Journal of Biomechanics 42 (2009) 2549–2554

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Validity of architectural properties of the hamstring muscles: Correlation of ultrasound findings with cadaveric dissection

Eleftherios Kellis [a,*], Nikiforos Galanis [b], Konstantinos Natsis [c], George Kapetanos [b]

[a] Laboratory of Neuromuscular Control and Therapeutic Exercise, Department of Physical Education and Sport Sciences at Serres, Aristotle University of Thessaloniki, 62110 Serres, Greece
[b] Department of Orthopaedics, Papageorgiou Hospital, Medical School, Aristotle University of Thessaloniki, Thessaloniki, Greece
[c] Department of Anatomy, Medical School, Aristotle University of Thessaloniki, Thessaloniki, Greece

ARTICLE INFO

Article history:
Accepted 5 July 2009

Keywords:
Morphology
Muscle mechanics
Knee flexors
Biceps femoris
Semitendinosus

ABSTRACT

The purpose of this study was to compare the architectural parameters of the long head of biceps femoris (BFlh) and semitendinosus (ST) muscles by comparing measurements from ultrasound (US) with those obtained from direct dissection. The BFlh and ST architectures were examined bilaterally in 6 legs from 3 male cadavers. The fascicle length, pennation angle, muscle thickness and muscle and tendon length were obtained from direct measurement and US scans along each muscle. Intraclass correlation coefficients between the two methods ranged from 0.905 to 0.913 for the BFlh variables and from 0.774 to 0.974 for the ST parameters. Compared with the direct measurements, the US method showed a mean typical error of 0.09–0.14 cm for muscle thickness, 1.01–1.31° for the pennation angle, 0.92–1.71 cm for fascicle length and muscle–tendon length measurements. The US method is a valid alternative tool for assessing basic architectural parameters of ST and BFlh components of the hamstring muscles.

1. Introduction

The hamstring muscle group consists of three muscles i.e. the semimembranosus, the semitendinosus (ST) and the biceps femoris (BF). Information on the architectural properties of the hamstrings is scarce and is mainly based on data obtained from cadavers. (Wickiewicz et al., 1983; Friederich and Brand, 1990; Woodley and Mercer, 2005; Makihara et al., 2006). However, it is commonly accepted that the study of functional implications of muscle architecture in humans based on in vitro data demonstrates some important limitations as cadavers usually come from an older population and the architecture is determined with the muscle in a fixed position (Fukunaga et al., 1997; Narici, 1999).

The use of ultrasound (US) imaging has allowed the description of muscle architecture in-vivo (Maganaris and Baltzopoulos, 2000; Fukunaga et al., 2002). However, the validity of US has been mainly examined for the ankle joint, the triceps brachii and the knee extensor muscles. Particularly, measures of pennation angle (PA) (error $<1.5^{\circ}$; (Kawakami et al., 1993; Narici et al., 1996; Chleboun et al., 2001) and fascicle length (FL) (error ≤ 1.5 mm; (Kawakami et al., 1993) have been shown to be similar to those measured directly in cadavers or three-dimensional ultrasound (Kurihara et al., 2005). Muscle thickness (MT) has also been validated against magnetic resonance imaging scans in various human muscles (Juul-Kristensen et al., 2000; Dupont et al., 2001). To date, only one study (Chleboun et al., 2001) has examined the validity of hamstring architecture using US. Particularly, Chleboun et al. (2001) reported good agreement between in vitro and US architectural properties of the long head of the BF (BFlh). Their data, however, are limited to the BFlh muscle. Anatomical descriptions show that the hamstring muscles display a complicated anatomy and therefore investigation of other muscle components, such as the ST, is necessary (Woodley and Mercer, 2005).

Examination of the length of the hamstring muscle–tendon unit is essential to examine the effects of stretching (Halbertsma et al., 1999), to facilitate planning for surgical lengthening of the hamstrings in children with cerebral palsy (Delp et al., 1996) or to determine the precise site of strain injury (Koulouris and Connell, 2005, 2006). In-vivo examination of hamstring muscle length is mainly based on estimates from anthropometric measurements (van der Krogt et al., 2008) or kinematic data (Blackburn et al., 2009). It is known, however, that US has been used not only to examine muscle properties in-vivo but also for investigation of tendon behavior and muscle–tendon interaction, under resting and contraction conditions (Magnusson et al., 2008). To the best of our knowledge, such analysis in the hamstring muscles is missing. The aim of this study was to correlate the cadaveric and sonographic architectural properties of the BFlh and the ST.

