Evaluation of Pressure Pain Sensitivity in the Forefoot of Healthy Individuals

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Background: The evaluation of musculoskeletal pain in podiatric medical practice is mainly based on anamnesis and manual examination. However, when manual palpation is performed, the digital pressure necessary to adequately explore the different structures of the foot is unknown. We evaluated the pressure pain threshold in forefoot structures to determine the intensity and duration of the stimulus as clinically relevant and representative.

Methods: In a transversal analytical study of 15 healthy individuals, 16 forefoot points were explored with a handheld pressure palpometer calibrated to exert maximum pressing force of 1.0 or 2.0 kilogram-force (kgf) applied during 5 or 10 sec. The combinations of the different pressures and intervals were selected randomly. Participants had to self-rate the pressure pain sensitivity of each stimuli on a 100-mm horizontal line (0–100 numeric rating scale), setting the pain threshold to 50 (100 being pain as bad as it could be). Likewise, aftersensation and referred pain patterns were recorded.

Results: All participants indicated painful stimuli at some of the 16 forefoot points studied in the experimental protocol when pressure was applied with the 2.0-kgf palpometer; 53.3% showed evidence of pain at any forefoot point when the 1.0-kgf palpometer was used. The odds of evoking a painful sensation are 9.8 times higher when using a 2.0-kgf palpometer versus a 1.0-kgf palpometer. In addition, referred sensations were observed with a significantly higher frequency when applying the 2.0-kgf palpometer.

Conclusions: Bone and soft structures show differences in pressure sensitivity, increasing significantly when applying higher pressure force. Soft structures, specifically intermetatarsal spaces, showed the lowest pain pressure thresholds. More research is needed to better understand pressure pain response. (J Am Podiatr Med Assoc 112(1), 2022)

Foot pain is one of the most frequent reasons for podiatric medical consultation. More specifically, forefoot disorders are a common source of local pain complaints, with metatarsalgia being one of the most common pain-related conditions managed in podiatric medical practice.

Epidemiologic studies reviewed provide very different forefoot pain prevalence depending on the etiology and the study population because its incidence is clearly correlated with age and sex.[1] In a study conducted between 1998 and 2008 in the Australian population, a prevalence of metatarsalgia of 10.9% is described, highlighting its greater incidence in women aged 50 to 55 years.[2] In 2016, a systematic review by Menz[3] found a prevalence of foot pain of 24%, located more frequently in the forefoot and toes. In this sense, many studies agree that the forefoot is more affected than any other part of the foot given that it is involved in approximately 60% of foot problems that require a podiatric medical evaluation.[4]

In general, pain located in the forefoot can be related to injuries in the different musculoskeletal structures that compose it, such as tendons, plantar plates (PPs), bones, nerves, and joints. Many of the causes of pain in the forefoot are due to an inadequate healing process of overuse injuries that result from repetitive microtraumas, exacerbated by excessive body weight and the use of inappropriate footwear.[5–7] Also, painful forefoot increases

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significantly with age and is related mainly to systemic conditions such as osteoarthritis, rheumatoid arthritis, gout, and diabetes.[8–11]

In clinical practice, diagnosis of chronic or acute forefoot pain is based primarily on anamnesis and clinical examination findings. Assessment of deep muscle and joint pain by digital palpation is an important part of the podiatric clinical examination. Manual palpation is a simple technique in which the examiner applies pressure with the fingers to assess the patient's subjective response of it being a nonpainful or painful stimulus. For measuring the subjective intensity of the pain, a visual analog scale or numeric rating scale (NRS) is commonly used.[12–14]

Many factors can influence sensitivity to pain, such as the psychological state of the patient, the ability to palpate the different types of deep structures through the surface of the skin, or the occurrence of irradiated painful patterns, known as referred pain. But one of the factors that could generate more bias in the pain sensation evaluation is to not have a precise knowledge of the amount of pressure stimulus applied; in this sense, the instruments—palpometers—used in this study allow us to know exactly the pressure being applied.[12]

To our knowledge, the adequate amount of digital pressure that should be applied for pressure pain evaluation of the forefoot, to be clinically relevant and representative, is not yet sufficiently established.

To improve the measure of pressure pain, standardized instruments can be used. Algometers have been the most commonly used tool to study deep pain; however, due to their complexity, they are not widely used in the podiatric medical clinic. An easier-to-use instrument is a palpometer, which has been used to measure pressure pain sensitivity in different human structures.[13,14] The usefulness of the palpometer was first described by Futarmal et al[15] in orofacial pain research, and later studies have shown high validity because this instrument allows control of the exact pressure that is being applied.[16]

The main objective of this study of healthy individuals is to know the pressure pain sensitivity of different musculoskeletal structures of the forefoot that are routinely palpated in clinical practice by using controlled pressures by palpometers applied for a time. Thus, better knowledge of the most painful forefoot structures in healthy individuals will allow for better understanding of patient responses when undergoing a manual foot examination for diagnosis or treatment.

