Author(s): Stosic, Jelena; Finni Juutinen, Taija

Title: Gastrocnemius tendon length and strain are different when assessed using straight or curved tendon model

Year: 2011

Version:

Please cite the original version:

Stosic, J., & Finni Juutinen, T. (2011). Gastrocnemius tendon length and strain are different when assessed using straight or curved tendon model. European Journal of Applied Physiology, 111(12), 3151-4. https://doi.org/10.1007/s00421-011-1929-9

Gastrocnemius tendon length and strain are different when assessed using straight or curved tendon model

Stosic J* and Finni T

Neuromuscular Research Center, Department of Biology of Physical Activity, University of Jyväskylä, Finland

* Present address: Perception and Motor System Laboratory, School of Human Movement Sciences, The University of Queensland, Australia

Corresponding author: Taija Finni, Ph.D.

Department of Biology of Physical Activity

University of Jyväskylä

PO Box 35 (VIV227)

FI-40014 University of Jyväskylä

Finland

Tel. +358-40-5566582 Fax. +358-14-2602071

E-mail: taija.finni@jyu.fi

Running Head: Straight vs. curved tendon model

Abstract

The present study investigated the effects of tendon curvature on measurements of tendon length using 3D-kinematic analysis. Curved and straight tendon models were employed for assessing medial gastrocnemius tendon length and strain during hopping (N=8). Tendon curvature was identified using small reflective markers placed on the skin surface along the length of the tendon and a sum of vectors between the markers from the calcaneous up to the marker at the origin of tendon was calculated. The straight tendon was defined as a length of vector from the calcaneous to the marker at the origin of tendon. The curved tendon method yielded 5.0 ± 1.3 mm longer tendon ($p<0.001$) than the straight tendon model. Tendon elongation was 2.1 ± 1.6 mm and peak strain 1.3 ± 0.7 % smaller in curved than in straight tendon model ($p<0.01$). The results suggest that the commonly used straight tendon model underestimate slightly but significantly the true tendon length but overestimate the strain and elongation.

Key words: ultrasonography, Achilles tendon, tendon length, tendon strain, hopping

Introduction

In nature, not many straight lines exist although we commonly use straight lines when analyzing distances between two points. For example, it is typically assumed that muscle fascicles (Maganaris et al. 1998, Kurokawa et al. 2003) and tendons (Kubo et al. 2000, Ishikawa et al. 2005) are straight. Measuring the shortest distance between two points from the ultrasound scan or video and observing fascicles and tendon as straight lines is the most common methodological approach used by the current researchers in the area of ultrasonography (Kubo et al. 2000, Kurokawa et al. 2001, Finni et al. 2001, Lichtwark & Wilson 2005, Ishikawa et al. 2007, Sousa et al. 2007). While this can make calculations easier (Finni 2006), a variety of errors may occur using this simplified approach (Muramatsu et al. 2002, Arampatzis et al. 2008). For instance, fascicle length can be underestimated by 6 % when it is considered as a straight line (Muramatsu et al. 2002). Another study investigated the effects of the curvature of Achilles tendon on the correctness of the measured displacement of the tendon on the ultrasound scan during isometric plantarflexion in an ergometer and found significantly smaller strain (by 0.3%) and elongation (by 1.1 mm) when curved tendon model was applied (Arampatzis et al. 2008). However, isometric conditions can differ from dynamic conditions where large joint rotations can occur (see supplementary material for visualization of *in vivo* tendon curvature during plantarflexions). Thus, the purpose of the present study was to examine if the straight and curved tendon models yield different results in dynamic conditions. We hypothesized that the strain and elongation will differ between the curved and straight tendon models during the contact phase of hopping.

Methods

Four males and four females (age: 25 ± 3 years, weight: 65 ± 13.3 kg, height: 173 ± 8 cm) volunteered for the study. They were informed about the study protocol and gave their written consent to participate in the study. The study protocol had been approved by the Ethics Committee of the University of Jyväskylä.

Prior to testing an ultrasound probe (UST-5712, Aloka, Tokyo, Japan) was attached to the leg over the muscle-tendon junction of the medial gastrocnemius. In this study the displacement of the muscle-tendon junction visualized with the ultrasonography is not reported and the difference between the curved and straight tendon models is entirely based on the differences obtained from the three-dimensional (3D) kinematic analysis. Thus, the confounding assumption of this study was that the length of the tendon visualized within the ultrasound probe is only a fraction of the tendon length and does not affect the study outcome.

