

Observational Study

Relationship Between Decreased Subcalcaneal Fat Pad Thickness and Plantar Heel Pain. A Case Control Study

Daniel López-López, PhD¹, Ricardo Becerro-de-Bengoa-Vallejo, MD, PhD²,
Marta Elena Losa-Iglesias, PhD³, Alfredo Soriano-Medrano, PhD³, Patricia Palomo-López, PhD⁴,
Ángel Morales-Ponce, PhD³, David Rodríguez-Sanz, PhD^{2,6}, and César Calvo-Lobo, PhD⁵

From: ¹Research, Health and Podiatry Unit, Department of Health Sciences, Faculty of Nursing and Podiatry, Universidade da Coruña, Spain; ²Facultad de Enfermería, Fisioterapia y Podología, Universidad Complutense de Madrid, Spain; ³Faculty of Health Sciences, Universidad Rey Juan Carlos, Spain; ⁴University Center of Plasencia, Universidad de Extremadura, Spain; ⁵Nursing and Physical Therapy Department, Institute of Biomedicine (IBIOMED), Faculty of Health Sciences, University of León, Ponferrada, León, Spain; ⁶Faculty of Sport Sciences, Universidad Europea de Madrid, Madrid 28670, Spain

Address Correspondence:
Marta E. Losa Iglesias, PhD
Faculty of Health Sciences, Universidad Rey Juan Carlos, Spain
E-mail: marta.losa@urjc.es

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Background: Heel pain is one of the most frequent complaints in medical clinical practice for conditions affecting the feet during weight-bearing tasks.

Objective: The goal of this study was to measure and compare the thickness of the fat pad in a sample of patients with current unilateral heel pain and patients without unilateral heel pain with normalized reference parameters.

Study Design: This was an observational case-control study.

Settings: The research took place in the podiatry department within a medical health care center.

Methods: A total of 375 patients were randomly selected from a pool of patients attending a medical health care center between the years 2008 and 2015 and diagnosed by a single medical podiatrist without having previous treatment. Patients were categorized in 2 groups: a heel pain group (n = 185) and a control group (asymptomatic; n = 190). The thickness of the plantar fat pad was measured with an ultrasonic probe (BodyMetrix® BX 2000; Intelametrix, Inc, Livermore, CA).

Results: Initial examination of both groups indicated no significant differences in age, height, weight, or body mass index ($P > 0.01$). There were, however, significant differences in the thickness of the fat pad between those in the heel pain group and those in the control group, when analyzed by group and by gender ($P < 0.01$; Cohen's d = 0.465-1.959).

Limitations: The study was not a randomized controlled trial. Although primary outcome data were self-reported, the assessor was not blinded.

Conclusion: This study provides further evidence that people with unilateral heel pain showed a significantly decreased thickness of the subcalcaneal fat pad, regardless of gender.

Key words: Heel pain, subcalcaneal fat, pain

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A subcutaneous layer of adipose tissue beneath the calcaneus on the heel is termed the heel fat pad (1). The heel is uniquely designed to provide cushioning and shock absorption to the underlying bone during weight-

bearing tasks. With advancing age, the structure of the foot changes (2) and the load-carrying ability under the plantar foot can become impaired (3). These structural and functional changes may contribute to foot pain (4,5).

The ability of the heel pad to withstand stress is derived from its unique anatomical structure, a configuration that consists of fat globules that are encapsulated by a cross-linked fibro-elastic structure divided into both superficial and deep microchambers (6,7). The tissue organization is comprised of a U-shaped partition that adheres to the skin surface by the deepest layer of the calcaneus.

Altered mechanical properties of the heel fat pad have been associated with the development of plantar pain (8,9). Local trauma can cause degeneration of the heel fat pad or the breakdown of fibrous tissue within the fat pad, both of which can diminish its compressibility (4). Inflammation and degeneration within the fat pad can also cause plantar heel pain (10). Repeated cycles of stress may decrease stiffness of the heel fat pad, defined as the ability of a tissue to rebound after deformation, leading to pain (1).