Methods

Participants

A convenience sample of 15 healthy adults (60% men, 40% women) with a mean ± SD age of 29.06 ± 9.5 years (range, 18–55 years) were invited to participate in the study. Participants were recruited through advertisements posted at the Podiatry Clinic of Complutense University, Madrid, Spain. Volunteers were informed in writing and verbally about the experimental procedure, and they signed and personally dated an informed consent form to participate. The study protocol followed the recommendations of the Declaration of Helsinki of 1975 (29th World Medical Assembly, Tokyo, Japan, October 1975), and data were processed according to the Spanish Organic Law of Protection of Personal Data 19/55.

To rule out the presence of any foot pain during the past 30 days, participants completed the Spanish version of the American Academy of Orthopaedic Surgeons Foot and Ankle Module (AAOS-FAMsp).[17] In addition, exclusion criteria were the presence of chronic musculoskeletal conditions in the past 6 months or the intake of analgesics in the past 3 days before the experiment. Other selection criteria are shown in the Table 1.

Study Design

An experimental laboratory study with repeated measures was conducted from May to June 2018. Sixteen points in the forefoot were selected to analyze pain sensitivity response to mechanical pressure applied by palpometers calibrated to 1.0 kilogram-force (kgf) (1.0 kgf/cm^2 = 98.06 kPa) and 2.0 kgf (2.0 kgf = 196.12 kPa) for 5 and 10 sec (Fig. 1): 1) second PP, 2) third PP, 3) fourth PP, 4) fifth PP, 5) diaphysis second metatarsal, 6) diaphysis third metatarsal, 7) dorsum hallux head, 8) first intermetatarsal space (IMTS), 9) second IMTS, 10) third IMTS, 11) fourth IMTS, 12) medial diaphysis hallux, 13) medial hallux head, 14) lateral fifth metatarsal head, 15) lateral fifth metatarsal diaphysis, and 16) fifth metatarsal apophysis.

The protocol was repeated again after a rest period of at least 5 days between both sessions. In both sessions and in all of the participants, the combinations for the two pressures tested (1.0 and 2.0 kgf) and for the two time intervals applied (5 and 10 sec) were randomized following a sequence generated by a randomization program (randomization.com). Each session took approximately 2 hours to complete. All of

Table 1. Experimental Study Procedure	
Selection criteria	Older than 18 y Agree freely to participate in the study No foot pain in the past 6 mo AAOS-FAMsp scale score = 0 Not having taken analgesics in the past 3 d Neither pregnant nor breastfeeding women Not having rheumatic, musculoskeletal, or psychological disorders
Clinical examination	Ankle dorsiflexion range First metatarsal mobility Hallux mobility Lachman test Mulder test Foot Posture Index Plantar hyperkeratosis
Randomization process	Left or right foot Pressure applied randomly (1.0 or 2.0 kg) Time applied randomly (5 or 10 sec) Points examined randomly (1–16 points)

Abbreviation: AAOS-FAMsp, American Academy of Orthopaedic Surgeons Foot and Ankle Module (Spanish version).[17]

the participants were assessed by the same trained examiner (I.P.-G.) in both sessions.

Clinical Examination of the Forefoot

Clinical tests were also recorded (Table 1) as presence of articular clicks or crepitus, plantar hyperkeratosis, flexion and extension range of movement of the ankle and first metatarsophalangeal joints, positive drawer test (Lachman test), and Mulder sign. Foot Posture Index (FPI)[15] was used for evaluation of the static position of the foot.[18]

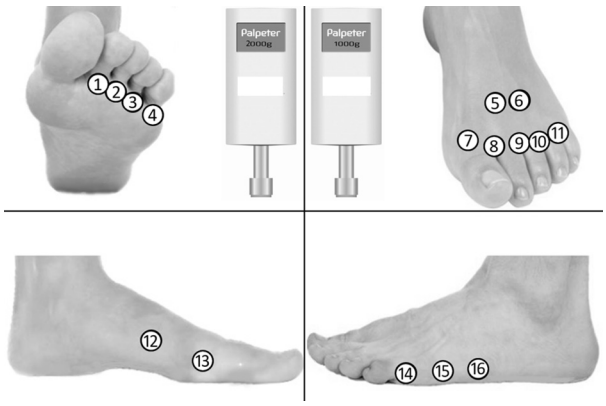


Figure 1. Forefoot points tested: 1) second plantar plate (PP), 2) third PP, 3) fourth PP, 4) fifth PP, 5) diaphysis second metatarsal, 6) diaphysis third metatarsal, 7) dorsum hallux head, 8) first intermetatarsal space (IMTS), 9) second IMTS, 10) third IMTS, 11) fourth IMTS, 12) medial diaphysis hallux, 13) medial hallux head, 14) lateral fifth metatarsal head, 15) lateral fifth metatarsal diaphysis, and 16) fifth metatarsal apophysis.

