

Effect of joint rotation correction when measuring elongation of the gastrocnemius medialis tendon and aponeurosis

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Received 9 August 2006; received in revised form 5 December 2006; accepted 5 December 2006

Abstract

It is well known that during maximal plantar flexion contractions the ankle joint rotation overestimates the actual elongation of the tendon and aponeurosis. The aim of this study was to examine the influence of the curve length changes of the Achilles tendon on the joint rotation corrected elongation and strain of the gastrocnemius medialis (GM) tendon and aponeurosis. Nine subjects (age: 29.4 ± 5.7 years, body mass: 78.8 ± 6.8 kg, body height: 178 ± 4 cm) participated in the study. The subjects performed maximal voluntary isometric plantarflexion contractions in the prone position on a Biodex-dynamometer. Ultrasonography (Aloka SSD 4000) was used to visualize the muscle belly of the GM muscle-tendon unit. To calculate the curve length changes of the Achilles tendon its surface contour was reconstructed using a series of small reflective skin markers having a diameter of 2.5 mm. The elongation of the GM tendon and aponeurosis was calculated (a) as the difference of the measured and the passive (due to joint rotation) displacement of the tendon and aponeurosis and (b) as the difference of the measured displacement and the length changes of the reconstructed Achilles tendon surface contour. The absolute difference between the elongation obtained by both methods were 1.2 ± 0.4 mm. These differences were due to the higher changes in length obtained by the reconstruction of the tendon curved surface contour as compared to the changes observed in the passive displacement of the digitised point at the aponeurosis. Without correcting for angle joint rotation, the measured elongation clearly overestimates the actual elongation of the GM tendon and aponeurosis. After the passive displacement correction the calculated elongation still overestimates the actual elongation of the GM tendon and aponeurosis. However, this overestimation has a negligible effect on the examined in vivo strain ($\sim 0.3\%$) of the tendon and aponeurosis.

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Keywords: Plantar flexion; Ultrasonography; Reconstruction; Tendon strain; In vivo; Human

1. Introduction

The development of the ultrasound technique enabled the investigation of the mechanical properties of tendon and aponeurosis from different muscle-tendon units in vivo in the last years (Magnusson et al., 2001; Rosager et al., 2002; Bojsen-Møller et al., 2003; Arampatzis et al., 2005a; Staflidis et al., 2005). The experimental procedure includes an isometric maximal voluntary contraction (MVC) on a dynamometer and the synchronous registration of the displacement of a point at the distal myotendinous junction (Maganaris and Paul, 2000; Magnusson

et al., 2001; Arampatzis et al., 2005a; Staflidis et al., 2005) or distal aponeurosis of the examined muscle-tendon unit (Kubo et al., 2001; Bojsen-Møller et al., 2003; Arampatzis et al., 2005a; Staflidis et al., 2005). The changes in displacement of the analysed point at the myotendinous junction or at the aponeurosis during the MVC in relation to the initial position (Maganaris and Paul, 2000) or in relation to a skin marker (Kubo et al., 2001) have been suggested to coincide with the elongation of the structures distal to the analysed point due to the exerted tendon force. This assumption will only be true if the whole length of the examined muscle-tendon unit remains constant during the MVC.

However in vivo conditions, it is well known that it is very difficult to completely avoid any joint motion using external strap fixations during maximal plantar flexion

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contractions. This is because of the large moments around the ankle joint, the relative motion of the foot to the dynamometer, the mechanical compliance of the dynamometer itself, the deformation of the chair and the deformation of the soft tissue of the foot (Magnusson et al., 2001; Muramatsu et al., 2001; Rosager et al., 2002; Arampatzis et al., 2005a,b). The ankle joint rotation during the MVC affects the length of the triceps surae muscle-tendon unit and leads to a significant overestimation of the actual elongation of the tendon and aponeurosis due to the exerted tendon force (Magnusson et al., 2001; Muramatsu et al., 2001). In order to correct the influence of ankle joint rotation on the actual elongation of the tendon and aponeurosis, the additional displacement of the analysed point at the myotendinous junction or at the aponeurosis due to joint rotation has been calculated relative to a fixed skin marker during a passive (inactive condition) motion of the ankle joint (Muramatsu et al., 2001; Rosager et al., 2002; Arampatzis et al., 2005a).