Small reflective markers (11.5 mm diameter) were placed on the calf following the line of tendon from calcaneous to the muscle-tendon junction of the medial gastrocnemius which was localized in the middle of the ultrasound image (Fig. 1A). The first marker was placed on the calcaneous and the following markers were placed two centimetres apart of each other toward the edge of the ultrasound probe. The number of the markers depended on the length of the leg of each subject. In addition, two markers were placed on the ultrasound probe; a small marker was in series with the skin markers reflecting the origin of tendon. After a warm-up the subjects performed two trials of 10 s hopping on the force platform with preferred frequency. The subjects were instructed to perform hopping only ‘using the ankle joints’. Minimal knee joint flexion was allowed to assure safe landing. Two high speed cameras (Peak Performance, Inc. USA) recorded the performances from behind and from the right side of the subjects. The recordings from the two high speed cameras were stored into video tapes with sampling frequency of 200 Hz.

The vertical ground reaction forces from a force plate were recorded to identify the contact phases during hopping (A-D converter, CED 1401, Cambridge Electronics Design, UK) and stored into the computer using Signal 2.14 software (CED, UK) with a sampling frequency of 2 kHz. The kinetic and kinematic data were synchronized using a light signal visible to the cameras and a simultaneous square signal sent to the A-D converter.

The videos were digitized and synchronized using Vicon Motus Software (version 8). From the filtered (Butterworth filter, cut-off 8 Hz) 3D raw coordinates the tendon lengths were further analysed. The straight tendon was defined as length of a vector from the calcaneous to the small marker on the ultrasound probe. The curved tendon was defined as sum of the vectors between small markers along the line of tendon, beginning from the calcaneous up to the small marker in the ultrasound probe (Fig. 1A).

The apparent g~~G~~astrocnemius tendon strain was calculated as (L-Lo)/Lo*100%, where the initial length (Lo) was defined just before ground contact and the maximum length (L) defined as the maximum tendon elongation during the contact phase of hopping.

Statistics. The results are given as mean ± standard deviation. The differences in tendon length and strain between curved and straight models were calculated using dependent t-test after confirming normality of the data. A level of $p<0.05$ was considered significant.

Results

During the contact phase of hopping both the initial length (23.85 ± 3.67 cm vs. 23.24 ± 3.54 cm, $p<0.001$) and the maximum tendon length (27.16 ± 3.62 cm vs. 26.76 ± 3.58 cm, $p<0.001$) were significantly longer for the curved than straight tendon model (Fig. 1B). The mean difference in tendon length between the two models during the contact phase of hopping was 5.0 ± 1.3 mm. Tendon elongation during the contact phase was less in the curved than in the straight tendon (3.31 ± 0.18 cm vs. 3.52 ± 0.22 cm, the mean difference being 2.1 ± 1.6 mm, $p<0.01$). Also peak tendon strains were smaller in the curved as compared to the straight tendon model (14.2 ± 2.3 % vs. 15.4 ± 2.2 %, the mean difference being 1.3 ± 0.7 %, $p<0.01$).

Discussion

We found a small but significant effect of tendon curvature on tendon length, strain and elongation. The curved tendon model yielded a greater length as compared to the length modeled as a shortest distance between the tendon origin and insertion. However, the strain and elongation were smaller when curved tendon model was used. This result is in agreement with results obtained in isometric condition (Arampatzis et al. 2008) although the difference in strain and elongation was greater during the contact phase of hopping in the present study.

The 1.3 % lower strain in the curved tendon model compared to the straight tendon is much higher than 0.3 % reported by Arampatzis and colleagues (2008) during isometric contractions. They measured elongations in the curved tendon model (based on the reconstructed surface contour over a calf muscle) and the straight tendon method (based on displacement of a point near tendon origin) and found that curved model has significantly lower strain than the model with single point analysis. Keeping in mind that we did not measure the true tendon elongation but length changes between the ultrasound probe and calcaneous ~~Besides different methodological approach,~~ also the tendon force levels during isometric plantarflexions and during hopping can have differences, which would explain the different magnitude of strain.

Furthermore, the surface contour near the ankle joint can vary quite much with the changing ankle joint angle (Hodgson et al. 2006, see also supplementary material). Consequently, the greater joint angular movements during a stance phase of hopping may be another contributor for pronounced differences between the two tendon models in the present study as compared to that found in isometric condition (Arampatzis et al. 2008).

The values of strain in the present study were much greater than previously reported in range of activities (Lichtwark and Wilson (2005), Peltonen et al. (2010), Magnusson et al (2003)) and in isolated Achilles tendon (Wren et al. 2001). In one-leg hopping the Achilles tendon strain has been reported to be 8 % (Lichtwark & Wilson 2005) as compared to ~15 % in the present study. This large difference may be devoted to the methodological differences between the studies. First, our observation was based only on the 3D kinematic analysis which excluded recordings from the ultrasound during the stance phase of a hop. Second, there might be differences in forces during one leg hopping (Lichtwark & Wilson 2005) and two leg hopping (the present study).