Pressure Sensitivity of the Forefoot

Sixteen points around the right forefoot were assessed with two different handheld palpometers calibrated with force of 1.0 and 2.0 kgf (1.0 kgf/cm^2 = 98.06 kPa and 2.0 kgf/cm^2 = 196.12 kPa).[15] The instruments had a tip of 1 cm in diameter (area of force application = 0.785 cm^2 so that the exact pressure applied over the forefoot structures analyzed by the 1.0-kgf/cm^2 instrument will be 76.98 kPa, and 153.96 kPa with the 2.0-kgf palpometer, although throughout the text we refer to palpometers according to their calibration, that is, palpometers of 1.0 and 2.0 kgf. The probe was covered with a thin layer of foam-top and placed perpendicular to the skin of the selected forefoot points, and a constant pressure speed was applied until reaching a proper force. Once reached, proper force was held for 5 or 10 sec[13] to assess the self-reported mechanical sensitivity of the participants for each point. The explored forefoot points are shown in Figure 1.

Due to the proximity between some points, a rest interval of 30 sec was maintained between each stimulus to avoid the temporal summation of mechanically evoked pain. All of the participants had to self-rate the intensity of pain sensitivity for pressure on a horizontal line 100 mm in length (0–100 NRS), anchored by three verbal descriptors: 0 mm = no feeling of pressure; 50 mm = pressure pain threshold (defined as the intensity of the stimulus reported by the participant as simply "became painful"), and 100 mm = the worst pain imaginable; this allowed us to register nonpainful and painful sensations.[19,20] Painful sensations that were perceived away from the stimulated point were recorded as referred pain.

Time Until Recovery of Baseline Sensitivity After Applying the Palpometers (Aftersensation)

This study also analyzed the time taken to return to normal sensitivity, called *aftersensation* (a residual sensation that remains after stimulation by an external pressure has ceased). For all of the time and pressure combinations (5 or 10 sec and 1.0 kgf [76.98 kPa] or 2.0 kgf [153.96 kPa]), the duration of aftersensation after finishing application of the pressure stimuli was measured with a stopwatch.

The time recording started once the participant felt the device on the skin and continued until the pressure sensation disappeared completely. The time to recovery of normal sensitivity (aftersensation) was obtained by subtracting the total time of sensation reported by the participant from the time of each time-pressure measure.

Referred Sensations Evoked by Pressure Stimuli

Referred sensation was considered if any painful or unpleasant sensation was felt somewhere away from the precise point of application of the mechanical stimulus. So, after applying each pressure-time stimuli, the participants were asked to report any spreading sensation beyond the site of stimulus. In the presence of these sensations, participants were invited to locate and draw the spread area on a drawing of a foot.

Statistical Analysis

Data obtained were analyzed using IBM SPSS Statistics for Windows, Version 21.0 (IBM Corp, Armonk, New York). Dichotomous variables such as sex, the presence of pain, and referred patterns are reported in frequencies and percentages. Descriptive statistics for quantitative variables, such as age, and the 0–100 NRS scores of pressure pain are presented as mean ± SD. Data of pressure sensitivity according to the conditions of application of the pressure palpometers and times explored in different structures were analyzed using an analysis of variance (ANOVA) test. When appropriate, the ANOVA tests were followed by post hoc Bonferroni tests, with adjustment for multiple comparisons. The risk of the occurrence of pain relative to the increase of the pressure applied was analyzed with the χ^2 test. Finally, for the analysis of possible relationships of pressure pain sensitivity and referred pain, the Student t test was used. For all of the analyses, statistical significance was set at $P < .05$.

Results

Pressure Pain Sensitivity

This study was conducted with 15 healthy participants (six women [40%] with a mean ± SD age of 26.16 ± 7.7 years; age range, 18–40 years; and nine men [60%] with a mean ± SD age of 31.00 ± 10.49 years; age range, 20–55 years). The mean ± SD anthropometric measurements for women were 1.64 ± 0.04 m in height and 55.33 ± 8.61 kg of weight and in men were 1.79 ± 0.06 m in height and 83.66 ± 11.23 kg of weight. All of the women had a neutral foot position (FPI range, 1–4), and men had FPI scores that ranged from –2 to 7, thus, 77.8% presented a neutral position, 11.1% a pronated position, and 11.1% a supine position using the FPI references.[15] None of the participants had foot pain in the past month, and all obtained a score of 0 on the AAOS-FAMsp scale.[17] More clinical characteristics of the participants are described in Table 2.