The assumption made in this method is that for a given ankle joint rotation, the displacement of the analysed point relative to the skin marker in the inactive situation will be the same as the curve length changes of the Achilles tendon from the origin to the skin marker during the MVC. However, the tendon and aponeurosis are not rigid structures and theoretically the displacement of the digitised point at the aponeurosis should be smaller than the curve length changes of the Achilles tendon during the contraction. Thus theoretically after the above correction the calculated elongation would still overestimate the actual elongation of the tendon and aponeurosis. Contrary to this, recently Maganaris (2005) reported that the suggested correction underestimates the actual elongation of the tendon by 35%. Therefore the aim of this study was to examine the influence of the curve length changes of the Achilles tendon on the joint rotation corrected elongation and strain of the GM tendon and aponeurosis.

2. Methods

2.1. Subjects

Nine male subjects (age: 29.4 ± 5.7 years, mass: 78.8 ± 6.8 kg, height: 178 ± 4 cm, tibia length: 423.2 ± 15.4 mm) participated in this study. All subjects were physically active and none suffered from any orthopaedic abnormality of the lower extremities. The subjects visited the laboratory on at least one occasion before testing to get familiarized with the experimental procedures.

2.2. Measurement of the ankle joint moment

The subjects performed maximal voluntary isometric plantar-flexion contractions (MVC, ankle angle 85° , knee fully extended) in the prone position on a Biodex-dynamometer. The subjects were instructed to exert a maximal isometric moment and hold it for about 3–5 s. Before each MVC the axis of rotation of the dynamometer was carefully aligned with the axis of rotation of the ankle. The axis of rotation of the ankle joint was defined to be

parallel to the axis of the dynamometer and passing through the midpoint of the line connecting both malleoli. During the contraction the axes clearly shifted away from each other. This shift significantly influences the resultant joint moments (Arampatzis et al., 2005b). Therefore, kinematic data were recorded using the Vicon 624 system with 8 cameras operating at 120 Hz.

To determine the centre of pressure under the foot a flexible pressure distribution insole (pedar-system, Novel GmbH, Germany) operating at 99 Hz was used. During the plantar flexion 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 resultant moments at the ankle joint were calculated through inverse dynamics (Arampatzis et al., 2005b).

In the literature it is often reported that during a maximal plantar flexion effort the antagonist muscle tibialis anterior (TA) is active. This means that during the contraction the TA generates a dorsal flexion moment and might significantly influence the measured plantar flexion moments at the dynamometer (Magnusson et al., 2001; Rosager et al., 2002). Therefore the additional moment due to the activation of the TA was estimated using the EMG-activity of the TA during the maximal voluntary plantar flexion (Mademli et al., 2004). The moments generated due to antagonistic coactivation of the TA during the plantarflexion efforts were quantified by assuming a linear relationship between surface EMG amplitude of the ankle dorsiflexor muscles and moment measured during one relaxed condition and two sub-maximal dorsi-flexion contractions (Mademli et al., 2004). A limitation of this method is that only the TA muscle can be considered for the dorsiflexion moment. From now on in the text, ankle joint moment refers to the joint moment values where the effect of gravitational forces, the effect of the joint axis shifts relative to the dynamometer axis and the effect of the antagonist moment on the moment measured at the dynamometer are taken into account (Fig. 1).

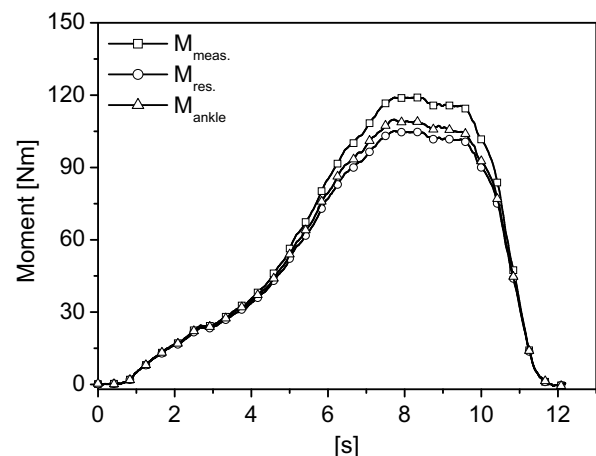


Fig. 1. Measured moments ($M_{\text{meas.}}$), resultant moments ($M_{\text{res.}}$) and moments considering the coactivation of tibialis anterior (M_{ankle}) at the ankle joint during a maximal voluntary plantar flexion contraction for one subject.

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