The heel fat pad tissue is affected by 2 different types of force: compression which occurs during heel strike (stance phase), and traction which occurs during the end of stance (off phase). It has been estimated that the heel fat pad absorbs 20% to 25 % of the contact force on the heel during gait (1). For a 70-kg man, the mean area of the heel pad is approximately 23 cm² and the pressure is approximately 3.3 kg/cm² (1). In addition, running causes a 2-fold increase in pressure (6). This area is also where heel spurs commonly develop. Histological examination has revealed free nerve endings and Pacinian corpuscles in the fat pad, suggesting that heel pain can arise from the heel fat pad itself (6).

Some studies have analyzed the relationship between fat pad thickness and mechanical properties of plantar pain. Ozdemir et al (8) related the thickness with a reduction in elasticity in the fat pad, which is thought to contribute to plantar pain. These changes in plantar morphology are associated with increases in age (9) and body weight (11-20). Falsetti et al (4) observed 2 different pathological mechanisms in the plantar fat pad: 1) inflammatory, an oedematous pattern related to the subcalcaneus pain; and 2) degenerative, an atrophic pattern associated with rheumatoid arthritis and spondyloarthropathy, which is thought to be less frequent.

Understanding the influence of heel fat pad thickness on the biomechanics of plantar soft tissue is of great importance for preventing injuries. Therefore, the goal of this study was to measure and compare the thickness of the fat pad in a sample of patients with unilateral heel pain and patients without unilateral

heel pain with normalized reference parameters. We hypothesized that patients with unilateral heel pain would present a lesser fat pad thickness compared with the control group.

METHODS

Study Design

An observational case-controlled study was designed to measure fat pad thickness at the calcaneal tuberosity in 2 groups of patients, those experiencing unilateral heel pain and those without unilateral heel pain with normalized reference parameters.

Patients

The study protocol meets the ethical principles and considerations set forth in the Declaration of Helsinki. Institutional review approval for the study was obtained from the Research Committee of the Rey Juan Carlos University at Madrid, Spain. All patients were informed of the purpose and procedures of the study and written informed consent was obtained from all patients.

The study included 375 patients, 198 men and 177 women, divided into 2 groups: 185 patients with unilateral heel pain diagnosed by a podiatrist and without previous treatment; and 190 patients without unilateral heel pain with normalized reference parameters.

The ages of the patients were 44.69 ± 14.20 years (range, 18-69 years). All patients were selected randomly in a podiatry care center in Madrid, Spain by randomly assigning each person with the number 1 or 2. The number 2 was used to select patients, so that measurements were taken from 1 of every 2 patients who expressed heel pain.

Data were collected after radiographic evidence was examined from the years 2008-2015, with the following exclusion criteria: presence of calcaneal fractures, skin lesions in the area of measurement, bone tumors of the foot, open heel wounds, previous surgery for bone problems in the ankle or foot, rigid flat feet, post-traumatic deformity of the foot, diagnosed rheumatologic disease, tarsal tunnel syndrome, sciatica, heel spurs, previous treatment of heel pain, morbid obesity, diabetes mellitus, or age younger than 18 years old.

Instruments and Measures

Data collected included gender, age, height, weight, body mass index, subcalcaneal fat pad thickness, and presence of heel pain in the area upon acupressure. In the first step, each patient was interviewed

and details of medical records were collected, including gender, age, height, weight, body mass index, and presence of heel pain while walking or upon acupressure with the ultrasound probe.

Procedure

The instrument used to measure the thickness of the subcalcaneal fat pad was the BodyMetrix® BX 2000 (IntelaMetrix, Inc., Livermore, CA) ultrasound probe and data were recorded using the Quirumed® scale (Quirumed, Valencia, Spain), which measures the amount of fat in millimeters. Before each measurement, all instruments were properly calibrated. BodyMetrix® BX 2000 ultrasound has been proven to be a valid and reliable tool for anthropometric measurements of subcutaneous fat thickness and muscle thickness (21). Recently, subcutaneous fat thickness measured by BodyMetrix® BX2000 has been compared to the fat thickness in dissected cadavers, proving its validity. BodyMetrix® BX2000 provides a measurement of subcutaneous fat thickness with an accuracy of < 1 mm, and the correlation between this tool and the dissected cadaver measurement was 0.76 (22).