* Corresponding author. Tel.: +30 2310 991053; fax: +30 23210 67135.
E-mail addresses: leftkell@yahoo.com, ekellis@phed-sr.auth.gr (E. Kellis).

0021-9290/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2009.07.011

2. Methods

2.1. Study design

Muscle architectural data from the long head of the BF and the ST were obtained from 6 legs of 3 human cadavers (males) with a mean age of 68.3 years (range 65.4–71.1 years) using dissection and US. The protocol was approved by the Aristotle University Ethics Committee.

2.2. Ultrasonographic assessment

Each cadaver was embalmed in the anatomical position with the hip and knee angles at 0° (full extension). An ultrasonic apparatus (SSD-3500, ALOKA, Japan) was used with an electronic linear array probe of 10 MHz wave frequency. The scanning head of the probe was coated with transmission gel to obtain acoustic coupling. To standardize the US probe positions, the origins of the ST and BF were initially determined (Fig. 1). Particularly, the common proximal BF and ST tendon at the lateral aspect of the medial portion of the ischial tuberosity was identified by taking axial and longitudinal scans. Once the ischial tuberosity was visualized, a visual echo marker was placed upon the skin. The distal origin of the ST was identified as the point where the ST inserts into the gracilis tendon and subsequently into the fascia cruris (Fig. 1). The distal origin of the BF was set from the inferior margin of the fibular head. The images obtained from the distal and proximal sites were used to determine the muscle and tendon length.

US video sequences were then taken as the probe moved slowly from the distal towards the proximal end of the muscle. This allowed visualization of the whole muscle for each specimen (Reeves et al., 2004; Blackburn et al., 2009). The distal myotendinous junction (MTJ) was then identified and its location was marked on the skin. Starting from the distal MTJ, US images were taken with the probe at approximately 10%, 30%, 50% and 70% of the curved path from the distal MTJ to the proximal origin. The angle of the probe relative to the mid-thigh line was monitored and it was standardized for all specimens (Klimstra et al., 2007).

The US images were digitized using a video-based software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Michigan, USA). From the US scans obtained from the middle-belly images, four different areas of the muscle were further analysed. For each image, six points were digitized (Fig. 2), as described by Blazevich et al. (2006). Two points were digitized in each aponeurosis while two additional points were digitized in order to define FL. Following digitization of the US images, MT thickness was estimated as the distance between the superficial and deep aponeurosis. The angle between the line marking the outlined fascicle and the deep (ST muscle) and intermediate aponeurosis (BF muscle) was then measured, giving the PA. When identification of the entire FL was not possible, it was estimated based on the PA, the MT and the angle between the two aponeurosis (Blazevich et al., 2006). The average value from all muscle sites was used for further analysis.

Muscle length was measured as the distance between the proximal and distal origins of each muscle. The tendon length was measured as the portion of the

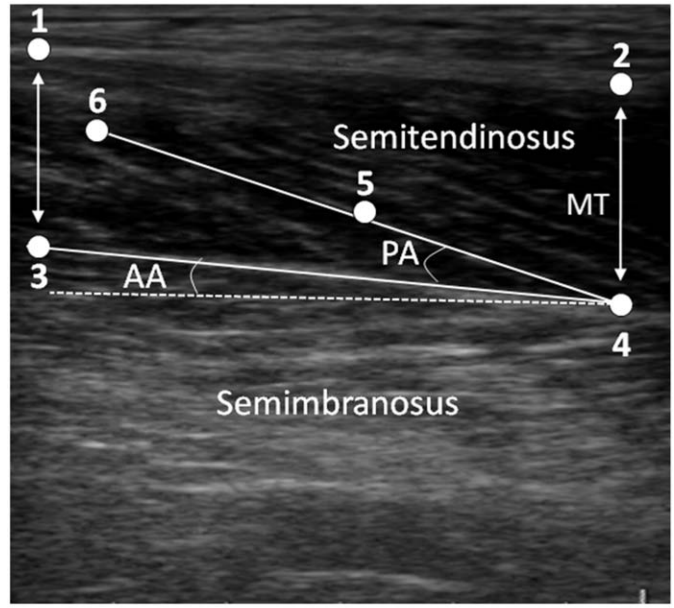

Fig. 2. Estimation of muscle thickness (MT), pennation angle (PA) and fascicle length (FL) from the mid-belly image of the semitendinosus. Points 1–4 corresponding to aponeuroses and fascicles (5–6) were digitized. The vertical distances between points 1–3 and 2–4 were calculated and averaged to obtain a representative score of MT. Two points (5–6) defined a selected fascicle. The PA was measured as the angle between points 2–4 and 5–6. The aponeurosis angle (AA) was calculated as the positive angle between points 3–4 and 1–2. When not visible, fascicle length (FL) was estimated using the following equation: $FL = \sin(AA+90^{\circ}) \cdot MT/\sin(180^{\circ}-(AA+180^{\circ}-PA))$.

