University of Wollongong

Research Online

Faculty of Science, Medicine and Health -
Papers: part A

Faculty of Science, Medicine and Health

1-1-2014

Ultrasound evaluation of foot muscles and plantar fascia in pes planus

Salih Angin

Dokuz Eylül University

Gillian Crofts

University of Salford, g.crofts@salford.ac.uk

Karen J. Mickle

University of Wollongong, kmickle@uow.edu.au

Christopher J. Nester

University of Salford

Follow this and additional works at: <https://ro.uow.edu.au/smhpapers>

Part of the [Medicine and Health Sciences Commons](#), and the [Social and Behavioral Sciences Commons](#)

Recommended Citation

Angin, Salih; Crofts, Gillian; Mickle, Karen J.; and Nester, Christopher J., "Ultrasound evaluation of foot muscles and plantar fascia in pes planus" (2014). *Faculty of Science, Medicine and Health - Papers: part A*. 2108.

<https://ro.uow.edu.au/smhpapers/2108>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Ultrasound evaluation of foot muscles and plantar fascia in pes planus

Abstract

Background Multiple intrinsic and extrinsic soft tissue structures that apply forces and support the medial longitudinal arch have been implicated in pes planus. These structures have common functions but their interaction in pes planus is not fully understood. The aim of this study was to compare the cross-sectional area (CSA) and thickness of the intrinsic and extrinsic foot muscles and plantar fascia thickness between normal and pes planus feet. **Methods** Forty-nine adults with a normal foot posture and 49 individuals with pes planus feet were recruited from a university population. Images of the flexor digitorum longus (FDL), flexor hallucis longus (FHL), peroneus longus and brevis (PER), flexor hallucis brevis (FHB), flexor digitorum brevis (FDB) and abductor hallucis (AbH) muscles and the plantar fascia were obtained using a Venue 40 ultrasound system with a 5–13 MHz transducer. **Results** The CSA and thickness of AbH, FHB and PER muscles were significantly smaller (AbH –12.8% and –6.8%, FHB –8.9% and –7.6%, PER –14.7% and –10%), whilst FDL (28.3% and 15.2%) and FHL (24% and 9.8%) were significantly larger in the pes planus group. The middle (–10.6%) and anterior (–21.7%) portions of the plantar fascia were thinner in pes planus group. **Conclusion** Greater CSA and thickness of the extrinsic muscles might reflect compensatory activity to support the MLA if the intrinsic foot muscle function has been compromised by altered foot structure. A thinner plantar fascia suggests reduced load bearing, and regional variations in structure and function in feet with pes planus.

Keywords

Ultrasound, Pes planus, Foot muscles, Plantar fascia

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

Angin, S., Crofts, G., Mickle, K. J. & Nester, C. J. (2014). Ultrasound evaluation of foot muscles and plantar fascia in pes planus. *Gait and Posture*, 40 (1), 48-52.

Ultrasound evaluation of foot muscles and plantar fascia in pes planus

Salih Angin^{1*}, Gillian Crofts², Karen J. Mickle³, Christopher J. Nester²

¹School of Physical Therapy and Rehabilitation, Dokuz Eylul University, Inciralti, 35340, Izmir, Turkey,

²School of Health Sciences, University of Salford, Salford, Manchester, M6 6PU,
United Kingdom,

³Biomechanics Research Laboratory, University of Wollongong, Wollongong, Australia,

Corresponding Author:

Salih ANGIN, PT, PhD

Dokuz Eylul University

School of Physical Therapy and Rehabilitation,

Inciralti, 35340, Izmir, Turkey

salih.angin@deu.edu.tr

Keywords:

1. Ultrasound
2. Pes planus
3. Foot muscles
4. Plantar fascia

Word count: 2845

1. Introduction

The pes planus foot type is present in 10 to 25% of the adult population [1] and has been associated with greater incidence of musculoskeletal symptoms including knee and back pain [2]. It is typically characterised by a lowered medial longitudinal arch (MLA), an everted rearfoot, and dorsiflexed and abducted midfoot [3, 4]. An explanation of the causes and consequences of pes planus lies in the complex interaction between external ground reaction forces and internal forces in ligaments, joint capsules, intrinsic and extrinsic muscle-tendon units and forces across articular facets [5, 6].