Muscle thickness has also been assessed via ultrasonography (Bodymetrix Pro System, IntelaMetrix, Inc., Livermore, CA), and has been used as an index of muscle hypertrophy for the chest and quadriceps (23). This technique has been previously used to assess the hypertrophic response to resistance exercise, and has compared favorably with magnetic resonance imaging (26).

Participants were seated with their foot at 90° to the tibia. The entire measurement protocol was performed in this position. The plantar aspect of the tuberosity of the heel was palpated by the physician to determine the anatomical localization of pain. The examiner both flexed and extended the big toe while palpating the patient's plantar fascia to allow accurate identification of the calcaneal tuberosity. Once identified, it was marked by a point with a marker. The same protocol was performed in the control group.

One sonographer independently assessed the fat thickness at the point marked previously for both groups in a blinded fashion because he was not allowed to ask whether the patient had heel pain or not. Quantitative evaluation of the fat pad thickness was performed automatically from



Fig. 1. The image depicts the patient's position during ultrasound testing. Once the area of interest was located, and labeled with the demographic marker, the probe was placed at 90°.

the skin to the calcaneus bone using the Quirumed® scale. Both groups were assessed 3 times to evaluate intrarater reliability.

Next, the BodyMetrix® probe was applied to the heel with a layer of conductive gel (Transonic®) at 90° to the measurement point of interest (Fig. 1). Avoiding pressure at the heel, the depth of the fat pad from the skin to the plantar aspect of the calcaneus bone were measured and automatically recorded from each patient.

Sample Size Calculation

The sample size was calculated with software from the Unidad de Epidemiología Clínica y Bioestadística, Complejo Hospitalario Universitario de A Coruña, Universidade da Coruña (www.fisterra.com) (27). The calculations were based on the population of the state of Madrid with a total population of 6,507,184 persons (<http://www.madrid.org/iestadis/fijas/estructu/demograficas/padron/estructupopc.htm>). For a 2-tailed test, an α level of 0.03, and a desired power of 90% with a β level of 3% and a precision of $\pm 3\%$, assuming an information loss of 15%, at least 143 cases were needed for the study. A total of 375 people were included in the study.

Data Analysis

The Kolmogorov-Smirnov test was applied to the data to determine a normal distribution in the full sample and for each group, as well as for the categories of gender and age.

The mean and standard deviation for quantitative variables and frequencies and percentages for categorical

variables were calculated for the full sample and for each group.

Intratrial reliability was established by completing 3 measurements for each patient in one session. Intra-class correlation coefficients (ICC) were calculated to determine reliability between trials in each group, and the mean value calculated.

To interpret ICC values, we used benchmarks proposed by Landis and Koch (28) as follows: 0.20 or less, slight agreement; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; and 0.81 or greater, almost perfect agreement. As recommended by Portney and Watkins (29), clinical measurements with reliability coefficients greater than 0.90 improve the probability that the measurement is valid.

The groups were compared using a 2-tailed Student t test for independent samples and a chi-square test was used to compare differences in heel pain between genders. In addition, the effect size calculation was based on the following formula $d = 2t/\sqrt{gdl}$, and determined by the SD in each group. Cohen's d (effect size) was interpreted as slight ($d < 0.20$), fair ($d = 0.20-0.49$), moderate ($d = 0.50-0.79$), or large ($d > 0.80$) (30).

