Journal of Biomechanics 40 (2007) 3193–3200

JOURNAL OF BIOMECHANICS

www.elsevier.com/locate/jbiomech
www.JBiomech.com

Changes in fascicle length from rest to maximal voluntary contraction affect the assessment of voluntary activation

Adamantios Arampatzis[a,*], Lida Mademli[a], Gianpiero De Monte[a], Mark Walsh[b]

[a]German Sport University of Cologne, Institute of Biomechanics and Orthopaedics, Carl-Diem-Weg 6, 50933 Cologne, Germany
[b]Department of Physical Education, Health and Sport Studies, Miami University, Oxford, OH, USA

Accepted 18 April 2007

Abstract

The purpose of this study was to investigate the effect of the differences between the actual fascicle length during a voluntary contraction and the fascicle length at rest of the triceps surae muscle on the determination of the voluntary activation (VA) by using the interpolated twitch technique. Twelve participants performed isometric voluntary maximal (MVC) and submaximal (20%, 40%, 60% and 80% MVC) contractions at two different ankle angles (75° and 90°) under application of the interpolated twitch technique. Two ultrasound probes were used to determine the fascicle length of soleus, gastrocnemius medialis and gastrocnemius lateralis muscles. Further, the MVCs and the twitches were repeated for six more ankle angles (85°, 95°, 100°, 105°, 110° and 115°). The VA of the triceps surae muscle were calculated (a) using the rest twitch force (RTF) measured during the same trial as the interpolated twitch force (ITF; traditional method) and (b) using the RTF at an ankle angle where the fascicle length showed similar values between ITF and RTF (fascicle length consideration method). The continuous changes in fascicle length from rest to MVC affect the accuracy of the assessment of the VA. The traditional method overestimates the assessment of the VA on average 4% to 12%, especially at 90° ankle angle (i.e. short muscle length). The reason for this influence is the unequal force–length potential of the muscle at twitch application by the measure of ITF and RTF. These findings provide evidence that the fascicle length consideration method permits a more precise prediction (an improvement of 4–12%) of the voluntary contraction compared to the traditional method.

Keywords: Ultrasonography; Twitch interpolation technique; Activation deficit; Force–length potential; Triceps surae

1. Introduction

The voluntary activation (VA) during isometric contractions has often been determined using the interpolated twitch technique (Merton, 1954; Rutherford et al., 1986; Allen et al., 1997). In this method the evoked interpolated twitch torque at the plateau region of torque generation during a submaximal or maximal voluntary contraction is normalised to resting twitch torque and this ratio has been used to calculate the VA (Hurley et al., 1992; Rice et al., 1992; Allen et al., 1995; Gandevia et al., 1996). This form of the VA assessment has been used in experiments which investigated the contribution of central factors in human muscle fatigue (Gandevia et al., 1996; Schillings et al., 2003), studies examining age-related differences in VA (Vandervoort and McComas, 1986; Philipps et al., 1992), changes in VA after immobilization or exercise intervention (Harridge et al., 1999; Gondin et al., 2004) and finally by works which analysed the extent of the VA after injuries and diseases (Hurley et al., 1992; Snyder-Mackler et al., 1994; Becker et al., 2004; Pap et al., 2004). Although a lot of studies reported a high reproducibility of the interpolated twitch technique for the assessment of the VA (Allen et al., 1995; Nørregaard et al., 1997; Gandevia et al., 1998; Todd et al., 2004; Morton et al., 2005) the inability of the twitch interpolation technique to precisely predict the voluntary contraction is well known (Allen et al., 1995; Suter and Herzog, 2001; Brondino et al., 2002; Oskouei et al., 2003; Todd et al., 2004).

*Corresponding author. Fax: +49 221 4971598.
E-mail address: Arampatzis@dshs-koeln.de (A. Arampatzis).

0021-9290/$ - see front matter
doi:10.1016/j.jbiomech.2007.04.011

The premise supporting the normalisation of the superimposed interpolated twitch torque to the resting twitch torque for the determination of the VA is that the force generating potential of the examined muscle is the same at rest as during the voluntary contraction at twitch application (i.e. equal electrical stimuli should initiate equal muscle mechanical responses). The force potential of the muscle due to the force–length relationship is dependent on the fascicle length. During an isometric contraction, despite a constant length of the muscle-tendon unit, the fascicle length of the muscle does not remain constant because of the non-rigidity of the tendon and aponeurosis (Fukunaga et al., 1997; Arampatzis et al., 2006). Different force–length potential of the muscle by twitch application at rest and during the voluntary contraction affect the accurate assessment of the VA and can contribute to the reported inability of the twitch interpolation technique to precisely predict the voluntary contraction. Furthermore, the effect of different fascicle length between rest and voluntary contraction at twitch application on the assessment of the VA may be muscle-length dependent due to the specific form of the force–length relationship of the muscle (i.e. ascending limb, plateau region and descending limb).

The purpose of this study was to investigate the influence of the differences between the actual fascicle length of the triceps surae muscle during a voluntary contraction and the fascicle length at rest on the assessment of the VA by using the twitch interpolated technique. Based on the reports about the continuous changes in fascicle length and thus in the force–length potential of the triceps surae muscle from rest to maximal voluntary contraction we expected an effect on the determination of the VA as well as on the prediction of the voluntary contraction using the twitch interpolated technique. Further, we expected an ankle-angle-dependent magnitude effect on the assessment of the VA due to changes in fascicle length.

