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Ultrasound and Quantitative Information of the Plantar Fascia

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Abstract

It is believed, quantitative information can make achievable to diagnose / to detect the problem (Gefen, 2003). This knowledge can be useful to study the specific mechanical properties of the plantar fascia for better understanding of its function (Wearing et al., 2006). It is believed, ultrasound (U/S) is easy and free radiation to evaluate the thickness of the plantar fascia (Akfirat et al., 2003).

The objective is to study quantitative information of the plantar fascia, in living individual, through U/S.

Method

To identify types of studies of the plantar fascia

To study U/S images of the plantar fascia thickness

To establish arguable points according to review the literatures

The out come of this review can be resulted in evaluating the real thickness of the plantar fascia, in non weight bearing position, as close as possible, in living individual.

Keywords: Ultrasound, Plantar fascia thickness, Evaluating

Introduction

Mechanical load can affect exteracellular matrix of the plantar fascia. Per the amount of the load, plantar fascia can be injured, also (Hammer et al., 2008).The mid substance of the plantar fascia contains fibroblast cells within wavy collagen fibers (extra cellular matrix) (Porta et al., 2005, Wearing et al., 2006). Plantar fascia elongates under loading (Bartold, 2004). Fibroblast cells reshape (Grinnell, 2008) and wavy collagen fibers are straightened under loading. (Aquino, 1999) They back again during unloading (Langevin et al., 2009).

Mechanical loading can affect fibroblast cells and plantar fascia behavior. As for the quantity of the applied load, the composition of the structure of the plantar fascia may be affected or may be injured (Hammer, 2008). There is a convergence of the plantar fascia splits to the medial side. Plantar fascia thickness is different along its length. It is composed of irregular compacted collagen fibers (La Porta & La Fata, 2005; Langevin et al., 2009). With regard to the changing of the thickness along the length of the plantar fascia, it can be either the address of each location of the plantar fascia or a biomechanical variable to understand the concentration of the amount of the identified load applied on the plantar fascia (Wearing et al., 2006, Garcia et al., 2008). Plantar fascia supports the medial longitudinal arch (MLA) of the foot (Caravaggi et al., 2010). It is assumed MLA is shock absorber (Golano et al., 2010).

Under loading, thickness of the plantar fascia and the quantity of metatarsophalangeal joint (MPJ) extension may be effective on the amount of displacing of the height of the MLA (Rao et al., 2011). In spite of using similar methods to evaluate thickness of the plantar fascia with U/S machine, results were not close or had been suggested with a wide range of difference (Li et al., 2003, Sandercock & Maas, 2008).

That's why it has been decided plantar fascia thickness is evaluated more precise through U/S image scanning.

Types of studies of the plantar fascia

Cadaveric studies of the plantar fascia

Most of cadaveric studies have focused on the biomechanical consequences of complete plantar fascia release and limited studies have quantified the effect of partial release of plantar fascia (Cheung et al., 2004). In cadaveric studies, progressive load results in increasing the tension of fascia and fasciotomy results in decreasing the stiffness of arch (Wearing et al., 2006). Cadaveric foot.

In cadaveric foot, plantar fascia is not detached from other tissues but the effect of the other tissues (Wearing et al., 2006) on the amount of plantar fascia modification under loading may not be possible. Weight of the body is calculated depending on the length of the foot, age and sex (Erdemir et al., 2004) but it is applied just in one foot, both in static and dynamic situations. The author believes that plantar fascia is torn under loading of three times of the body weight but there are different body weights with same age, sex and foot length. The quantity of the vertical force to modify the plantar fascia (without tearing and plasticity) is equal to the body weight, but living person can carry different things without tearing of the plantar fascia.