A receiver operating characteristic (ROC) analysis was used to determine the optimal combination of sensitivity and specificity for plantar tissue calcaneal thickness to predict heel pain. Sensitivity is the ability of a test – in this case, plantar tissue thickness cutoff point – to detect a positive result when the target condition (i.e., heel pain) is present; specificity is the ability of a test to correctly identify the true negative result when the condition – in this case, heel pain – is absent. The calcaneal tissue thickness and heel pain from both feet were used for the analysis. A nonparametric analysis with 95%

confidence intervals was used to estimate the standard error of the area under the sensitivity/specificity curve and to compare the ROC curve's area to the null hypothesis area of 0.5. A P value < 0.01 with a 99% confidence interval was considered statistically significant for all tests (SPSS Version 20.0; IBM Corporation, Armonk, NY).

RESULTS

Table 1 presents the demographic data of the study patients, representing a normal distribution. The ICC (95% IC) was 0.93 (0.87-0.96) and 0.95 (0.90-0.97) for the heel pain group and control group, respectively. There were significant differences in height and weight between women and men ($P < 0.001$); however, there were no significant differences between groups with regard to age and BMI ($P = 0.188$ and $P = 0.340$, respectively). Surprisingly, there were no significant differences with regard to the thickness of the calcaneus fat pad by gender ($P = 0.941$), indicating that heel pain is not influenced by gender.

Table 2 stratifies the study patients by existence of heel pain. Significant differences regarding the thickness of the heel fat pad were evident between the heel pain and control groups ($P < 0.001$). Examining the relationship of the thickness of the heel fat pad stratified by gender revealed that women in the control group had a thicker heel fat pad compared to the group experiencing heel pain (10.13 ± 1.68 mm vs. 7.09 ± 1.44 mm, $P < 0.001$). This was also true for men, whereby the subcalcaneal fat pad thickness was greater in the control group compared with men in the heel pain group (8.58 ± 3.43 mm vs. 7.37 ± 1.33 mm; $P < 0.001$). As expected, when data from all patients were combined, the control group maintained a thicker heel fat pad (control group 10.36 ± 1.78 mm vs. 7.23 ± 1.39 mm; P

Table 1. Demographic data for study patients.

Variables	Total (n = 375) M ± SD	Women (n = 177) M ± SD	Men (n = 198) M ± SD	P Value	Effect Size Cohen's d
Age (yrs)	44.69 ± 14.10	42.20 ± 12.06	47.64 ± 17.06	0.188	0.368
Height (cm)	166.87 ± 8.37	162.84 ± 5.02	173.94 ± 9.01	0.001	1.374
Weight (kg)	73.43 ± 14.55	68.76 ± 11.68	80.01 ± 15.43	0.001	0.822
BMI (kg/cm ²)	26.52 ± 5.80	25.98 ± 4.59	26.97 ± 7.57	0.340	0.158
Heel Fat Pad Thickness (mm)	8.82 ± 2.23	8.83 ± 2.42	8.93 ± 2.07	0.941	0.004

Abbreviations: M, mean; SD, standard deviation; BMI, Body Mass Index. P value < 0.01 with a confidence interval of 99% was considered statistically significant.

Table 2. Study participants stratified by level of heel pain.

Variables	Gender Women (n = 177) Men (n = 198) Total (n = 375) M ± SD	Heel Pain Group Women (n = 90) Men (n = 95) Total (n = 185) M ± SD	Control Group Women (n = 87) Men (n = 103) Total (n = 190) M ± SD	P Value	Effect Size Cohen's d
Age (yrs)	Women	42.10 ± 12.34	42.26 ± 12.08	0.962	0.013
	Men	51.45 ± 15.65	40.66 ± 18.07	0.223	0.638
	Total	47.00 ± 14.74	42.00 ± 12.96	0.115	0.360
Height (cm)	Women	161.20 ± 4.02	163.93 ± 5.38	0.170	0.574
	Men	174.27 ± 7.50	173.33 ± 11.87	0.860	0.094
	Total	168.04 ± 8.94	165.50 ± 7.53	0.176	0.307
Weight (kg)	Women	68.30 ± 14.89	69.06 ± 9.22	0.838	0.061
	Men	84.54 ± 15.83	71.66 ± 10.32	0.227	0.963
	Total	76.80 ± 17.28	69.50 ± 9.30	0.020	0.526
BMI (kg/cm ²)	Women	26.25 ± 5.35	25.80 ± 4.10	0.749	0.094
	Men	28.28 ± 7.52	24.57 ± 7.33	0.306	0.499
	Total	27.32 ± 6.58	25.59 ± 4.67	0.182	0.303
Heel Fat Pad Thickness	Women	7.09 ± 1.44	10.13 ± 1.68	0.001	1.942
	Men	7.37 ± 1.33	8.58 ± 3.43	0.001	0.465
	Total	7.23 ± 1.39	10.36 ± 1.78	0.001	1.959

