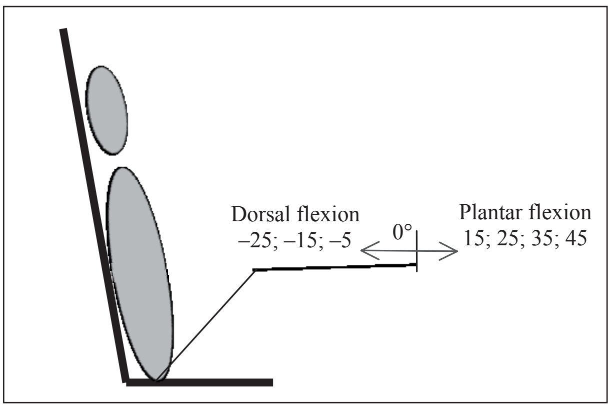


Figure 1. **Testing ankle joint position during electrical stimulation-evoked and maximal voluntary contraction torque testing**

placed on the proximal part of the gastrocnemius (electrode size, 4 × 4 cm) and the distal part of soleus and gastrocnemius muscles (electrode size, 7.5 × 11.5 cm). Firstly, we measured the torque of muscles performing dorsal flexion and then plantar flexion. We evoked the contractile force of muscles by 1-s train of electrical stimuli at 100 Hz and voltage of 150 V (Skurvydas et al., 2008) at eight (Fig. 1) ankle angles with a 60 s pause between stimulations. The measurements were performed in a randomized sequence.

Measurement of maximal voluntary contraction torque. Isometric muscle torque testing was performed using the Biodex System 3 (*Biodex Medical System,* Shirley, NY). This device, which was equipped with a footplate that was fixed to the rotational axis of the motor, recorded the torque generated by the dorsiflexor muscles under static conditions for different ankle joint angles. The subject was secured on an adjustable chair in a slightly reclined position and strapped at the hip and chest. The foot was strapped to the plate so that the axis of rotation of the ankle joint was aligned with the shaft of the motor. In neutral position, the plate was inclined at an angle of 45° relative to the floor. The position of the subject was adjusted to obtain a 90° angle for the ankle (neutral position or 0°). The foot was held in place by a heel block and was tightly attached to the plate by two straps. One strap was placed around the foot, 1–2 cm proximal to the metatarsophalangeal joint of the toe, and the second strap was placed around the foot, just below the ankle joint. To correct the effect of gravity on the measured joint movements, the passive mass of the foot was measured in the dynamometer at an ankle joint angle of 15°. All the subjects were tested without shoes. The dominating leg was identified by asking each participant which leg they preferred to kick a ball as far as possible (Ford et al., 2003).

Measurements of muscle electrical activity. EMG signals were recorded in the ankle dorsal flexion muscle (anterior tibialis muscle) and the ankle plantar flexion muscles (soleus, gastrocnemius lateralis and medialis mucles) using Biometrics Ltd electromyography (UK). After the careful preparation of the skin (shaving, abrasion and cleaning with alcohol), electrodes (Ag / AgCl) were placed following the recommendations of SENIAM for the location of sensors on muscles. Before starting the experiment we performed a manual test of EMG electrodes to be sure that they were placed correctly (Hermes et al., 1999). All EMG signals were synchronously recorded with MVC measurements.

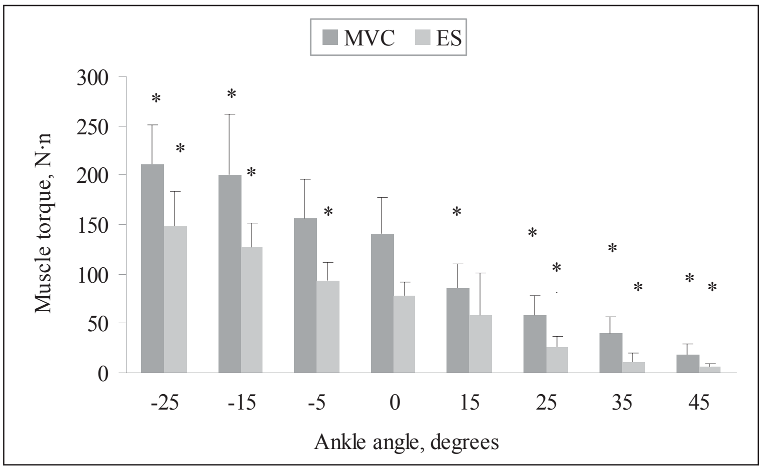
Mathematical statistics. The research data were processed using Microsoft Excel 2007 program mathematical statistical analysis. The data are reported as group mean values ± standard deviations (SD). Changes between 0 and –25, –15, –5, 15, 25, 35, 45º angles were evaluated using Student's (t) test ($p < 0.05$ level of significance).