Table 1: Medial longitudinal arch displacement in cadaveric foot after fasciotomy

Study	Subjects	Method	Under Load	vertical displacement
Huang et al. (1993)	12 cadaveric feet	After fasciotomy	690 N	8.4 mm from Talar neck to Platform
Murphy et al. (1998)	6 cadaveric feet	After fasciotomy	682 N	29% increasing of vertical displacement
Kitaoka et al. (1997)	12 cadaveric feet	After fasciotomy	445 N	1.1 mm from dorsal navicular to the line between calcaneal tubercle and first metatarsal head

Although in most of cadaveric studies, biomechanical consequences arise after complete plantar fascia release, (Table 1) but in cadaveric foot ligaments may be stretched more or less than the same living ligament stretched in living individual and muscles are not active.

Cadaveric Specimen

The tension of plantar fascia because of the dorsiflexion of toes causes the foot acts like a truss during gait cycle (Aquino et al., 1999). If tension within the Achilles tendon is used to reproduce heel position in terminal stance, it results in continuous lowering of MLA in cadaveric specimens. The modulus of elasticity within the specimens of plantar fascia is from 342 to822 megapascal (MPa) (Wearing et al., 2006). The application of stress is effective on the shape of the specimens of the plantar fascia so that collagen and elastic fibers are changed from wavy to straight arrangement. The modulus of elasticity of the plantar fascia is up to the failure point increasing the load and tends to resisting deformation or becoming stiffer of the plantar fascia specimen (Wright et al., 1964).

Cadaveric Model

There is a positive correlation between plantar fascia tension and Achilles tendon force during simulation of stance phase with cadaveric model (Cheung et al., 2006). If the plantar fascia is cut, there will be 25% loss of arch stiffness in cadaver model which is the greatest reduction when it is compared with the spring and long and short plantar ligaments. It results in increasing the strain of metatarsal and digital clawing when flexor digitorum longus (FDL) muscle is loaded. In cadaveric model arch collapse is more in unstable feet, also (Wearing et al., 2006).

Dynamic Cadaveric Model

The function of plantar fascia can be studied with dynamic cadaveric model, also. A fiber optic cable is put within the plantar fascia. It is compressed with the tension of fascia, so the intensity of transmitted light is decreased. At 80% of the stance phase, fascial load is closed to bodyweight which is equal to 45% of the strength of the tensile of plantar fascia (Wearing et al. 2006, Erdemir et al., 2004).

Computational Model

The biomechanical role of the plantar fascia in load bearing is quantified with computational models (Cheung et al, 2004). The effect of plantar fascia, after partial or full releasing, on arch support, energy storage, and stress distribution can be studied by computer models, also (Erdemir et al., 2004). In computational model, the foot is modeled as a passive mechanism as the quantity of the force applied by muscles is not available, (Gefen, 2003) but in passive mechanism antagonist muscles are effective. In modeling the location of the load exertion is unchanged, (Cheung et al., 2004) but it may be shifted in living individual. In modeling the effect of the Achilles tendon on plantar fascia is studied but gastrocnemius is two joint muscles. In addition, data is collected through magnetic resonance imaging (MRI) scanning from neutral position of ankle joint, (Cheung et al, 2006) but in long sitting position foot tends to plantar flexion. Collagen fibers of the plantar fascia are changed from wavy to straight arrangement after loading (Wright et al., 1964). The structure of the plantar fascia may be changed under loading (Hammer 2008) but there are different types of collagen (LeMoon, 2008).

2D Finite Element (FE) Model

After removing of plantar fascia, metatarsal stress and ligaments tension are increased and the height of the arch is decreased. Depending on this model the tension of the long plantar ligament is up to 200% after releasing of plantar fascia (Cheung et al., 2004). Relying on a simple 2D model, plantar fascia is more effective to maintain the arch of the flat or low-arched foot. Plantar fascia bears 15% of the exerted load on the normal arched foot (Wearing et al., 2006).