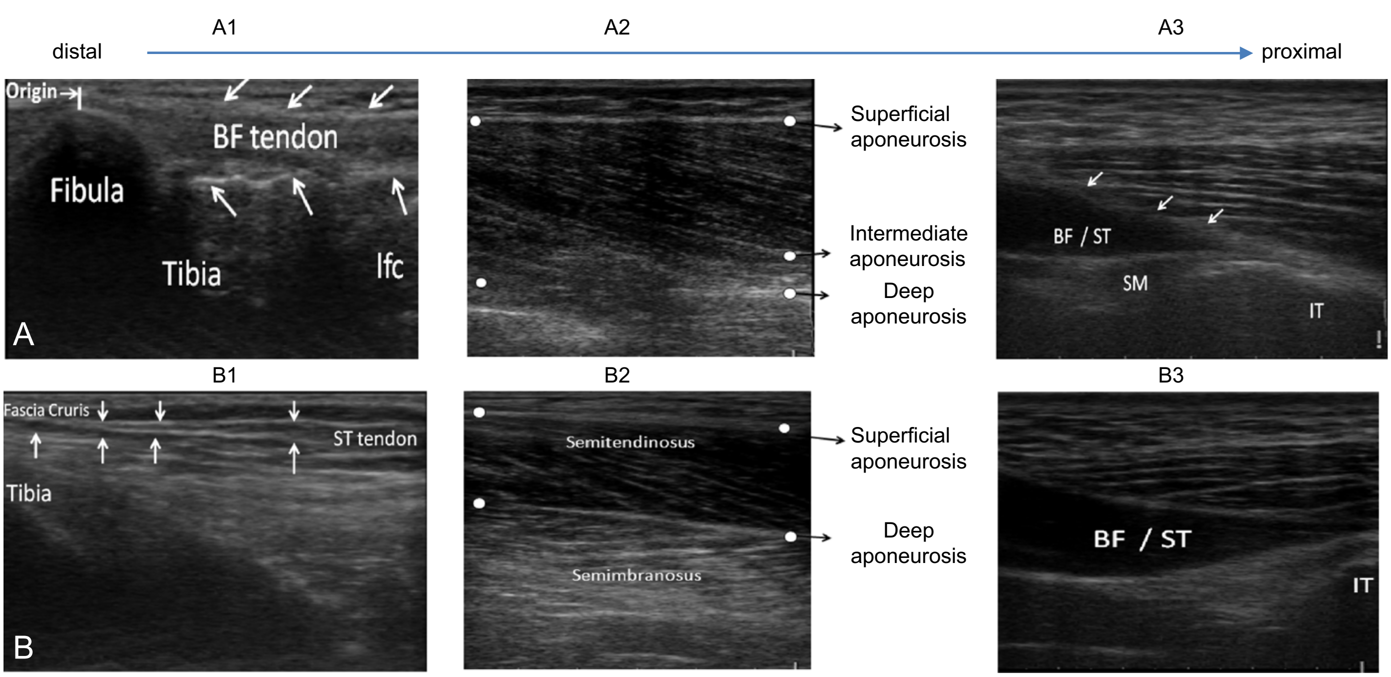

Fig. 1. Example US images obtained from (A) the long head of the biceps femoris (BF) and (B) semitendinosus (ST) muscles (IT = ischial tuberosity; SM: semitendinosus). (A1) The distal origin of the BF muscle. The margin of the fibular head was considered as the origin. Arrows indicate the borders of the BF tendon. (A2) US image from the mid-belly of the long head of the BF. (A3) The proximal end of the BF muscle. The muscle displays a common tendon with the ST and inserts into the ischial tuberosity. (B1) The distal origin of the ST muscle. The borders of the ST tendon are identified as it gradually inserts on the gracilis tendon and to the fascia cruris. (B2) US image from the mid-belly of the ST. (B3) The proximal end of the ST muscle. The common tendon with the BF is visible as it inserts into the ischial tuberosity.