RESEARCH RESULTS

The highest ES-evoked torque of plantar flexion muscles (Fig. 2) was developed at –25° angle (149.1 ± 31.6 N·m). The data between the angles showed that at –25; –15; –5° angles the muscle torque was higher ($p < 0.05$), and at 25; 35; 45° angles the muscle torque was lower ($p < 0.05$) compared to 0° angle torque.

The highest MVC muscle torque of foot plantar flexion (Fig. 2) was also developed at the –25° angle (207.8 ± 38.1 N·m). Comparing the data between the angles we established that at the –25; –15 angles the muscle torque was higher ($p < 0.05$), and at the 15; 25; 35; 45° angles the muscle torque was lower ($p < 0.05$) than the torque at the 0° angle (Fig. 2).

Figure 2. **Maximal voluntary contraction (MVC) and electrical stimulation (ES)-evoked muscle torques during plantar flexion at different angles**



Note. * – $p < 0.05$, the difference between 0° and –25; –15; –5; 15; 25; 35; 45° angles.

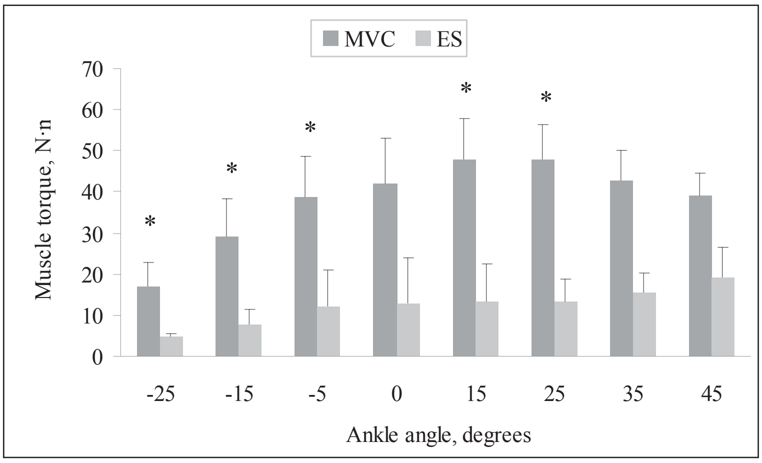


Figure 3. **Maximal voluntary contraction (MVC) and electrical stimulation (ES) – evoked muscle torques during ankle dorsal flexion at different angles**

Note. * – $p < 0.05$, the difference between 0° and –25; –15; –5; 15; 25; 35; 45° angles.

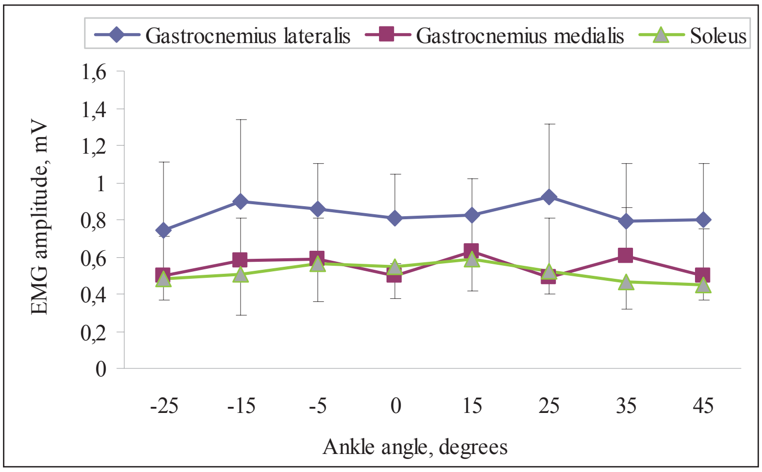


Figure 4. **Maximal soleus, gastrocnemius medialis and lateralis muscle electrical activity (EMG) amplitude during foot plantar flexion at different ankle angles**