Abbreviations: M, mean; SD, standard deviation; BMI, Body Mass Index. *P* value < 0.01 with a confidence interval of 99% was considered statistically significant.

Table 3. Optimal subcalcaneal fat pad thickness cutoff value to predict heel pain.

Subcalcaneal Fat Pad Thickness	Optimal Thickness Cutoff Value (mm) for No Heel Pain	Area Under ROC Curve (95% CI)	P Value	Sensitivity (%)	Specificity (%)
Total	≥ 8.77	0.915 (0.887-0.943)	0.001	85.8	82.2
Women	≥ 8.15	0.933 (0.898-0.969)	0.001	94.3	78.9
Men	≥ 9.20	0.900 (0.857-0.942)	0.001	72.8	94.7

Abbreviations: ROC, receiver operating characteristic; CI, confidence interval.

< 0.001). The Cohen's d effect sizes varied from fair to large (d = 0.465-1.959).

Table 3 presents the results of the ROC analysis of the heel for the control group. Cutoff values defined at relatively greater heel fat pad thickness were very sensitive for detecting risk of heel pain and also very specific for predicting a lack of heel pain. Gender differences were found between the optimal heel fat pad tissue thickness cutoff values to predict no heel pain, as determined by a balance of sensitivity and specificity. The area under the ROC curve was significantly greater than the null hypothesis (*P* < 0.001) for no heel pain when heel fat pad thickness was ≥ 8.77 mm in the total population, ≥ 8.15 mm in women, and ≥ 9.20 mm in men. Conversely, cutoff values made at lower fat pad heel thickness were very sensitive for predicting heel pain.

DISCUSSION

The subcalcaneus fat pad may play an important role in shock absorption at the heel, which may minimize the risk of heel pain. Fat pad thickness may be considered the most important factor in the development of forces imposed on the deeper tissue. The ability of the heel fat pad to withstand stress is derived from its unique anatomical structure divided into a superficial microchamber and deep macrochamber layers that contain fat globules and U-shaped partitions that are connected with the skin and the heel (31). This region of the foot also has specialized fat, containing 19% to 25% more unsaturated fatty acids than other adipose tissues in the human body. Preventing subcalcaneal fat pad injury and pain is very important both clinically and with regard to the improvement of quality of life.

Unique to this study, the BodyMetrix® probe was used to measure the thickness of the heel fat pad. Although others (32-34) have suggested ultrasonography as an appropriate method of measurement, less portable and more expensive models have been utilized. Measuring the thickness of the heel fat pad has been of great interest throughout history. Jackson (11) stated that the height of the heel fat pad is higher in obese individuals. Gooding et al (12) reported the loss of heel fat pad thickness in patients with diabetes.

We found that the heel pain group may show a decrease in subcalcaneal fat pad thickness. These results differ from other studies such as Prichasuk et al (13), who studied heel fat pad compressibility with lateral radiographs during bodyweight loading and unloading in patients with heel pain compared to normal controls. They found that heel pad thickness ranged from 14 mm to 27 mm. Ozdemir et al (9) also found a greater amount of subcalcaneal fat pad in patients afflicted with plantar pain. The authors state that the increased fat pad thickness produces a decrease in elasticity. Even though the results of our study may contradict other reports in the literature, decreased fat pad thickness of the subcalcaneal area would increase the impact during ground reaction, which can lead to chronic traumatic heel pain.