The contribution of muscles to foot posture and thus pes planus has been the focus of several studies. Anaesthetic paralysis and deliberate fatiguing of plantar intrinsic muscles results in reduced MLA height [5, 7], though these experimental approaches do not indicate how individual plantar structures contribute to arch integrity. Previous studies have shown that abductor hallucis (AbH) and flexor digitorum brevis (FDB), and plantar fascia each make specific contributions to supporting the MLA [8, 9]. The AbH muscle has been described as a dynamic elevator for the MLA and loss of its function has been shown to lower medial arch height [10]. However, it has also been suggested that pretensioning of the fascia in late swing resists lowering of the MLA in early stance [11] and almost 80% of the force resisting further lowering of the arch was provided by plantar fascia [6]. These prior studies illustrate the importance of understanding interactions between different soft tissue structures that have common functions in the foot (e.g. supporting the MLA). For example, changes in the forces experienced by one plantar structure influence the forces experienced by other structures with the same function [6].

Thickening of plantar fascia has been reported in cases of plantar fasciitis in those with pes planus [1], implying that the fascia bears greater load, and adapts to become thicker and stiffer as a result. Indeed, in the absence of the recognisable signs of fascia inflammation, Huang's et al [1] observation of thicker plantar fascia in cases of pes planus is not easily explained unless the assumption that fascia thickness is a surrogate of tensile strength is generally true. To date however, measures of plantar fascia structure have focused on the calcaneal attachment site [12, 13] and little is understood of mid and forefoot fascia structures in cases of pes planus [14]. This is important since at the mid foot the fascia divides into various digital slips that will have different moment arms with respect to the MLA and might have different functional roles with respect to MLA height.

The extrinsic foot muscles including tibialis posterior (TP), tibialis anterior (TA), flexor hallucis longus (FHL), and flexor digitorum longus (FDL) provide additional support for the MLA [8]. Hypertrophy of FDL (suggesting greater activity) has been noted on MRI in cases of pes planus that are associated with posterior tibial tendon insufficiency [15]. Tibialis anterior contracts in early stance to allow gradual plantarflexion of the foot and to decelerate downward motion of the foot. FHL and FDL further contribute to the maintenance of the MLA [16] but their actions are perhaps more coupled with intrinsic muscle and plantar fascia function than TP and TA, since all these structures insert into the digits [17, 18]. However, the relationship between the extrinsic and intrinsic foot structures that share common functions has not been reported in pes planus.

The role of the peroneus longus and brevis (PER) in determining rearfoot position and MLA height is less clear. These muscles plantarflex the ankle and evert the ankle and subtalar joints, with the latter movement being associated with pes planus. Decreased activity of

peroneus longus in pes planus has been reported [19, 20]. This would advantage the invertor muscles on the medial aspect of the ankle whose EMG activity Murley et al. found to increase in pes planus [19]. This seems contrary to the fact that by inserting on the plantar aspect of the first metatarsal, the peroneus longus might be able to plantarflex the metatarsal and thereby elevate MLA height. However, its moment arm for this function is likely very small and combined with the small muscle volume compared to other leg muscles, it seems unlikely that PL contributes significantly to supination of the foot.

There are thus multiple intrinsic and extrinsic soft tissue structures that apply forces and moments around the joints of the foot and that are implicated in pes planus. Many structures have common functions and their interaction in pes planus is not fully understood. These structures cannot be measured dynamically due to small size and limited accessibility due to the complex layers of plantar foot muscles. However, measuring muscle morphology (cross sectional area, muscle thickness) has been shown to be indicative of muscle performance, including strength, thus providing a surrogate measure of mechanical function [21].