Pressure pain sensitivity was analyzed in 16 points of the participants' right forefoot as indicated in the study protocol (Fig. 1). Mean ± SD pressure sensitivity scores (0–100 NRS) at each point, according to the applied pressure of the palpometers (1.0 kgf/0.785 cm^2 = 76.98 kPa and 2.0 kgf/0.785 cm^2 = 153.96 kPa) and the time intervals (5 and 10 sec) are shown in Figure 2. According to the intervals applied, no significant differences were found in pressure pain sensitivity in any points of the forefoot, except in the second IMTS when applying 1.0 kgf of pressure (mean ± SD NRS scores, 13.3 ± 11.48 for 5 sec versus 26.26 ± 21.15 for 10 sec; P = .04). However, significant differences at almost every point analyzed were found comparing the different pressures ($P < .05$), except in two points: the fourth PP when tested for 5 sec (mean ± SD 0–100 NRS scores, 11.73 ± 18.08 for 1.0 kgf versus 24.93 ±

Table 2. Descriptive Characteristics of the 15 Study Participants and the Clinical Tests Performed

Characteristic	Participants (No. [%])
Sex	
Women	6 (40)
Men	9 (60)
Body mass index	
Low weight	2 (13.3)
Normal	6 (40)
Overweight	6 (40)
Obesity	1 (6.7)
Passive first metatarsophalangeal joint dorsiflexion	
Normal	12 (80)
Limitus	3 (20)
First-ray mobility	
Normal	10 (66.7)
Limited	4 (26.7)
Increased	1 (6.7)
Mulder test result = negative	15 (100)
Foot Posture Index	
Normal	13 (86.7)
Pronated	1 (6.7)
Supinated	1 (6.7)

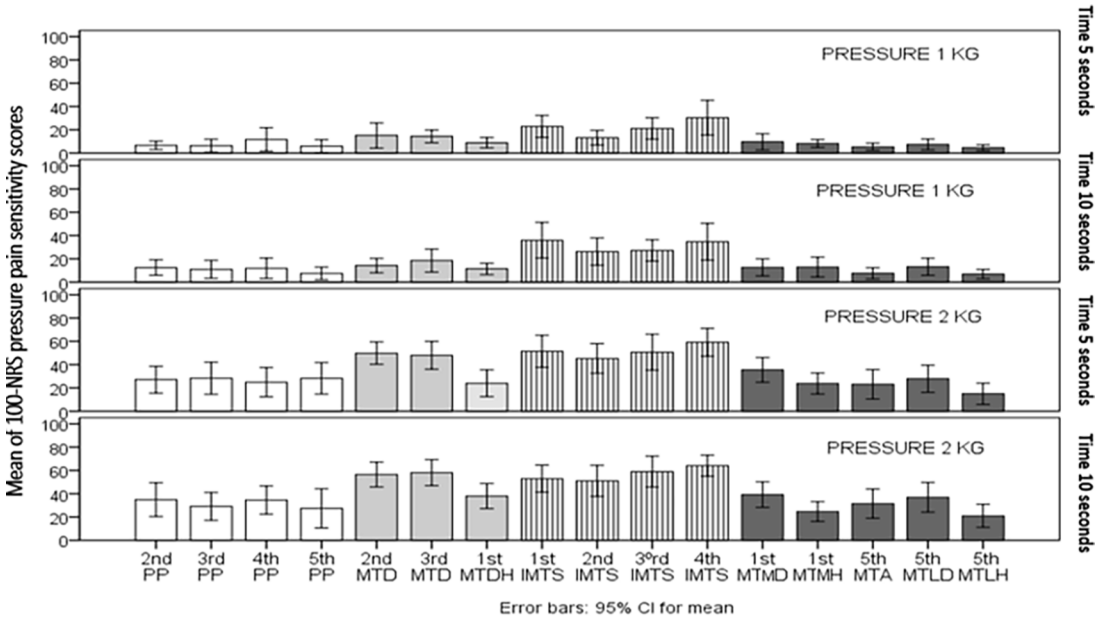


Figure 2. Absolute numeric rating scale (0–100 NRS) scores of pressure sensitivity by intervals and force of the palpometers over the different foot structures studied. IMTS, intermetatarsal space; MTA, metatarsal apophysis; MTD, metatarsal diaphysis; MTDH, metatarsal dorsum head; MTLD, metatarsal lateral diaphysis; MTLH, metatarsal lateral head; MTMD, metatarsal medial diaphysis; MTMH, metatarsal medial head; PP, plantar plate. Error bars represent the 95% confidence interval for the mean.

22.59 for 2.0 kgf; P = .08) and the first IMTS when applied for 10 sec (mean ± SD 0–100 NRS scores, 35.93 ± 11.48 for 1.0 kgf versus 52.93 ± 20.97 for 2.0 kgf; P = .6).

Calculating the averages of pressure sensitivity in the 0–100 NRS scores among the four scenarios (1.0 or 2.0 kgf during 5 or 10 sec), the results after using the Bonferroni post hoc criterion for significance indicated that mean ± SD pressure pain sensitivity was significantly higher in the 2.0-kgf pressure conditions (35.15 ± 16.26 for 5 sec versus 41.17 ± 16.37 for 10 sec) compared with the 1.0-kgf conditions (11.97 ± 7.68 for 5 sec versus 16.51 ± 10.36 for 10 sec), combined (F_3 = 17.17; $P < .001$).