Our results regarding the relationship between weight and heel pain do not coincide with the study of Hill and Cutting (14), which found that weight gain was associated with heel pain. This association also occurs in other studies by Snook and Chrisman (15) and Furey (16). In our study, we observed that the fat pad thickness of men and women was not the same. Other studies, such as Uzel et al (17) also obtained mean values of the fat pad thickness that were significantly higher in men than in women ($P < 0.05$), as did a study by Prichasuk (13). The average thickness of the fat pad in a study by Udoh et al (18) using an ultrasound technique was 14.33 ± 0.24 mm in men and 12.14 ± 0.26 mm in women. These values are also consistent with the findings of Morag et al (19). Both studies determined that fat pad thickness of a normal adult was 14.33 mm. Nass (20) found that the average fat pad thickness of men was 14.6 mm and 12.2 mm in women. These gender differences are most likely due to anatomical and hormonal differences.

Another likely cause of the decreased fat pad thickness associated with heel pain may be degeneration and bone changes of the periosteum. Such bone changes may be related to repetitive microtrauma of

the calcaneal tuberosity, which causes a gradual loss of collagen within the adipose tissue of the fat pad; and a decreased water content of the fibro-elastic tissue, which causes tearing of the fibrous septa. All of these changes result in a decrease in the elastic properties of the heel fat pad by approximately 24% (1,3,4,12). In addition, inflammation of the heel fat pad and degeneration can also cause plantar heel pain (4).

The results of this study indicate that there is a cutoff value with respect to the thickness of the heel fat pad tissue, below which heel pain is highly likely. This may be clinically important, indicating that patients with heel pain may show thinner heel fat pads. Nevertheless, longitudinal studies in order to determine the risk and cause-effect relationships should be carried out in the future.

Currently, the treatment for fat pad atrophy consists mainly of offloading and cushioning via padding, shoe inserts, and modifications. An autolipotransplantation approach was reported by Chairman (35) in 20 patients, 2 years after surgery, and 96% of patients experienced pain relief and retention of the plantar fat pad. Recently, there are Lipofilling techniques that have proven to be an effective and versatile surgical technique for both reconstructive and regenerative purposes. Our findings could potentially predict the necessary thickness of the heel fat pad required to obtain an appropriate amount of filler to relieve heel pain (36).

Despite prior studies that have focused on plantar fascia alterations (37-40), energy dissipation of the plantar fat pad during walking associated with plantar enthesopathy (41), as well as heel fat pad influence on rheumatoid arthritis and spondyloarthropathies (4) and magnetic resonance findings of the painful heel (42), our study showed that patients with unilateral heel pain have decreased subcalcaneal fat thickness, regardless of gender.

We believe this study provides an important contribution to the study of heel pain by determining a cutoff value for predicting an absence of heel pain, and may influence appropriate quantities of filler that could be injected into the heel to alleviate heel pain.

The main limitations of our research include the fact that the provider measuring fat pad thickness was not blinded. Also, the heel thickness measurements were made on patients who were in a sitting position, not standing, so any influence of applied pressure was not accounted for in this analysis. In addition, tissue elastography, plantar fascia thickness, and Doppler ultrasonography were not assessed and could improve

the scientific knowledge of future research studies of patients with plantar heel pain.

It will be important to conduct further studies examining the relationship between the presence of pain and decreased thickness of the plantar fat pad in order to establish the most appropriate interventions for patients. We found that patients without heel foot pain have a thicker heel fat pad compared to patients

experiencing heel pain, and established a cutoff value for pain prediction.

CONCLUSIONS

This study provides further evidence that people with unilateral heel pain show a significantly decreased thickness of the subcalcaneal fat pad, regardless of gender.

