Journal of Biomechanics 44 (2011) 1801–1804

Contents lists available at ScienceDirect

Journal of Biomechanics

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

Short communication

An instrumented tissue tester for measuring soft tissue property under the metatarsal heads in relation to metatarsophalangeal joint angle

Wen-Ming Chen [a], Victor Phyau-Wui Shim [b], Seung-Bum Park [c], Taeyong Lee [a,*]

[a] Division of Bioengineering, National University of Singapore, Block E3A #07-15, 7 Engineering Drive 1, Singapore 117574, Singapore
[b] Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, Singapore
[c] Footwear Biomechanics Team, Footwear Industrial Promotion Center, South Korea

ARTICLE INFO

Article history:
Accepted 28 March 2011

Keywords:
Foot
Metatarsal head
Soft-tissue pad
Localized mechanical response
Metatarsophalangeal joint

ABSTRACT

Identification of the localized mechanical response of the plantar soft tissue pads underneath the metatarsal heads (i.e., sub-MTH pad) to external loading is key to understand and predict how it functions in a gait cycle. The mechanical response depends on various parameters, such as the external load (direction and rate), the sub-MTH tissue properties (anisotropy and viscoelasticity), and the configuration of the metatarsophalangeal (MTP) joint overlying the tissue. In this study, an instrument-driven tissue tester that incorporates a portable motorized indentor within a special foot positioning apparatus was developed for realistic *in vivo* mechanical characterization (i.e. tissue stiffness and force relaxation behavior) of the local sub-MTH pad with the MTP joint configured at various dorsiflexion angles associated with gait. The tester yields consistent results for tests on the 2nd sub-MTH pad. Measurement errors for the initial stiffness (for indentation depths ≤ 1 mm), end-point stiffness, and percentage force relaxation were less than 0.084 N/mm, 0.133 N/mm, and 0.127%, respectively, across all test configurations. The end-point tissue stiffness, which increased by 104.2% due to a 50° MTP joint dorsiflexion, also agreed with a previous investigation. *In vivo* tissue's force relaxation was shown to be pronounced (avg. = 8.1%), even for a short holding-time interval. The proposed technique to facilitate study of the dependence of the local sub-MTH pad and tissue response on the MTP joint angle might be preferable to methods that focus solely on measurement of tissue property because under physiologic conditions the sub-MTH pad elasticity may vary in gait, to adapt to drastically changing mechanical demands in the sub-MTH region of the terminal stance-phase, where MTP joint dorsiflexion occurs.

1. Introduction

The plantar soft tissue in the pads underneath the metatarsal heads (MTHs) is an optimal load-bearing structure (Bojsen-Moller and Flagstad, 1976), particularly for cushioning the highest sub-MTH ground reaction forces (GRF) exerted in the terminal stance-phase of gait (Cavanagh, 1999). Identification of the mechanical response of the sub-MTH pad to external loading is essential for clinicians or users who wish to distinguish between normal and pathological tissue functions. Both *in vivo* and *in vitro* studies have observed stiffening (Gefen et al., 2001; Klaesner et al., 2002; Pai and Ledoux, 2010), hardening (Piaggesi et al., 1999), or diminished energy dissipation (Hsu et al., 2007; Hsu et al., 2000) of the sub-MTH pad in neuropathic diabetic foot. Many believe that such altered tissue properties that accompany diabetes may severely compromise its cushioning capacity with the consequence of elevated peak plantar pressure at the sub-MTH region, where ulcers are most common (Boulton et al., 1983).

Indentation tests offer a convenient way for direct *in vivo* investigation of the mechanical responses of the soft tissue, and commonly involve applying a known deformation (i.e., indentation) directly to the living subject's tissue, e.g. the amputee residual tissue covering long bones (Silver-Thorn, 1999; Vannah et al., 1999) and the heel pad (Rome and Webb, 2000), where the naturally immobile skeleton acts as a rigid foundation. However, the intrinsically small MTH has great mobility in the plantar–dorsal direction, which often limits the maximum indenting force to be directly applied at a desired loading rate using general-purpose indentors. Previously, for sub-MTH pad indentation, large tissue deformation similar to that during actual gait was not always achieved (Zheng et al., 2000; Kwan et al., 2010). Moreover, poor instrument alignment is inherent to hand-held devices (Kawchuk and Herzog, 1996; Zheng and Mak, 1999) and limited measurement reliability in trial-and-error procedures (Klaesner et al., 2001; Wang et al., 1999) often makes interpretation of data even difficult.

* Corresponding author. Tel.: +65 6516 1471; fax: +65 6872 3069.
E-mail address: bielt@nus.edu.sg (T. Lee).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.03.031