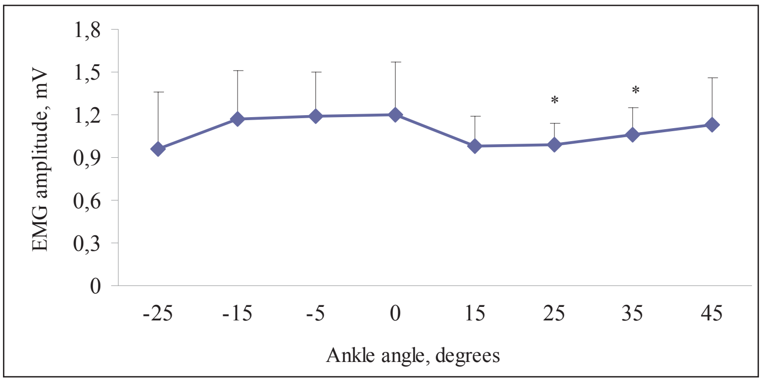


Figure 5. **Maximal tibialis anterior muscle electrical activity (EMG) amplitude during foot dorsal flexion at different ankle angles**

Note. * – $p < 0.05$, the difference between the 0° and the –25; –15; –5; 15; 25; 35; 45° angles.

Unlike the ES-evoked torque of plantar flexion muscles, dorsal flexion muscle did not show any statistical significant changes compared to 0° angle (Fig. 3).

The highest dorsal flexion MVC muscle torque (Fig. 3) was developed at the 25° angle (47.2 ± 8.1 N·m). The comparison of the data between the angles showed that at the –25; –15; –5° angles the muscle torque was lower ($p < 0.05$), and at the 15°; 25° angles the muscle torque was higher ($p < 0.05$) than the torque at the 0° ankle angle.

We did not establish any statistically significant differences of the EMG amplitude of soleus, gastrocnemius lateralis and medialis muscles at different ankle angles (Fig. 4). However the tibialis anterior muscles EMG amplitudes data (Fig. 5) at 25 and 35° ankle angles were lower ($p < 0.05$) compared to 0° angle.

DISCUSSION

We have established that in presence of the maximum muscle length, the highest plantar flexion ES-evoked and plantar / dorsal flexion MVC muscle torque is developed. Though there have not been established any ES-evoked dorsal flexion muscle torque differences at different ankle angles, we observed a tendency that, when the muscle length increased, the muscle torque increased as well. No plantar flexion muscle EMG amplitude dependencies on different ankle angles have been estimated, either. However there is evidence about dorsal flexion muscle EMG amplitude differences at 25 and 35 º ankle angles.

In scientific research dealing with ankle angle and muscle torque dependence, MVC is usually explored in the amplitude of 30° of a foot plantar flexion and –20º of a foot dorsal flexion (Sale et al., 1982; Anderson et al., 2007; Arnold et al., 2009). In our research, the MVC torque of calf muscles was measured at the maximal ankle joint amplitude (i. e. 45° plantar flexion and –25° dorsal flexion) in order to investigate the muscle capabilities to develop muscle force at wider range of amplitudes. D. E. Anderson and co-authors (2007) established that the highest muscle torques performing dorsal flexion of a foot was at the angles of –15° and –20°, respectively – 156 N·m and 170 N·m. In our research we established that the highest MVC plantar flexion muscle torque was at the –25° angle.

It has been estimated that dorsal flexion muscle (tibialis anterior) is thin; therefore the developed muscle torque during a movement does not change significantly at different angles (Arnold et al., 2009). E. M. Arnold and co-authors (2009) performed a study where they established that the highest MVC torque was at the 7° angle. In our research we established that the highest MVC torque was developed at the 25° angle. Interestingly, at the 35 and 45° ankle angles the length of the muscle increased, but the MVC torque decreased. We suppose that the 25° ankle angle coincides with the optimal ankle angle.