For the plantar fascia, measures have focused on fascia thickness as a surrogate for tensile strength, which seems a reasonable assumption in the absence of data to the contrary (and absence of inflammation). However, prior reports have limited measures to its origin on the calcaneus, which might fail to capture important mid and forefoot variations in structure that reflect regional variation in plantar fascia function.

The aim of this study was to compare extrinsic (FDL, FHL and PER) and intrinsic (AbH, FDB and FHB) muscle CSA and thickness, and plantar fascia thickness (at heel, mid and forefoot sites), between normal and pes planus feet. We hypothesised that these selected

muscles and plantar fascia would demonstrate structural changes indicative of attempts to restore a more normal foot posture.

2. Materials and methods

Following approval from the institutional ethics panels (REP10/062), 98 adults aged 18-44 years were purposefully recruited from university communities based on their foot posture and gender/age mix. All participants gave written consent to participate. The six item Foot Posture Index (FPI) [22] was used to classify normal and pes planus foot types because it has been shown to be reliable and boundaries for different foot types have been developed [23]. In total 49 individuals recruited had normal feet (29 male, mean FPI 1.3 ± 1.2 , range 0-5) and 49 had pes planus feet (29 male, mean FPI 8.1 ± 1.7 , range 6-11). None of the participants reported recent lower limb pain or a significant medical or surgical history.

2.1. Data Collection

A Venue 40 musculoskeletal ultrasound system (GE Healthcare, UK) with a 5-13 MHz wideband linear array probe with 12.7 x 47.1 mm surface area was used to image cross sectional area (CSA) and thickness of the foot structures. In the corresponding image, CSA is described as an area of the cross section of a structure perpendicular to its longitudinal dimension, whilst thickness of the structure is defined as the distance between its aponeuroses [24]. Ultrasound images were captured on one foot of each subject selecting the foot with higher FPI in the pes planus group and lower FPI in the normal foot group. If both sides were equal in FPI then the right side was scanned.

Details of probe position and orientation for each structure are provided in Figure 1 and all other aspects were as per prior reported protocols [25], which also reports the reliability of

the protocol used. Each subject lay in the prone position for scanning PF, FHB and FDB muscles, and in the supine position for scanning the AbH, FDL, FHL and PER muscles. Three assessments were taken at each site with the probe removed between each recording. For plantar structures all scans were performed via the plantar surface. For the leg scans the probe was positioned at specific locations along the length of each segment; 50% between the medial tibial plateau and inferior border of the medial malleolus on the medio-posterior aspect of the tibia for the FDL and at the same point but more posteriorly for the FHL. Peroneus longus and brevis (PER) were scanned together at a section 50% of the distance between fibular head and the inferior border of the lateral malleolus. All scans were performed with the ankle joint in the neutral position.

2.2. Image measurements

All images were allocated a random number and subject information hidden from the single image assessor (SA), who was therefore blind to group allocations. All measures were taken using Image J software (National Institute for Health, Bethesda, USA).

2.3. Data analysis

Independent sample t-tests were performed to assess for significant differences between the normal and pes planus groups. The difference between equivalent measures was deemed to be significant if the corresponding p value was less than 0.05. MedCalc® software (trial version 12.2.10.0, <http://www.medcalc.org>) was used for all data analysis.

3. Results

There were no statistically significant differences in baseline characteristics of the participants between the two groups (Table 1). The CSA and thickness of the measured

structures and comparison of the two participant groups are represented in Figures 2 and 3. The CSA of AbH, FHB and PER muscles were significantly smaller (AbH -12.8%, FHB -8.9% and PER -14.7%) in pes planus feet compared to the normal group. Thickness of these muscles was likewise smaller (6.8%, 7.6% and 10% respectively). Both FDL and FHL CSA was significantly larger by 28.3% and 24% and measured thicknesses of these muscles were similarly greater as much as 15.2% and 9.8% in the pes planus group. Differences between pes planus and normal group were not statistically significant for CSA and thickness of the FDB muscle and the calcaneal portion of the PF. However, the middle and metatarsal portion of the PF were thinner by -10.6% and -21.7% respectively in pes planus group.

