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● *Original Contribution*

HEEL PAD STIFFNESS IN PLANTAR HEEL PAIN BY SHEAR WAVE ELASTOGRAPHY

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Abstract—The goal of the study was to evaluate the reliability of supersonic shear wave elastography in measuring heel pad stiffness and the change in heel pad stiffness in patients with plantar heel pain. In the reliability test involving 12 normal participants, each heel pad was tested six times in succession, and adequate reliability was reflected in the intraclass correlation coefficients (0.95, 0.93 and 0.96 for the microchambers, macrochambers and bulk heel pad, respectively). In the clinical assessment involving 20 normal participants and 16 unilateral plantar heel pain patients, diseased heel pads (86.8 ± 22.9, 36.8 ± 7.7 and 46.6 ± 10.9 kPa for the microchambers, macrochambers and bulk heel pad, respectively) were significantly stiffer than unaffected heel pads (66.8 ± 14.1, 25.2 ± 5.7, 34.2 ± 6.6 kPa) and those of normal participants (60.9 ± 11.4, 26.3 ± 6.1, 31.8 ± 6.3 kPa), suggesting that the heel pad with plantar heel pain was associated with loss of elasticity. (E-mail: chungli@ntu.edu.tw) © **2015 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Shear wave elastography, Stiffness, Plantar heel pain, Heel pad, Microchamber, Macrochamber.**

INTRODUCTION

Plantar heel pain, one of the most common musculoskeletal disorders of the lower extremities, is characterized by pain in the plantar heel region during prolonged periods of weight-bearing activity such as standing and walking (Cotchett et al. 2015; McPoil et al. 2008). It affects about 10% of people during their lifetime (Riddle et al. 2003) and is prevalent in both athletic and non-athletic populations (Rome 1997, 2005). The symptoms markedly limit activities of daily life and sports, and have a detrimental impact on quality of life (Cotchett et al. 2015; McPoil et al. 2008). Hence, plantar heel pain is a major health problem and should be further studied to ensure better diagnosis and management.

Plantar heel pain has been attributed to numerous causes, but the most common cause is a mechanical etiology (Tu and Bytomski 2011). The heel pad, a fibro-adipose structure located beneath the calcaneus bone that is responsible for cushioning and protecting the musculoskeletal system during locomotion (Bennett and Ker 1990; Rodgers 1995), is thought to be related to plantar heel pain (Rome 1998; Rome et al. 2001; Tsai et al. 1999). Histologically, the heel pad comprises dense strands of fibrous chambers enclosing closely packed fat cells, and is divided into a superficial thin microchamber layer containing small fat chambers and a deep thick macrochamber layer containing big fat chambers (Blechschmidt 1982; Jahss et al. 1992). Overuse, cumulative microtrauma or acute traumatic injury may damage the architecture of the heel pad, decrease its ability to cushion and protect and, consequently, cause the foot to be more vulnerable to mechanically related complications such as heel pad syndrome, plantar fasciitis and calcaneal stress fracture (Liddle et al. 2000; Perry 1983; Rome 1998; Rome et al. 2002). It was believed that change in the architecture and mechanical properties of the heel pad is one of the basic causes of plantar heel pain (Prichasuk 1994; Tsai et al. 1999).

It has been suggested that stiffness (or elastic modulus), one kind of soft tissue mechanical property, is crucial to the function and health status of the heel pad (Ker et al. 1989; Rome et al. 2001; Tong et al. 2003). Several studies have been reported on the

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measurement of the stiffness of the heel pad *in vivo* using various techniques, including radiologic measurements (Gefen et al. 2001; Kanatli et al. 2001; Kao et al. 1999; Ozdemir et al. 2004; Turgut et al. 1999; Uzel et al. 2006; Wearing et al. 2009), indentation systems (Challis et al. 2008; Kwan et al. 2010; Rome et al. 2001; Zheng et al. 2000) and ultrasound-based mechanical devices (Hsu et al. 1998; Hsu et al. 2007; Hsu et al. 2009; Tong et al. 2003; Tsai et al. 1999; Wang et al. 1999). In these studies, a significant amount of force was required to externally compress the heel pad to induce a significant deformation for measuring heel pad stiffness. Because of the highly non-linear force-deformation behavior of the heel pad, the measured stiffness value is dependent on the magnitude of applied force and loading rate (Hsu et al. 2012; Miller-Young et al. 2002; Spears et al. 2005). Consequently, different studies with different instruments and loading conditions may yield inconsistent results, making it difficult to compare results across different studies and to draw a consistent conclusion (Hsu et al. 2012; Miller-Young et al. 2002; Spears et al. 2005). Hence, a consistent method is needed for investigating heel pad stiffness and its association with pathologies.