2. Methods

2.1. Experimental design

Twelve adults (three females and nine males, age: 28.1 ± 6.8 years, body mass: 70.7 ± 9.7 kg, body height: 178.9 ± 6.6 cm) participated in this study. All participants were physically active and none suffered from any orthopaedic abnormality of the lower extremities. The participants performed isometric maximal voluntary plantar flexion contractions (MVC) with the left leg at two different ankle angles (75° and 90°; tibia perpendicular to the sole corresponding to 90° ankle angle), with the knee fully extended at 180° and the hip flexed at 140° on a Biodex dynamometer (Biodex-System3, Biodex Medical Systems Inc., USA). In addition, four submaximal voluntary isometric contractions (20%, 40%, 60% and 80% of the previous MVCs) were recorded at each position (75° and 90° ankle angle). The twitch (triple twitches) interpolation technique was used to determine the VA of the triceps surae muscle during the contractions. Furthermore, the MVCs and the twitches were repeated for six more ankle positions (85°, 95°, 100°, 105°, 110° and 115° ankle angle). Two ultrasound probes (Aloka SSD 4000 and Shimadzu, JPN, SDU-350 XL) were used to determine the fascicle length of the soleus (SOL), gastrocnemius medialis (GM) and gastrocnemius lateralis (GL) muscles.

2.2. Measurement of the ankle joint moment and muscle architecture

After a warm-up period, consisting of 2–3 min of submaximal isometric contractions and three MVCs, the participants were instructed to perform the maximal and the four submaximal (20%, 40%, 60% and 80% MVC) isometric plantar flexion contractions at the two different ankle joint positions (75° and 90° ankle angle) in a randomised order. After that participants performed MVCs for the other six ankle joint positions (ankle angle: 85°, 95°, 100°, 105°, 110° and 115°). The subjects had a brake of at least 3 min between each of the isometric contractions. We used a stimulator (Model DS7A digitimer, Digitimer Ltd., Welwyn Garden City, Hertfordshire, England) to evoke a superimposed twitch (three 500 μs square-wave pulses separated by 5 ms) at the plateaus of the maximal as well as of the submaximal plantar flexion efforts as well as three supramaximal twitches after the contractions when the plantar flexor muscles were relaxed (Fig. 1). We used a triple twitch instead of single twitches to increase the duration of the twitch contraction and thus to reduce the influence of tendon compliance on muscle force production. It has been reported that multiple twitches decreased the variability of the muscle responses (Suter and Herzog, 2001).

The resultant moments at the ankle joint were calculated through inverse dynamics (Arampatzis et al., 2005). To calculate the lever arm of the ankle joint during ankle plantar flexion the centre of pressure under the foot was determined by means of a flexible pressure distribution insole (Pedar-System, Novel GmbH, Germany) operating at 99 Hz. Kinematic data were recorded using the Vicon 624 system (Vicon Motion Systems, United Kingdom) with eight cameras operating at 120 Hz. During the plantar flexion efforts 10 reflective markers (radius 7 mm) fixed on the following positions were captured: tuber calcanei, lateral and medial malleolus, the most prominent points of the lateral and medial femoral condyles, trochanter major, forefoot on the pressure insole between the second and third metatarsals, axis of the dynamometer and two markers on the foot plate to define the line of force application. The moments measured by the dynamometer were registered synchronously by the vicon-system at a sampling rate of 1080 Hz.

The two ultrasound probes were placed above the SOL, GM and GL muscle belly to determine the architecture of the three muscles (Fig. 2). The muscle architecture of the SOL, GM and GL (fascicle length and angle of pennation) was determined at all examined positions at rest and at the plateau (at twitch application) of the plantar flexion moment during the maximal as well as submaximal contractions. The fascicle length was

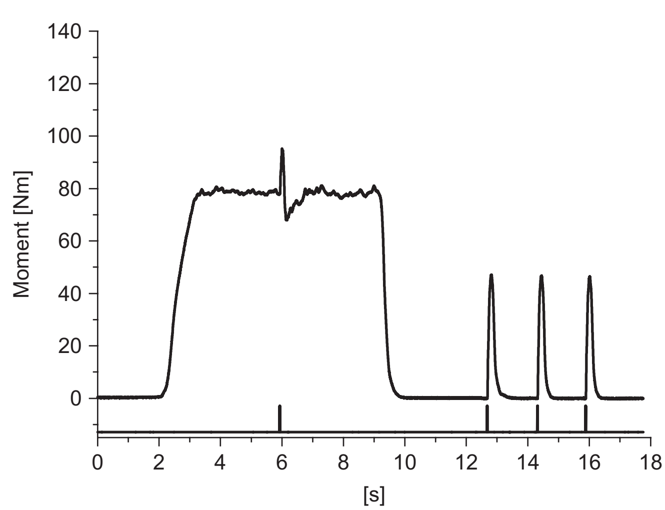

Fig. 1. Plantar flexion moment-time history during a voluntary contraction at 60% MVC from one participant with a superimposed and three rest twitches. The vertical lines indicate the instant of the electrostimulation.