4. Discussion

The key muscular difference between the pes planus and normal foot types was larger extrinsic supinator muscles (FDL and FHL) and smaller intrinsic muscles of the 1st ray (AbH and FHB) in those with pes planus. To maintain or restore a more normal, or less planus, foot posture, these extrinsic and intrinsic muscles might be expected to act together to support the MLA. Thus increases in all supinator structures would be expected, but this is not what our data suggests.

The key difference in function between intrinsic and extrinsic supinators of the foot is their action around the midtarsal, subtalar and ankle joints, specifically the latter. Perhaps in pes planus, the different posture of the foot disadvantages FHL and FDL so that they need to generate greater forces to contribute the required moments and thus facilitate normal sagittal plane ankle function. This preference for FHL and FDL contributions to MLA support may result in hypertrophy [15, 18].

Flexor hallucis brevis and AbH differed in the pes planus group, but FDB did not, suggesting there is perhaps something related to hallux function, or proximity to the medial arch, that is important. The thinner plantar fascia observed in pes planus was arguably measured medially too, since measures were taken on a line between the calcaneus and second metatarsal head. More medial structures probably have a greater lever arm around the joints of the medial arch compared to more lateral and deeper structures such as FDB. The fact that FDL was different in pes planus and FDB was not, does not detract from this argument if the reason for the larger FDL is the requirement to create supination moments at the ankle joint.

The finding that the plantar fascia was thinner in mid and forefoot regions in pes planus is novel and these measurements have not been previously reported in the literature. The failure to observe change in fascia thickness at the calcaneus but thinner fascia elsewhere justifies our adoption of mid and forefoot measures. Thickness at the attachment site might relate to the need for specific properties at the bone/fascia interface, perhaps related to total loads in the lengthened MLA in pes planus [26]. Plantar fascia was previously shown to undergo continuous elongation from arch-contact to toe-off, reaching a deformation of 9 to 12% between these positions in a normal foot [14]. Moreover, as the plantar fascia plays an important role in transmitting Achilles tendon forces to the forefoot in the stance phase of walking [27] our result may be linked to the thinner Achilles tendon in pes planus recently reported by Murley et al. [28]. Having demonstrated the potential for regional variation in fascia structure, further work is now warranted.

The reduced peroneal muscle tissue in pes planus concurs with Murley et al's [19] report of decreased peroneal muscle activity in flatfeet. Whilst their recent study of muscle morphology suggests otherwise [28] there is no suggestion of a causal link between increased CSA of

peroneal muscles and pes planus. Since peroneal muscles are evertors of the rearfoot, any increase in their action would directly oppose the apparently increased efforts of TP, FHL, FDL that Murley et al. [19] and our data indicate. The data therefore suggests the peroneals reduce their action so as to advantage the supinators muscles [19]. However, any ability of the peroneal muscles to plantarflex the first metatarsal and support the MLA would also be lost. This latter function is probably a minor contributor to arch height given the line of action of the peroneus longus tendon, its small moment arm at the first metatarsal–cuneiform joint, and small peroneal muscle volume compared to the supinator muscles on the posterior calf.

The results of the current study do not provide an explanation as to the cause of pes planus. Foot type is multifactorial and whilst ligament, bone and joint structures, footwear choices and perhaps activity too will influence foot posture, they were out of scope of the current study. Focusing solely on the structures we did is arguably a limitation of our study, as is the exclusion of TP muscle. Ultrasound evaluation of TP is challenging due to the deep location of the muscle within the posterior compartment of the leg [28]. TP tendon, of which the injury is the primary cause of TP muscle dysfunction can easily be reached and evaluated by ultrasound [29]. Our use of a static measure of foot type may also be seen as a limitation, however, there are few measures of pes planus that have such clearly defined boundaries as the FPI. Finally, our hypothesis assumes that the body considers pes planus to be problematic and therefore worthwhile avoiding by modifying muscle activity. By contrast recent meta-analysis [30] suggests foot types are only moderately associated with symptoms.