When observing different responses depending on the structures analyzed, we group them into three categories to determine whether the observed differences were significant: soft structures (first, second, third, and fourth IMTSs), bony structures (diaphysis second metatarsal, third metatarsal, dorsum hallux head, medial diaphysis hallux, medial hallux head, lateral fifth metatarsal head, lateral fifth metatarsal diaphysis, and fifth metatarsal apophysis), and the foot's sole structures (second, third, fourth, and fifth PPs) (Fig. 1). Figure 3 shows statistically significant differences in pressure sensitivity (1.0 versus 2.0 kgf) but not between times (5 versus 10 sec) in the three different structures analyzed.

Soft tissues seem to be the most sensitive to high and sustained pressures given that the ANOVA between the different structures (Fig. 3), with forces and intervals as fixed factors, revealed significant differences in soft-tissue pain sensitivity compared with PPs and bone structures $F_{(2)}$ = 10.39, $P < .001$) but not between bone tissues and PP structures ($P > .05$).

Pain in the Forefoot

Of all of the combinations of stimuli and points performed (total = 64 tests), 23.95% were painful. When applying the 2.0-kgf palpometer, 100% of the participants expressed feeling pain in at least one of the stimuli checked of the experimental protocol; however, only half of them (53.3%) felt pain when the 1.0-kgf palpometer was used. Frequencies of painful stimuli (established when the scores on the 0–100 NRS were ≥50, which was considered to be the pressure pain threshold) after random application of the palpometers calibrated according to pressure (1.0 kgf/0.785 cm^2 = 76.98 kPa and 2.0 kgf/0.785 cm^2 = 153.96 kPa) and interval of application (5 or 10 sec) for each of the points tested are shown in Figure 4. The 16 points analyzed are shown on the y-axis, ordered from bottom to top.

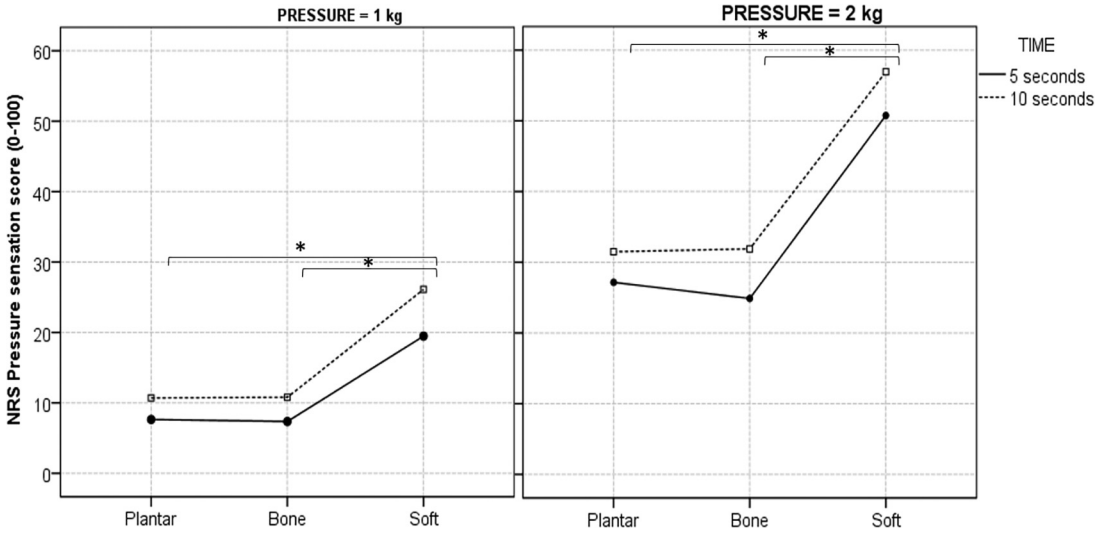


Figure 3. Comparison (analysis of variance) of mean differences in pressure sensitivity on the numeric rating scale (0–100 NRS) scores among plantar, bone, and soft structures of the forefoot by experimental condition. *$P < .05$.

Given the clear influence of the pressure on painful sensitivity, the measure likely to evoke pain when applying the maximum pressure was calculated (odds ratio), observing a significant increase in the odds of evoking painful sensations when using the 2.0-kgf palpometer compared with the 1.0-kgf palpometer (χ^2_1 test = 157.5; $P < .001$; odds ratio = 9.83). These differences can be observed in Figure 5.