Supersonic shear wave elastography (SWE) is a new technology that non-invasively and quantitatively measures soft tissue stiffness *in vivo* using ultrasonic waves (Bercoff 2008; Bercoff et al. 2004). It emits focused ultrasound beams to generate acoustic radiation forces to perturb the soft tissue of interest. These perturbations induce shear waves that propagate transversely within the soft tissue. The shear wave propagation speed is then captured by the ultrasound transducer at an ultrafast frame rate. Soft tissue stiffness E can then be appropriately estimated with the equation $E = 3\rho c^2$, where c is the shear wave propagation speed and ρ is the density of the soft tissue (Bercoff 2008; Bercoff et al. 2004). SWE can measure soft tissue stiffness without significantly stretching or compressing the soft tissue, and has the potential to be a consistent method for studying the stiffness of soft tissue. For a better understanding of the concept and principle underlying SWE, a white paper by Bercoff (2008) is recommended for further reading. SWE has been used to assess the stiffness of various musculoskeletal soft tissues, such as muscles and tendons (Arda et al. 2011; Lacourpaille et al. 2012; Peltz et al. 2013). To our best knowledge, no study has been conducted to assess heel pad stiffness using this technology. Before SWE can be recommended as a clinical tool for assessment of the pathogenesis of heel pad disorders, its reliability and effectiveness should be investigated.

The purposes of the present study were: (i) to investigate the reliability of SWE in measuring the stiffness of the heel pad and its microchamber and macrochamber layers (reliability test); and (ii) to compare heel pads with plantar heel pain and normal heel pads with respect to the stiffness of the heel pad and its microchamber and macrochamber layers, to understand how changes in heel pad stiffness are related to plantar heel pain (clinical assessment).

METHODS

Participants

Research ethics approval of the present study was received from the National Taiwan University Hospital institutional review board. Each participant was informed of the testing procedures before signing the informed consent.

In the reliability test, 12 normal participants (5 men and 7 women aged = 31.9 ± 5.2 y; body mass index [BMI] = 22.5 ± 3.2 kg/m^2) were recruited. To be included, normal participants had to have been free of plantar heel pain for the 6 mo prior to the study. The exclusion criteria were systematic disease, neural disease, recent trauma to the foot and history of surgery of the foot. Both heel pads of each participant were tested, and each heel pad was tested in six successive trials to evaluate the reliability of the technique.

In the clinical assessment, two groups of participants were recruited. The normal group consisted of 20 normal participants (10 men and 10 women aged = 25.5 ± 3.1 y; BMI = 23.6 ± 5.7 kg/m^2) without plantar heel pain within the 6 mo prior to the study. The patient group comprised 16 patients (7 men and 9 women aged = 51.8 ± 16.3 y; BMI = 24.6 ± 2.7 kg/m^2) with unilateral plantar heel pain for more than 1 y recruited from the outpatient clinic of the National Taiwan University Hospital Yun-Lin Branch. Plantar heel pain was defined as pain around the posterior plantar heel and swollen plantar fascia (>4 mm) origin at the calcaneal tuberosity revealed by B-mode ultrasonography. The exclusion criteria for both groups were systematic disease, neural disease, recent trauma to the foot and history of surgery of the foot. In both groups, both heel pads of each participant were tested, and each heel pad was tested in two successive trials. The average of the two trials was taken as the value for statistical analysis for the clinical assessment. The data for both groups in the clinical assessment were also used to further confirm the repeatability of the measurement by evaluating how close the two trials were to each other.

System

The Aixplorer ultrasound system (SuperSonic Imagine, Aix-en-Provence, France) equipped with a linear array transducer (SuperLinear SL15-4 with 4- to

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