3D Finite Eelement (FE) Model of the Ankle-Foot Complex

This model is designed to study the effects of the plantar fascia stiffness on load bearing qualities of the plantar foot and internal bony structures. FE model predicts the internal stress within the bony and soft tissue structures which tends to increase the knowledge of ankle-foot biomechanics. According to this model, plantar fascia can bear 45% of the applied load and after fasciotomy, dropping of navicular will be 4.7mm (Cheung et al., 2004). The biomechanical effects of Achilles tendon tension on plantar fascia in standing foot are investigated with this model, also. Achilles tendon load has two-times effect on the strain of plantar fascia than the body weight on the foot, so lengthening of Achilles tendon results in decreasing of plantar fascia stress (Cheung et al., 2006). With a computational FE model of the foot in standing posture, the maximum lengthening of normal and healthy foot (with intact plantar fascia) relates to the first ray when the head of first metatarsal is displaced anteriorly about 0.13mm and the minimum elongation relates to the fifth ray which is 0.08 mm while after releasing of plantar fascia, deformation of the arch is more than 10 times to the arch with intact plantar fascia (Gefen, 2002). Relying on FE model, the reduction of plantar fascia stiffness more than 50%, results in increasing of load distribution (Cheung et al., 2004).

Vivo Studies

In vivo studies with the method of digital radiographic fluoroscopy (imaging system to measure the length of plantar fascia from tubercle of the calcaneus to the convexity of the head of the first metatarsal), plantar fascia elongates faster in mid stance in compare with heel off to toe off (Geffen, 2003) but in dynamic MRI, plantar fascia is not stretched up to heel off or toe dorsiflexion (Wearing et al., 2006). In both studies, the elongation of the plantar fascia is the result of the applied load on the foot or on the bony segments attached to the plantar fascia. In vivo studies through dynamic MRI, plantar fascia is relaxed (not stretched) up to heel off or toe dorsiflexion, and with hallux dorsiflexion, there will be either an immediate or delayed arch raising in asymptomatic weight bearing feet. About 20˚ of hallux dorsiflexion is required before increasing of height in delayed group (Wearing et al., 2006).

Vitro Studies of the Plantar Fascia

In vitro studies the strain of plantar fascia is up to 7% in standing posture when Achilles tendon is loaded and MP joint is extended. Both in vitro and computer models, plantar fascia save energy in the foot (Erdemir et al., 2004). After fasciotomy, the force under digits decreases and hallux dorsiflexion increases (Wearing et al., 2006).

Ultrasound Images of the Plantar Fascia Thickness

Ultrasound is easy, quick performance, available, low-cost and free radiation to evaluate the thickness of the plantar fascia. The thickness of the plantar fascia is evaluated longitudinally in ultrasound image as it is more echogenic and small points are visible (Akfirat et al., 2003). To isolate the symptomatic medial, central, and lateral bands, the thickness of the plantar fascia is evaluated longitudinally and transversely in ultrasound image (Vohra et al., 2002) but based on accepted method the origin of the plantar fascia in ultrasound image is identified visually. The calcaneal attachment is identified visually in image. It is an accepted method to evaluate the plantar fascia thickness (Huerta et al., 2007) but plantar fascia attaches to the calcaneus in plantar of the foot. It attaches to the medial process of calcaneus in an area not in a point.

