ARTICLE IN PRESS

Journal of Biomechanics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

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

Site specificity of mechanical and structural properties of human fascia lata and their gender differences: A cadaveric study

Shun Otsuka [a,b], Tomiko Yakura [b], Yusuke Ohmichi [b], Mika Ohmichi [b], Munekazu Naito [b], Takashi Nakano [b], Yasuo Kawakami [b,c,*]

[a] Graduate School of Sport Sciences, Waseda University, Saitama, Japan
[b] Department of Anatomy, Aichi Medical University, Aichi, Japan
[c] Faculty of Sport Sciences, Waseda University, Saitama, Japan

ARTICLE INFO

Article history:
Accepted 19 June 2018
Available online xxxx

Keywords:
Human fascia lata
Mechanical property
Structural property
Site-specificity
Gender-dependence
Anisotropic characteristics

ABSTRACT

The whole thigh muscles are covered with the fascia lata, which could have morphological and mechanical features that match the underlying muscles' functions. In this study, we investigated the morphological and elastic properties of the human fascia lata taken from four (anterior, medial, lateral, and posterior) sites on the thigh of 17 legs of 12 cadavers (6 males and 6 females, 75–92 years). The thickness of the fascia lata was determined with a caliper. The interwoven collagen fiber's directions were measured and classified into longitudinal, transverse, and diagonal in two opposing directions, relative to the thigh. Tensile strength test along the longitudinal and transverse directions was performed, and the stiffness, Young's modulus, and hysteresis were determined. Fascia lata at the lateral site (0.8 ± 0.2 mm) was significantly thicker compared to other sites (0.2–0.3 mm). Fiber's directions showed substantial variability among sites, and longitudinally directed fibers were higher in proportion (28–32%) than those in other directions (20–27%) at all sites except for the posterior site. The stiffness and Young's modulus in the longitudinal direction (20–283 N/mm; 71.6–275.9 MPa, highest at the lateral site) were significantly higher than in the transverse direction (3–16 N/mm; 3.2–41.9 MPa, lowest at the lateral site). At the medial site, the proportion of the transversely directed fibers was higher in females than males, with higher stiffness and Young's modulus thereof. The present study shows that the fascia lata possesses site- and gender-dependence of the morphological characteristics and elastic properties.

1. Introduction

The deep fascia, wrapping the skeletal muscles, is composed of interwoven collagen fibers (Stecco et al., 2011). The skeletal muscles have various shapes, architecture, and contractile properties, thus their mechanical load imposed on the deep fascia can vary depending on the features of underlying muscles. It has been shown that fascia can transmit forces generated by the contraction of skeletal muscles referred to as epimuscular myofascial force transmission (Huijing, 2009; Wilke et al., 2018). Such force transmission was reported to occur in some regions of the human body (e.g., lower limb, thoracolumbar, upper limb, etc.) including the deep fascia (Huijing et al., 2011; Carvalhais et al., 2013; Marinho et al., 2017; Yoshitake et al., 2018), and fascial fibers were shown to run along the loading directions (Schleip et al., 2012). Epimuscular myofascial force transmission could cause differences in the characteristics of the fascial tissues at different sites within the fascial structure. Indeed, the thickness and fiber directions of the deep fascia taken from a pectoral region were different from that of a femoral region (Stecco et al., 2009). Mechanical properties of the soft tissue material also vary, and Henderson et al. (2015) reported that the thoracolumbar fascia and fascia lata of the canine show anisotropic stiffness in the longitudinal and transverse directions. There is only one study focusing on the elastic properties of the human deep fascia, which demonstrated that the stiffness of the dissected human crural fascia differed between the loading directions (Stecco et al., 2014).

The force generated by the contraction of the skeletal muscles is partly transferred to the deep fascia through the extracellular matrix and/or by the directed connection at the origin or insertion of muscle fibers onto the deep fascia (Marshall, 2001; Stecco et al., 2008). Large muscles such as the quadriceps femoris, hamstrings, and adductors comprise the thigh segment, and the architectural properties including the pennation angles, fascicle lengths, and

* Corresponding author at: Faculty of Sport Science, Waseda University, 2-579-15 Mikazima, Tokorozawa, Saitama 359-1192, Japan.
E-mail address: ykawa@waseda.jp (Y. Kawakami).

https://doi.org/10.1016/j.jbiomech.2018.06.018
0021-9290/© 2018 The Authors. Published by Elsevier Ltd.

volumes of these muscles are different from each other (Ema et al., 2015; Cutts and Seedhom, 1993). The thigh is also characterized by site- and gender-specific differences of the mass of the skeletal muscles and adipose tissue (Kanehisa et al., 2006; Maruyama et al., 1991). It is therefore presumed that the morphological and mechanical properties of the fascia lata vary depending on the site and gender by such diverse characteristics of underlying muscles. However, there have been few studies on the morphological and mechanical properties of the human fascia lata. The hypothesis of this study was that the morphological properties of the human fascia lata show site- and gender-specificity, which is associated with the mechanical properties.