REFERENCES

- Jørgensen U, Bojsen-Møller F. Shock absorbency of factors in the shoe/heel interaction--with special focus on role of the heel pad. *Foot Ankle* 1989; 9:294-299.
- Scott G, Menz HB, Newcombe L. Age-related differences in foot structure and function. *Gait Posture* 2007; 26:68-75.
- Gefen A. Plantar soft tissue loading under the medial metatarsals in the standing diabetic foot. *Med Eng Phys* 2003; 25:491-499.
- Falsetti P, Frediani B, Acciai C, Baldi F, Filippou G, Marcolongo R. Heel fat pad involvement in rheumatoid arthritis and in spondyloarthropathies: An ultrasonographic study. *Scand J Rheumatol* 2004; 33:327-331.
- Chang C-D, Wu JS. MR Imaging findings in heel pain. *Magn Reson Imaging Clin N Am* 2017; 25:79-93.
- Jørgensen U. Achillodynia and loss of heel pad shock absorbency. *Am J Sports Med* 1985; 13:128-132.
- Paul IL, Munro MB, Abernethy PJ, Simon SR, Radin EL, Rose RM. Musculo-skeletal shock absorption: Relative contribution of bone and soft tissues at various frequencies. *J Biomech* 1978; 11:237-239.
- Wearing SC, Smeathers JE, Yates B, Urry SR, Dubois P. Bulk compressive properties of the heel fat pad during walking: A pilot investigation in plantar heel pain. *Clin Biomech (Bristol, Avon)* 2009; 24:397-402.
- Ozdemir H, Söyüncü Y, Özgörge M, Dabak K. Effects of changes in heel fat pad thickness and elasticity on heel pain. *J Am Podiatr Med Assoc* 2004; 94:47-52.
- Williams AE, Nester CJ, Ravey MI. Rheumatoid arthritis patients' experiences of wearing therapeutic footwear - A qualitative investigation. *BMC Musculoskelet Disord* 2007; 8:104.
- Jackson DM. Heel-pad thickness in obese persons. *Radiology* 1968; 90:129.
- Gooding GA, Stress RM, Graf PM, Grunfeld C. Heel pad thickness: Determination by high-resolution ultrasonography. *J Ultrasound Med* 1985; 4:173-174.
- Prichasuk S, Mulpruek P, Siriwongpairat P. The heel-pad compressibility. *Clin Orthop Relat Res* 1994; 300:197-200.
- Hill JJ, Cutting PJ. Heel pain and body weight. *Foot Ankle* 1989; 9:254-256.
- Snook GA, Chrisman OD. The management of subcalcaneal pain. *Clin Orthop Relat Res* 1972; 82:163-168.
- Furey JG. Plantar fasciitis. The painful heel syndrome. *J Bone Joint Surg Am* 1975; 57:672-673.
- Uzel M, Cetinus E, Bilgic E, Karaoguz A, Kanber Y. Bilateral os trigonum syndrome associated with bilateral tenosynovitis of the flexor hallucis longus muscle. *Foot Ankle Int* 2005; 26:894-898.
- Udoh B, Ezeokpo O, Ulu O, Egwu D. Sonographic assessment of the heel pad thickness in normal Nigerians. *World J Med Sci* 2010; 5:85-88.
- Morag E, Lemmon D, Cavanagh P. What role does plantar soft tissue stiffness play in determining peak pressure under the heel? *Gait Posture* 1997; 5:164-165.
- Nass D, Hennig EM, Treck VN. The thickness of the heel pad loaded by bodyweight in obese and normal weight adults. Conference: Fourth Symposium on Footwear Biomechanics. 1995. Available at: <https://www.uni-due.de/~qp800/FWISB/Manuscr/Nass10.pdf>.
- Bielemann RM, Gonzalez MC, Barbosa-Silva TG, Orlandi SP, Xavier MO, Bergmann RB, Assunção MC. Estimation of body fat in adults using a portable A-mode ultrasound. *Nutrition* 2016; 32:441-446.
- Wagner DR, Thompson BJ, Anderson DA, Schwartz S. A-mode and B-mode ultrasound measurement of fat thickness: A cadaver validation study. *Eur J Clin Nutr* 2018; Epub ahead of print.
- Klemp A, Dolan C, Quiles JM, Blanco R, Zoeller RF, Graves BS, Zourdos MC. Volume-equated high- and low-repetition daily undulating programming strategies produce similar hypertrophy and strength adaptations. *Appl Physiol Nutr Metab* 2016; 41:699-705.
- Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, Sonmez GT, Alvar BA. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. *J Strength Cond Res* 2014; 28:2909-2918.
- Simão R, Spinetti J, de Salles BF, Matta T, Fernandes L, Fleck SJ, Rhea MR, Strom-Olsen HE. Comparison between non-linear and linear periodized resistance training: Hypertrophic and strength effects. *J Strength Cond Res* 2012; 26:1389-1395.
- Reeves ND, Maganaris CN, Narici MV. Ultrasonographic assessment of human skeletal muscle size. *Eur J Appl Physiol* 2004; 91:116-118.
- Pita Fernández S. Determinación del tamaño muestral. *Cad Aten Primaria* 1996; 3:138-152.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33:159-174.
- Portney L, Watkins M. *Foundations of Clinical Research: Applications to Practice*. 3rd ed. Upper Saddle River, NJ: Prentice Hall; 2009.
- Cohen J. A power primer. *Psychol Bull* 1992; 112:155-159.
- Hsu C-C, Tsai W-C, Wang C-L, Pao S-H, Shau Y-W, Chuan Y-S. Microchambers and macrochambers in heel pads: Are they functionally different? *J Appl Physiol* 2007; 102:2227-2231.