Figure 1: Plantar fascia thickness, Calcaneus area

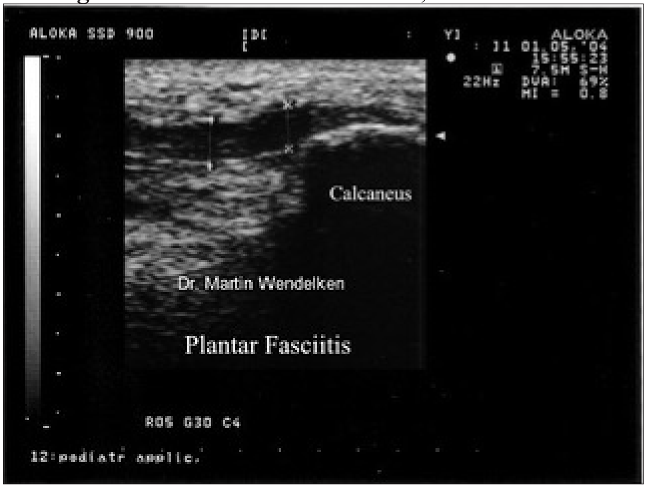


Figure 2: Plantar fascia thickness, Right foot, Longitudinal

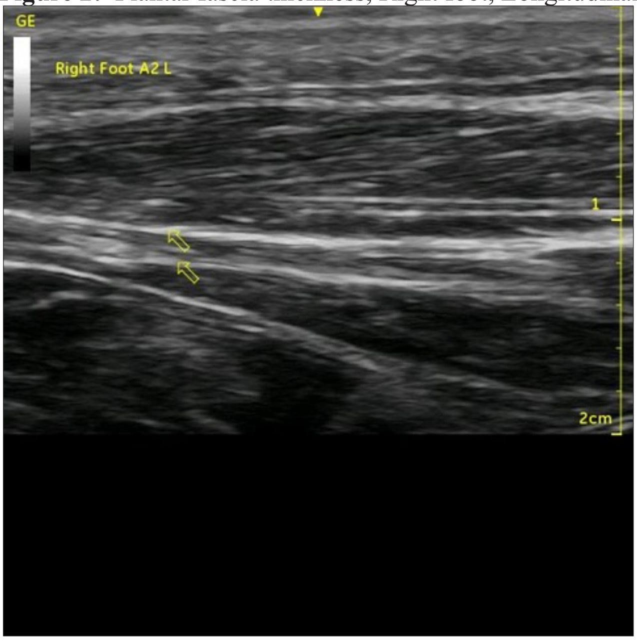


Figure 3: Plantar fascia thickness, Left foot, Transverse

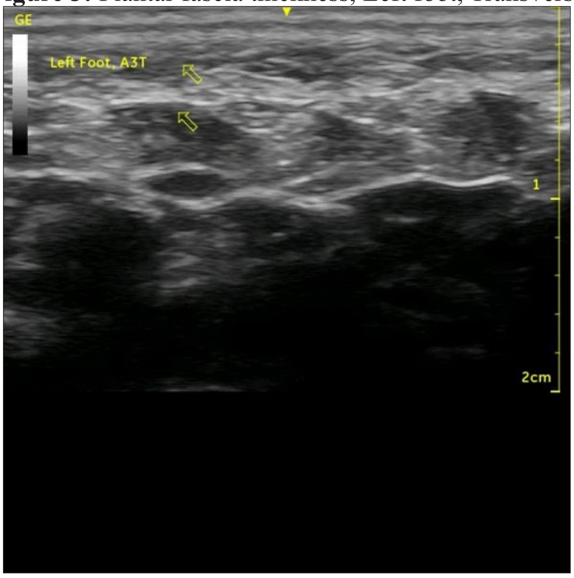
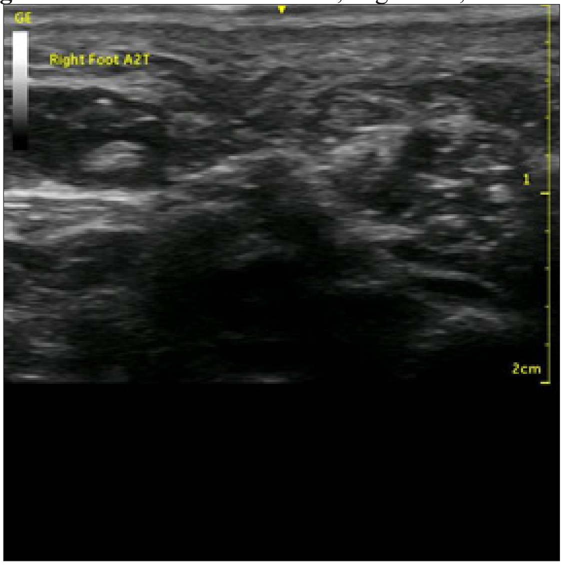