While the strain values reported in the present study may not represent true tendon strain, the comparison of the strain values between straight and curved condition can be considered valid. In both conditions the same point of tendon insertion (marker in calcaneous) and origin (marker in US probe) was used. Only the part of the tendon that was visible within the ultrasound probe was not taken into account and the assumption was made that this length was only a fraction of the total tendon length and does not affect the study outcome.

Do then, the observed small differences have any practical relevance? It may be that the difference between these two tendon models is so small that it is lost in the uncertainty of the measurements where typically 3D kinematic analysis is combined with ultrasound methodology to determine tendon length (Lichtwark & Wilson 2005, Peltonen et al.

2010). However, even small differences may be important and 1% greater or smaller strain may well be relevant when injury mechanisms are investigated, for example.

In conclusion, the apparent tendon length and strain were found to be different between curved and straight tendon models. The straight tendon model underestimated the ~~actual~~ tendon length but overestimated the elongation and strain. Therefore, the curved tendon model is suggested to be used when accurate assessment of tendon length and strain is needed.

References

Arampatzis A, De Monte G, Karamanidis K (2008) Effect of joint rotation correction when measuring elongation of the gastrocnemius medialis tendon and aponeurosis. J Electromyogr Kinesiol 18:503 – 508

Finni T, Ikegawa S, Lepola V, Komi PV (2001) In vivo behaviour of vastus lateralis muscle during dynamic performances. Eur J Sport Sci 1 (1)

Finni T (2006) Structural and functional features of human muscle-tendon unit. Scand J Med Sci Sports 16:147-158

Hodgson JA, Finni T, Lai AM, Edgerton R, Sinha S (2006) Influence of structure on the tissue dynamics of the human soleus muscle observed in MRI studies during isometric contractions. J Morphol 267:584-601

Ishikawa M, Pakaslahti, J & Komi, PV (2007) Medial gastrocnemius muscle behaviour during human running and walking. Gait Posture 25:380-384

Kubo K, Kanehisa H, Kawakami Y, Fukunaga T (2000) Elasticity of tendon structures of the lower limbs in sprinters. Acta Physiol Scand 168:327-335

Kurokawa S, Fukunaga T & Fukashiro S (2001) Behavior of fascicles and tendinous structures of human gastrocnemius during vertical jumping. J Appl Physiol 90:1349-1358

Kurokawa S, Fukunaga T, Nagano A, Fukashiro S (2003) Interaction between fascicle and tendinous structures during counter movement jumping investigated in vivo. J Appl Physiol 95:2306-2314

Lichtwark GA & Wilson AM (2005) In vivo mechanical properties of the human Achilles tendon during one-legged hopping. J Exp Biol 208:4715-4725

Maganaris CN, Baltzopoulus V, Sargeant, AJ (1998) Changes in Achilles tendon moment arm from rest to maximum isometric plantarflexion: in vivo observation in man. J Physiol 510 (3):977-985

Magnusson SP, Hansen P, Aagaard P, Brond J, Dyhre-Poulsen P, Bojsen-Moller J, Kaer M (2003) Differential strain patterns of the human gastrocnemius aponeurosis and free tendon, in vivo. Acta Physiol Scand 177:185-195

Muramatsu T, Muraoka T, Kawakami Y, Shibayama A, Fukunaga T (2002) In vivo determination of fascicle curvature in contracting human skeletal muscle. J Appl Physiol 92:129-134

Peltonen J, Cronin NJ, Avela J, Finni T (2010) *In vivo* mechanical responses of human Achilles tendon to a single bout of hopping exercise. J Exp Biol 213:1259-1256

Sousa F, Ishikawa M, Vilas-Boas JP, Komi PV (2007) Intensity and muscle-specific fascicle behavior during human drop jumps. J Appl Physiol 102: 382-389

Wren TA, Yerby SA, Beaupre GS, Carter DR (2001) Mechanical properties of the human Achilles tendon. Clin Biomech 16:245-251

Figure captions

Fig1. A) Subject's leg with markers along the line of tendon. The straight tendon was a length of a vector from the most distal marker in the calcaneous to the small marker in the ultrasound probe. The curved tendon was the sum of the vector lengths between each marker from calcaneous to the small marker in the probe. B) Tendon lengths during the contact phase of hopping from each individual calculated using curved tendon model (dashed thin lines) and straight tendon model (solid thin lines). Mean curved and straight tendon lengths with standard deviations are given in thick lines