32. Blaivas M, Brannam L, Theodoro D. Ultrasound image quality comparison between an inexpensive handheld emergency department (ED) ultrasound machine and a large mobile ED ultrasound system. *Acad Emerg Med* 2004; 11:778-781.
33. Sobhani MR, Ozum HE, Yaralioglu GG, Ergun AS, Bozkurt A. Portable low cost ultrasound imaging system. In: 2016 *IEEE International Ultrasonics Symposium (IUS)*. Tours, France: Institute of Electrical and Electronics Engineers; 2016:1-4.
34. Fuller MI, Ranganathan K, Shiwei Zhou, Blalock TN, Hossack JA, Walker WF. Experimental system prototype of a portable, low-cost, C-scan ultrasound imaging device. *IEEE Trans Biomed Eng* 2008; 55:519-530.
35. Chairman EL. Restoration of the plantar fat pad with autolipotransplantation. *J Foot Ankle Surg* 1994; 33:373-379.
36. Nicoletti G, Brenta F, Jaber O, Laberinti E, Faga A. Lipofilling for functional reconstruction of the sole of the foot. *Foot (Edinb)* 2014; 24:21-27.
37. Gadalla N, Kichouh M, Boulet C, Machiels F, De Mey J, De Maeseneer M. Sonographic evaluation of the plantar fascia in asymptomatic subjects. *J Belg Soc Radiol* 2014; 97:271-273.
38. McNally E, Shetty S. Plantar fascia: Imaging diagnosis and guided treatment. *Semin Musculoskelet Radiol* 2010; 14:334-343.
39. Mohseni-Bandpei MA, Nakhaee M, Mousavi ME, Shakourirad A, Safari MR, Vahab Kashani R. Application of ultrasound in the assessment of plantar fascia in patients with plantar fasciitis: A systematic review. *Ultrasound Med Biol* 2014; 40:1737-1754.
40. Sabir N, Demirlen S, Yagci B, Karabulut N, Cubukcu S. Clinical utility of sonography in diagnosing plantar fasciitis. *J Ultrasound Med* 2005; 24:1041-1048.
41. Wearing SC, Smeathers JE, Urry SR, Sullivan PM, Yates B, Dubois P. Plantar enthesopathy: Thickening of the enthesis is correlated with energy dissipation of the plantar fat pad during walking. *Am J Sports Med* 2010; 38:2522-2527.
42. Narváez JA, Narváez J, Ortega R, Aguilera C, Sánchez A, Andía E. Painful heel: MR imaging findings. *Radiographics* 2000; 20:333-352.