In conclusion, we have shown smaller CSA and thickness in AbH, FHB and PER, and greater CSA and thickness in FDL and FHL in cases of pes planus. Greater CSA and thickness of the extrinsic muscles might reflect compensatory activity to maintain the shape of MLA if the

intrinsic foot muscle function has been compromised by altered foot structure. The action of extrinsic muscles at the rear as well as mid and forefoot might explain the failure of extrinsic and intrinsic structures to work in tandem. Mid and forefoot plantar fascia was thinner in pes planus, suggesting reduced load bearing, and further research on the regional variations in structure and function of the plantar fascia is warranted.

Conflict of interest statement

None

References

- [1] Huang YC, et al., The relationship between the flexible flatfoot and plantar fasciitis: ultrasonographic evaluation. *Chang Gung Med J*, 2004. 27(6):443-8.
- [2] Kosashvili Y, et al., The correlation between pes planus and anterior knee or intermittent low back pain. *Foot Ankle Int*, 2008. 29(9):910-3.
- [3] Haendlmayer K, Harris N, Flatfoot deformity: an overview. *J Orthop Trauma*, 2009. 23(6):395-403.
- [4] Kido M, et al., Load response of the tarsal bones in patients with flatfoot deformity: in vivo 3D study. *Foot Ankle Int*, 2011. 32(11):1017-22.
- [5] Fiolkowski P, et al., Intrinsic pedal musculature support of the medial longitudinal arch: an electromyography study. *J Foot Ankle Surg*, 2003. 42(6):327-33.
- [6] Iaquinto JM, Wayne JS, Computational model of the lower leg and foot/ankle complex: application to arch stability. *Journal of biomechanical engineering*, 2010. 132(2):021009.

- [7] Headlee DL, et al., Fatigue of the plantar intrinsic foot muscles increases navicular drop. *J Electromyogr Kinesiol*, 2008. 18(3):420-5.
- [8] Thordarson DB, et al., Dynamic support of the human longitudinal arch. A biomechanical evaluation. *Clin Orthop Relat Res*, 1995(316):165-72.
- [9] Jung D-Y, et al., A comparison in the muscle activity of the abductor hallucis and the medial longitudinal arch angle during toe curl and short foot exercises. *Phys Ther Sport*, 2011. 12(1):30-5.
- [10] Wong YS, Influence of the abductor hallucis muscle on the medial arch of the foot: a kinematic and anatomical cadaver study. *Foot Ankle Int*, 2007. 28(5):617-20.
- [11] Caravaggi P, et al., Dynamics of longitudinal arch support in relation to walking speed: contribution of the plantar aponeurosis. *J Anat*, 2010. 217(3):254-61.
- [12] Cheng J-W, et al., Reproducibility of sonographic measurement of thickness and echogenicity of the plantar fascia. *J Clin Ultrasound*, 2012. 40(1):14-9.
- [13] Pascual Huerta J, Alarcón García JM, Effect of gender, age and anthropometric variables on plantar fascia thickness at different locations in asymptomatic subjects. *Eur J Radiol*, 2007. 62(3):449-53.
- [14] Gefen A, The in vivo elastic properties of the plantar fascia during the contact phase of walking. *Foot Ankle Int*, 2003. 24(3):238-44.
- [15] Wacker J, et al., MR morphometry of posterior tibialis muscle in adult acquired flat foot. *Foot Ankle Int*, 2003. 24(4):354-7.
- [16] Ferris L, et al., Influence of extrinsic plantar flexors on forefoot loading during heel rise. *Foot Ankle Int*, 1995. 16(8):464-73.