2. Materials and methods

2.1. Specimens preparation

We analyzed the fascia lata at the different sites taken from formalin-fixed human cadavers (17 legs: 9 legs from 6 males and 8 legs from 6 females, 75–92 years). This study's experimental design was approved by the local ethics committee at Aichi Medical University. Specimens of the fascia lata were collected from four sites (anterior, lateral, medial, and posterior) of the 50% of the thigh length (Fig. 1). The anterior site was determined so that its mediolateral midpoint corresponded to the center of rectus femoris, and other sites were determined accordingly. The lateral, medial, and posterior sites included portions covering vastus lateralis, gracilis, and semitendinosus respectively. In some samples, the sartorius was partly included in the medial site, so was biceps femoris long head for the posterior site, depending on the muscle sizes of the cadavers. The amount of co-existence of such different muscles was not consistent among samples, but due to the infiltration of adipose tissues between the fascia lata and underlying muscles, quantification of such variations was not possible in the present study. Each specimen was 40 × 40 mm in the longitudinal (proximal–distal) × transverse (anterior-posterior or lateral-medial) directions. The direction from the greater trochanter to the popliteal fossa was defined as the longitudinal direction and the orthogonal direction to it was defined as the transverse direction. Adipose and connective tissues were manually removed from the specimens using tweezers. After collection, the specimens were stored in a 50% alcoholic solution at room temperature. The specimens were kept moist throughout the testing (described below) by pipetting them with alcohol. After collection of the specimens, morphological tests were conducted, followed by the mechanical tests.

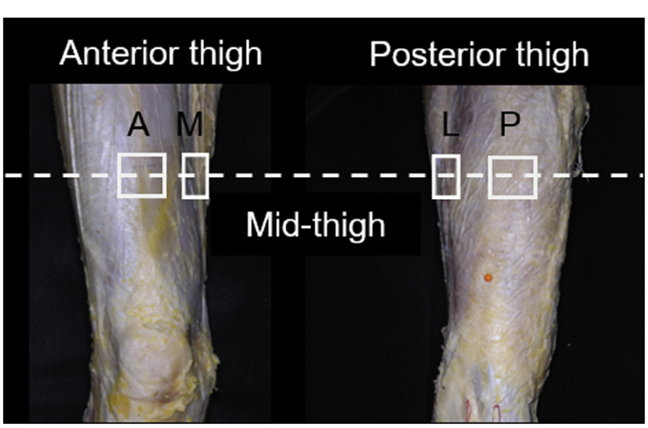

Fig. 1. Pictures showing the anterior and posterior aspects of the thigh of a cadaver with the collected sites of the specimens of the fascia lata. (A: anterior, M: medial, L: lateral, P: posterior).

2.2. Morphological tests

2.2.1. Thickness

The thickness of the fascia lata was measured with a digital caliper (LIXIL VIVA, Japan). Briefly, five different points (upper, lower, right, left, and center parts) of the sample were randomly selected at each point, and the average value was calculated as the representative of the thickness of that sample. To avoid the deformation of the tissue due to an applied pressure by the caliper, we used the flat part of the caliper and paid great attention to provide pressure to the sample as small as possible.

2.2.2. Distribution of fiber direction

An image of each specimen's surface was taken by a digital camera (ILEX-QX1, SONY, Japan) adapted to a stereomicroscope (nobita, Micronet, Japan) while radiating light from the back side using a lamp. The image was digitally binarized and the power spectrum was obtained by a fast Fourier transformation (FiberOri8 single03, v.7.10, Japan, Fig. 2). The distribution of fiber direction was determined using the same program (Enomae, 2005). The fiber direction angle was classified into longitudinal, transverse, and two opposite diagonal directions (Fig. 3). Then, the proportion of the fibers in each direction was calculated.

2.3. Mechanical tests

2.3.1. Tensile test

To verify the site specificity and anisotropy of the mechanical properties of the fascia lata, a tensile strength test was performed. Specimens of the fascia lata from each region were tested in the longitudinal and transverse directions. Two pieces of sandpapers were adhered to the specimen with tissue glue, which ensured that fascial layers did not slide over each other or out of the clamp when the tissue was loaded (Henderson et al., 2015). A loading–unloading test was carried out with a displacement-force measurement unit (ZTA-500N; EMX-1000N, Imada, Japan). The ends of each specimen were fixed to the clamp of 5 mm. The loading–unloading cycle was repeated 3 times at a speed of 25 mm/min (Henderson et al., 2015). The loading distance was 1.5–6.0 mm depending on

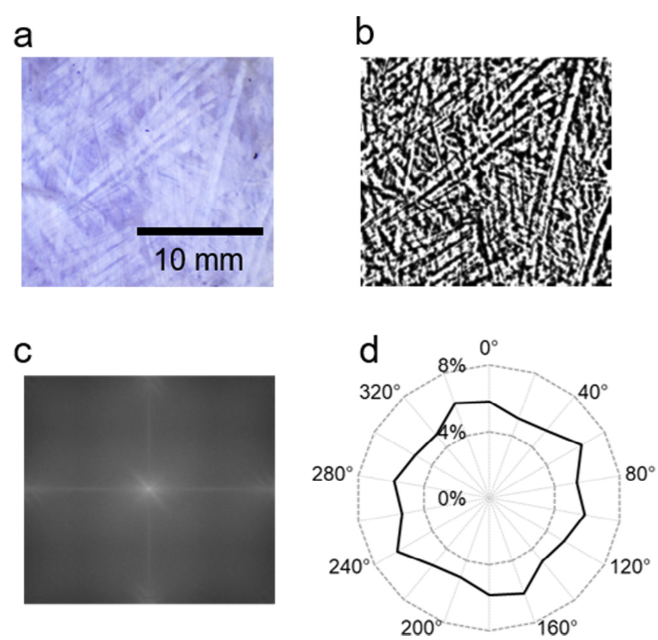

Fig. 2. (a) Original and (b) binarized image of the fascial specimen. The results of (c) fast Fourier transformation and (d) distribution of fibers' directions are also shown.