Aftersensation and Referred Pain Analysis

A prolongation of pressure sensation after the stimulus disappeared (aftersensation) was observed in 8.02% of the total stimuli tested. The mean ± SD time of aftersensation was 0.12 ± 0.48 sec (range, 0–6 sec). Mean ± SD prolongation of the poststimulus sensation was significantly greater when the pressure applied was higher (0.04 ± 0.33 sec in 1.0 kgf versus 0.21 ± 0.72 sec in 2.0 kgf; t = –4.66; 95% confidence interval [CI], –0.24 to –0.98 sec; $P < .001$) and when the stimuli were painful (0.04 ± 0.21 sec versus 0.40 ± 0.85 sec; t = –10.41; 95% CI, –0.42 to –0.29 sec; $P < .001$) but not when the application time was longer (10 sec) (Fig. 6).

Referred sensations were observed in 60% of the participants when applying the 2.0-kgf palpometer at some intervals and some structures but only in 20% of them when using the 1.0-kgf palpometer. These referred sensations were significantly correlated with higher pressure sensations (mean ± SD 0–100 NRS scores, 25.40 ± 23.79 versus 60.45 ± 2589; t = –6.8; gl = 958; 95% CI, –45.14 to –24.96; $P < .001$) (Fig. 7) and painful stimuli (NRS score ≥50; χ^2_1 test = 35.12; $P < .001$). The forefoot points that evoked greater referred sensations were located in the dorsum of the forefoot, specifically in the diaphysis of the third metatarsal, followed by the fourth IMTS.

Discussion

In this study, we analyzed the pressure sensitivity at 16 points of the forefoot of healthy people. Forefoot pain is one of the main reasons for podiatric medical consultation.[2–4] Recent studies report the palpation method of joint and periarticular soft tissues as a key to identify injured structures.[13,14,21] It is generally accepted that the pain reported by the patient during palpation occurs when tissues are injured and that, in theory, healthy tissues should not cause any pain during ordinary palpation, but the force we apply could influence the results. Thus, in the present study we assessed pressure pain sensitivity by using two palpometers calibrated to exert 1.0 kgf (1.0 kgf/0.785 cm^2 = 76.98 kPa) and 2.0 kgf (2.0 kgf/0.785 cm^2 = 153.96 kPa) of pressure. These instruments had been previously validated in other studies.[13,15] It can be reasonably assumed that the pressure supported by the forefoot structures is greater than the force applied in this study so that stimuli theoretically should not produce pain. The sample analyzed was composed of healthy individuals free of pain in the forefoot and with a score of 0 on the AAOS-FAMsp scale.[17] The present results show that the 2.0-kgf