- [17] Locke J, Baird SA, Frankis J, Preliminary observations of muscle fibre cross sectional area of flexor digitorum brevis in cadaver feet with and without claw toes. *J Foot Ankle Res*, 2010. 3:32.
- [18] Kirane YM, Michelson JD, Sharkey NA, Contribution of the flexor hallucis longus to loading of the first metatarsal and first metatarsophalangeal joint. *Foot Ankle Int*, 2008. 29(4):367-77.
- [19] Murley GS, Menz HB, Landorf KB, Foot posture influences the electromyographic activity of selected lower limb muscles during gait. *J Foot Ankle Res*, 2009. 2(1):35.
- [20] Hunt AE, Smith RM, Mechanics and control of the flat versus normal foot during the stance phase of walking. *Clinical Biomechanics*, 2004. 19(4):391-7.
- [21] Kent-Braun JA, Ng AV, Specific strength and voluntary muscle activation in young and elderly women and men. *J Appl Physiol*, 1999. 87(1):22-9.
- [22] Redmond AC, Crosbie J, Ouvrier RA, Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. *Clin Biomech*, 2006. 21(1):89-98.
- [23] Redmond AC, Crane YZ, Menz HB, Normative values for the Foot Posture Index. *J Foot Ankle Res*, 2008. 1(1):6.
- [24] Narici M, Human skeletal muscle architecture studied in vivo by non-invasive imaging techniques: functional significance and applications. *J Electromyogr Kinesiol*, 1999. 9(2):97-103.
- [25] Crofts G, et al., Reliability of ultrasound for measurement of selected foot structures. *Gait Posture*, 2013. 10.1016/j.gaitpost.2013.05.022.
- [26] Mann R, Inman VT, Phasic activity of intrinsic muscles of the foot. *J Bone Joint Surg. Am*, 1964. 46:469-81.

- [27] Erdemir A, et al., Dynamic loading of the plantar aponeurosis in walking. *J Bone Joint Surg. Am*, 2004. 86-A(3):546-52.
- [28] Murley GS, et al., Foot posture is associated with morphometry of the peroneus longus muscle, tibialis anterior tendon, and Achilles tendon. *Scand J Med Sci Sports*, 2013. 10.1111/sms.12025.
- [29] Rosenfeld PF, Dick J, Saxby TS, The response of the flexor digitorum longus and posterior tibial muscles to tendon transfer and calcaneal osteotomy for stage II posterior tibial tendon dysfunction. *Foot Ankle Int*, 2005. 26(9):671-4.
- [30] Tong JW, Kong PW, Association Between Foot Type and Lower Extremity Injuries: Systematic Literature Review With Meta-analysis. *J Orthop Sports Phys Ther*, 2013. 10.2519/jospt.2013.4225.

Figure 1

The scanned structures and scanning protocol definitions with probe position, and corresponding sample images.

Figure 2

Cross-sectional area (cm²) of the selected structures in the two groups. AbH (Abductor Hallucis), FDB (Flexor Digitorum Brevis), FHB (Flexor Hallucis Brevis), FDL (Flexor Digitorum Longus), FHL (Flexor Hallucis Longus), PER (Peroneal muscles), Mean±Standard Deviation, * $P < 0.01$

Figure 3

Thickness (cm) of the selected structures in the two groups. AbH (Abductor Hallucis), FDB (Flexor Digitorum Brevis), FHB (Flexor Hallucis Brevis), FDL (Flexor Digitorum Longus), FHL (Flexor Hallucis Longus), PER (Peroneal muscles), PF1 (Plantar Fascia calcaneal portion), PF2 (Plantar Fascia middle portion), PF3 (Plantar Fascia metatarsal portion), Mean ± Standard Deviation, * $P < 0.01$

Table 1: Baseline characteristics of the groups

Scanned Structures	Pes Planus Mean ($\pm$ SD)	Control Mean ($\pm$ SD)	<i>P Value</i>
Age (year)	24.10 (5.58)	23.41 (4.26)	0.49
Weight (kg)	70.67 (14.58)	68.65 (12.69)	0.47
Height (cm)	171.73 (8.26)	171.33 (8.16)	0.81
Body Mass Index	23.80 (3.84)	23.29 (3.45)	0.49

SD = Standard Deviation

Highlights:

We measured muscles and plantar fascia in pes planus using ultrasound

Intrinsic muscles and plantar fascia decreased in cross-sectional area and thickness

Extrinsic muscles increased in size to compensate intrinsic muscles