We estimated that ES-evoked plantar flexion muscle torque was the highest at the –25° angle, and the lowest – at the 45° angle. We established that the plantar flexion muscle ES-evoked torque directly depended on the ankle angles. At the angle where the length of the muscle was the biggest, we observed the highest plantar flexion muscle ES-evoked torque. However, we did not establish significant differences in the dorsal flexion muscle torque at different angles, but we noticed that when the length of a muscle increased the torque increased, too.

Some authors provide contradictory results of the electrical activity of muscles. It has been known that muscle EMG depends on muscle length (Farina, 2006). However, A. G. Cresswell et al. (1995) performed plantar flexion EMG muscle studies at different muscle lengths and observed that the activity of a soleus muscle did not change, when the length changed. Our research results confirmed that not only soleus muscle but also gastrocnemius muscles did not depend on different ankle angles.

E. Marsh et al. (1981) established that the tibialis anterior muscle activity was lower at the longest muscle length. In our research we also observed the tendency that when the tibialis anterior muscle was at longer length the EMG amplitude was lower, and vice versa, when the muscle was shorter the EMG amplitude was higher. However, the significant changes were observed only at 25 and 35º ankle angles.

Summarizing the results of the research we may state that the value of the calf muscle torque depends on the muscle length and EMG amplitude was independent of ankle angle, except for tibialis anterior EMG amplitude which was significantly lower at 25 and 35° ankle angles.

CONCLUSIONS AND PERSPECTIVES

Plantar flexion muscle electrical stimulation evoked and plantar / dorsal flexion muscle maximal voluntary contraction torques are highest at that ankle angle where muscle length is the longest. It was established that the torque of the dorsal flexion electrical stimulation evoked muscle torque was independent of different ankle angles. Furthermore, electrical activity of plantar and dorsal flexion muscles at different ankle angles was independent of muscle length, except for tibialis anterior EMG amplitude at 25 and 35° ankle angles.

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PĖDOS LENKIAMŲJŲ IR TIESIAMŲJŲ RAUMENŲ JĖGOS MOMENTO IR PĖDOS SĄNARIO KAMPO PRIKLAUSOMYBĖ

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SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Moksliniuose straipsniuose gausu informacijos apie šlaunies keturgalvio raumens jėgos momento ir kelio sąnario kampo priklausomybę (Mohamed et al., 2002). Tačiau nėra plačiai tyrinėta blauzdos raumenų jėgos momento ir pėdos sąnario kampo priklausomybė.

Tikslas: nustatyti pėdos lenkiamųjų, tiesiamųjų raumenų maksimaliosios valingos jėgos (MVJ) ir elektros stimuliacijos (ES) sukelto jėgos momento bei raumenų elektrinio aktyvumo (EMG) priklausomybę nuo pėdos sąnario kampo. Buvo iškelta hipotezė, kad pėdos lenkiamųjų ir tiesiamųjų raumenų MVJ, ES sužadintas jėgos momentas bei raumenų EMG amplitudė didės, kuomet raumuo bus ilgas (t. y. didės kampas).

Metodai. Buvo tiriama dešimt nesportuojančių vyrų. Tyrimo metu pėdos lenkiamųjų ir tiesiamųjų raumenų jėgos momentas tirtas atsitiktine tvarka parinkus aštuonis skirtingus (-25^o; -15^o; -5^o; 0^o; 15^o; 25^o; 35^o; 45^o) pėdos sąnario kampus. Tiriamųjų priekinio blauzdos, plekšninio, vidinio ir šoninio dvilypio raumenų EMG buvo registruota izometrinio MVJ momentu.

Rezultatai. Nustatyta, kad pėdos lenkiamųjų raumenų ES sukeltas ir MVJ išugdytas didžiausias jėgos momentas buvo tada, kai pėda sulenkta –25° kampu (149,1 ± 31,6 ir 207,8 ± 38,1 N·m). O pėdos tiesiamųjų raumenų didžiausias MVJ momentas – kai pėda sulenkta 25° kampu (47,2 ± 8,1 N·m).

Aptarimas ir išvados. Pėdos tiesiamojo priekinio blauzdos raumens ES sukeltos jėgos momentas nepriklauso nuo pėdos sąnario kampo.

Raktažodžiai: maksimalioji valinga jėga, elektrostimuliacija, EMG.

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