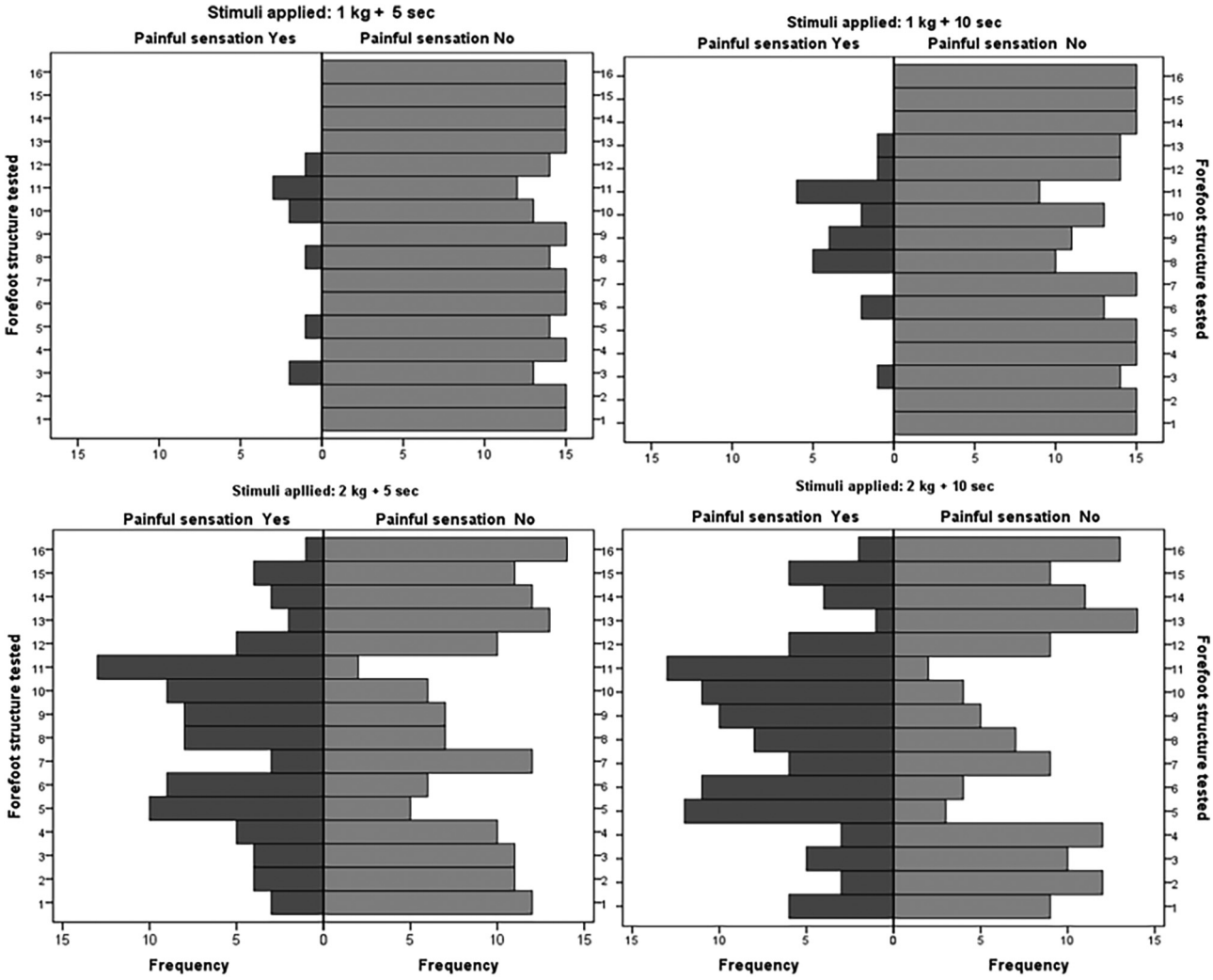


Figure 4. Frequency of painful stimuli in all of the experimental scenarios. Correspondence of the 16 points of the forefoot structures on the ordinate axis is as follows: 1, second plantar plate (PP); 2, third PP; 3, fourth PP; 4, fifth PP; 5, diaphysis second metatarsal; 6, diaphysis third metatarsal; 7, dorsum hallux head; 8, first intermetatarsal space (IMTS); 9, second IMTS; 10, third IMTS; 11, fourth IMTS; 12, medial diaphysis hallux; 13, medial hallux head; 14, lateral fifth metatarsal head; 15, lateral fifth metatarsal diaphysis; and 16, fifth metatarsal apophysis.

(153.96-kPa) palpometer produced painful sensations in all of the participants in some of the structures, calculating an odds ratio of pain 9.83 times greater than when applying the 1.0-kgf (76.98-kPa) palpometer. It was also observed that 53.3% of the participants presented pain in some of the foot structures when applying 76.98 kPa of pressure. In addition, we note that pain sensitivity increased significantly when 153.96 kPa of pressure was used. In patients with chronic forefoot pain, pressure pain thresholds are lower, as stated by Fernández-Lao et al.[22] Although, to our knowledge, there are no pressure pain threshold values in patients with forefoot pathologies, we could hypothesize that the ideal pressure to perform a forefoot examination to avoid false-positives or false-negatives would be approximately 1.0 kgf/cm^2. Therefore, it would be desirable for future studies to analyze this situation to establish adequate ranges of digital pressure scans to avoid misinterpretations.

Comparing the pressure sensitivity between soft and bony structures, we found that the pressure exerted on the soft tissues showed a significantly lower pain threshold than on the bone or PP structures. Specifically, the present findings point out that we must be careful when exploring IMTSs

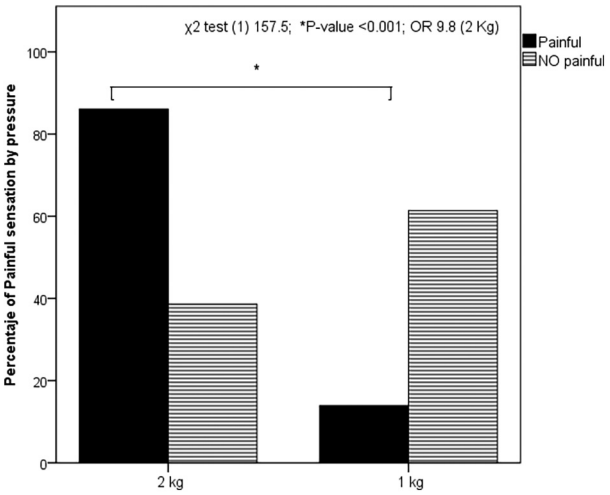


Figure 5. Measure of painful stimuli by increasing pressure from 1.0 kg (76.98-kPa) to 2.0 kg (153.96-kPa) palpometers in the total sample studied. *$P < .05$.

during clinical assessment to avoid triggering pain due to the magnitude of pressure applied rather than the fact that the structure is injured. These results are in line with those of other studies that note different sensitivities on the foot, pointing out that the sole of the foot and the lateral structures of the foot show higher thresholds of tolerance to pain, and interdigital areas are the most sensitive to pain.[23] Rolke et al[24] also described this relationship when they compared the pressure threshold