Figure 4: Plantar fascia thickness, Right foot, Transverse



Arguable Points According to Review the Literatures

1. In cadaveric and modeling studies, the weight of the body is applied just on one foot, both in static and dynamic situations, but in living individual, all activities are done with both feet. (Sitting, standing, walking, stairs up/down, running)
2. In living individual, plantar fascia attaches to different tissues. (Aquino, 1999) The amount of modification of the plantar fascia under loading may be affected with living attached soft tissues but in cadaveric studies soft tissues may be stretched more or less in compare with the same living soft tissue.
3. In computational model the body weight is applied on the foot through the shank and ankle joint but in living individual the weight bearing line can vary during gait.
4. In modeling studies, data may be collected through MRI scanning in long sitting position with neutral (90˚) position of ankle joint but in living individual it is neutral position for the angle of ankle not for the thickness of the plantar fascia. In long sitting position foot tends to plantar flexion not 90˚ position.
5. In modeling studies, (Gefen, 2003), the ground reaction force on attached bony segments is considered the same body weight. Indeed, in mid stance, the ground reaction force on the attached bony segments neutralizes vertical vectors and plantar fascia is modified with horizontal vectors in opposite directions, but in living individual, plantar fascia is affected with the horizontal vector after MPJ extension and in one direction.
6. In living individual, plantar fascia maintains the medial longitudinal arch, but in different studies as long as the foot is under vertical load the plantar fascia is pulled from two opposite sides horizontally.
7. MPJ extension may affect the role of the plantar fascia on structure and function of the foot and ankle, (Rao et al., 2011, Dugan et al., 2005) but in living individual, the angle of MPJ extension may be affected with knee flexion in loading.
8. Calcaneal attachment is identified visually in U/S image. It is an accepted method to evaluate the plantar fascia thickness (Huerta et al., 2007). Through palpation of the heel at the insertion of the plantar fascia the location of each band is determined (Vohra et al., 2002). The medial band of the plantar fascia is thin. It is non existent at its proximal (Wearing et al., 2006).

Conclusion / Recommendation

1. To evaluate the real thickness of the plantar fascia along its length and to evaluate the thickness of the plantar fascia in equivalent location in opposite foot, as close as possible, it is recommended, U/S images are scanned according to the plan of investigation.
(DOI: https://doi.org/10.47485/2693-2490.1129) in two planes (sagittal and frontal).
2. It is recommended, thickness of the plantar fascia is evaluated via "Image J" soft ware with the resolution of tenth of a millimeter.

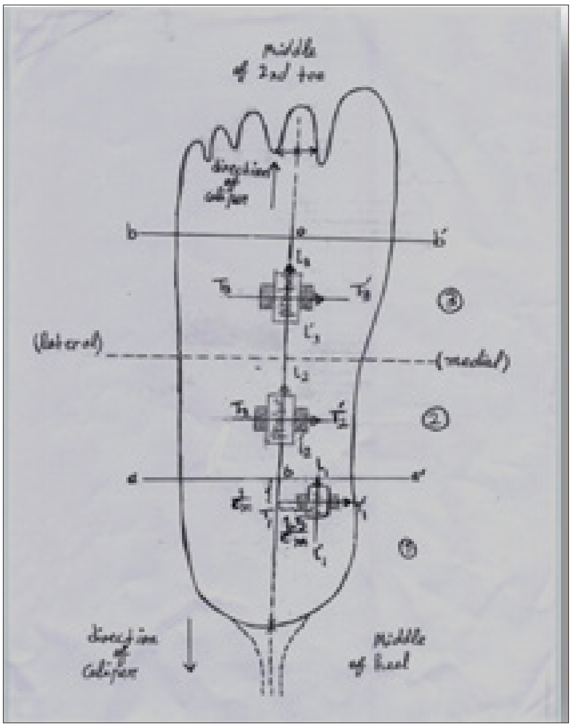


Figure 5: Plan of investigation

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