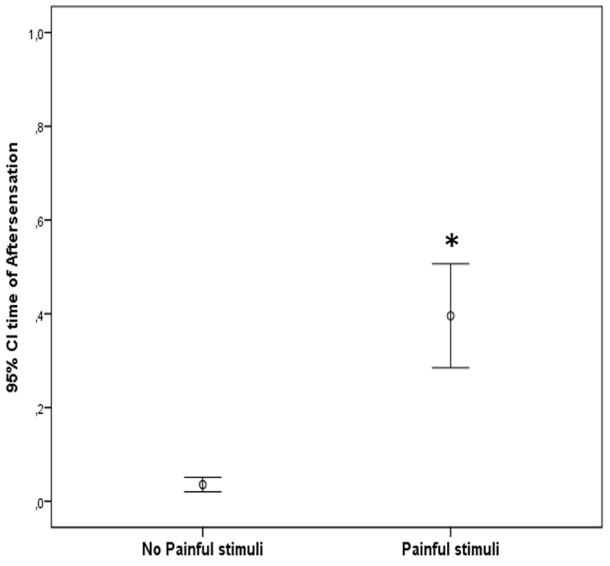


Figure 6. Aftersensation related to painful or painless stimuli. Error bars represent 95% confidence intervals. *$P < .05$.

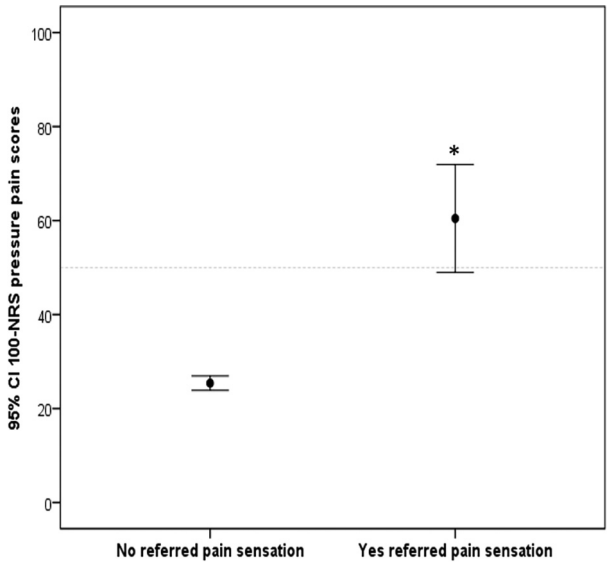


Figure 7. Referred pain sensations correlated with pressure sensitivity on the numeric rating scale (0–100 NRS). The dotted line marks the pressure pain threshold (50 NRS). *$P < .05$. Error bars represent 95% confidence intervals.

between muscles and bony structures in the foot, probably related to the adaptation in the ball of the foot to endure the great pressures exercised during gait and running. The painful sensitivity to pressure could also be related to the size of the tip of the instrument, decreasing the pain threshold when the surface of the stimulus is smaller in diameter, as described by Xiong et al[25] in their study performed in a laboratory with an indentation apparatus. In the present study, the palpometers had a circle area of 0.785 cm^2 (1 cm in diameter), similar to the fingertip of the clinical examiners, which facilitates the extrapolation of the results obtained.

Sporadically during the routine examination some patients state feeling discomfort or painful sensations in another point away from the site of palpation, that is, referred sensations, and this situation may generate doubts in the podiatric physician. In this sense, note that in the present study, conducted in healthy individuals, we found that 60% of the participants reported referred sensations when using the 2.0-kgf (153.96-kPa) palpometers but only 20% when using pressure stimuli of 76.98 kPa. These findings could suggest that during clinical examination referred sensations can be triggered because of the magnitude of the applied pressure. The areas of the forefoot that evoked the greatest number of referred sensations were the diaphysis of the third metatarsal and the fourth IMTS. The sites of the forefoot that evoked the greatest number of

referred sensations were the diaphysis of the third metatarsal and the fourth IMTS.

The last objective of this study was to examine the relationship between the intensity of the pressure and the time to recovery of the baseline sensitivity after applying the force of the palpometers (aftersensation). We found that 8% of the participants with a painful sensation had a longer mean ± SD time to recovery (0.12 ± 0.48 sec). This finding should be taken into account much more when exploring a painful forefoot and not applying a new stimulus until the aftersensations triggered by the previous stimulus have disappeared.[26] Special care is also necessary when exploring contiguous anatomical structures.

The present study has some limitations. Because the study was performed with healthy participants free of forefoot pain, the results cannot be extrapolated to patients with chronic forefoot pain or with systemic pathologies that may cause changes in painful perception to normal stimuli.

Conclusions

The different forefoot structures studied show greater sensitivity to pain when pressures of 153.96 kPa are applied: soft structures had the lowest pain thresholds, especially IMTS, and bone structures showed the greatest pain tolerance. The 153.96-kPa stimuli also evoked more referred sensations to other areas of the foot than the stimulated one and a longer time to recover the normal sensitivity once the pressure stimulus has disappeared. However, more research is needed to better understand the pain response to pressure during digital palpation of the forefoot in the podiatric medical assistance routine.

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