The Relationship between Heel Pad Compressibility Index, Age, Body Mass Index and Foot Area Contact in Calcanea Spur Patients

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Abstract

This study was performed to investigate the relationship between heel pad compressibility index (HPCI), age, body mass index (BMI) and (FAC) for calcanea/heel spur patients. Thirteen patients with a symptomatic heel spur (3 males and 10 females) participated in this study. The HPCI increased with age and HPCI of the elderly is greater than the adult. The HPCI increased with pain minimum compressive pressure (PMCP) indicated HPCI are all significantly greater in patients with plantar heel pain than in normal subjects. The BMI increased with FAC is caused by BMI and FAC of males is greater than females. The PMCP decreased with BMI indicated that patient with excessive body mass will make experience more pain. The result of pain measurement showed that there are 7 patients who indicated the abnormality (the PMCP value is lower than 2 kg/cm^2). From this study, it can be concluded that the quantitatively pain level is worst when PMCP< 2.0 kg/cm^2, it is severe when 3.0> PMCP ≥ 2.0 kg/cm^2 and it is moderate when PMCP≥3.0 kg/cm^2.

Keywords: calcanea spur, heel pad compressibility index, pain minimum compressive pressure, age, BMI

1. Introduction

Plantar heel pain caused by calcaneal/heel spur is defined as insertional heel pain of the plantar fascia with a inferior heel spur [1]. This pain is tenderness beneath the heel which is typically severe in the morning and improve after a routine daily weight bearing activity [2]. Patient with excessive body mass will experience more pain and can cause serious plantar fasciitis which makes the patient cannot walk [3]. A variety of treatment options are available, but the precise etiology must be known. The most common treatment performed for patient with heel spur syndrome is by taking a nonsteroidal anti-inflammatory drug for a certain time or corticosteroid injections or by using orthotic shoe to reduce heel pressure [1][4].

Pressure distribution on the foot depends on many factors such as body mass index (BMI) [5], gender [6], foot type or foot area of contact (FAC) [7] and the type of activity performed [8]. Foot deformities are generally caused by excessive pressure mainly due to the mechanical properties of the plantar soft tissues and different in young and aged adults. Previous research studies reported that heel pad deformities are influenced by aging expressed by the average heel pad compressibility index (HPCI) was smaller in the young people than in the elderly people [9]. The results also demonstrated that heel pad thickness, HPCI and BMI were all significantly greater in patients with plantar heel pain than in normal subjects [10,11].

This study aimed to determine both the heel pad thickness and its compressibility in patients with plantar heel pain caused by calcaneal spur and relate them to age, FAC and BMI.

2. Materials and Methods

Twenty six patients with complaints of plantar fasciitis from the Medical Records Section of RSUD (local public hospital) Tugurejo Semarang selected by an orthopaedic specialist to sort out the patients who feel pain only caused by calcaneal spur based on medical records and x-rays [12]. From 26 patients, there are 13 patients who suffer from calcaneal spur with the characteristics as shown in Table 1.

Table 1: Subject characteristics

Gender (male : female)	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
3 : 10	56 ± 10	61.3 ± 9.0	155.6 ± 7.6	25.5 ± 3.7

(N = 13) Values are expressed as mean ± standard deviation

The ages of the patients can be divided into two groups which are adults with age between 18-50 years old [11] [13] consisting of one male and four females and elderly with age between 51-75 years old [14] consisting of two males and six females. The patients' jobs vary from 3 civil servants (1 male and 2 females) whose activities need to stand up and walk often, 3 females factory workers whose activities need to stand up often, 1 female entrepreneurer whose activities need to stand up and walk often, 3 unemployed people (2 the males and 1 female) whose activities need to stand up often and 3 housewifes whose activities need to stand up often. These patients have been suffering from heel pain due to calcaneal spur since 1.5 years ago in average and the treatment was only by taking a nonsteroidal anti-inflammatory drug and/or corticosteroid injections. Surgery procedure was never done since the last 10 years because the patient complains that their foot could not be used to walk after the surgery and an infection happened because patients' living environment was not clean [12].

Calcaneal spur location and dimension of each patient was determined by lateral x-ray, where L is the length of spur (Fig. 1a). Pain in the heel area of each patient was inspected by giving emphasis around the spur growth. Therefore, the location and dimension of the spur must be plotted in plantar view by using digital footprint (Fig. 1b) [15]. In this study, the base of the spur is assumed to be located in the heel centre line which is a line drawn from the centre of the heel to the tip of the second toe (Fig. 1c) [16].

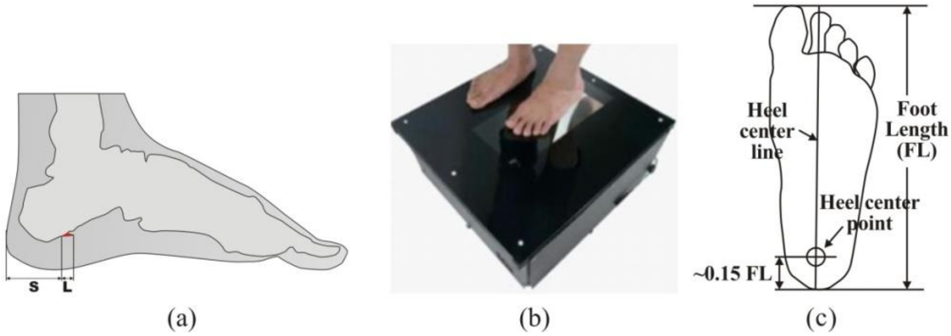

Figure 1. Determination of spur location in plantar view

Research ethics committee guidelines relating to the use of patients of RSUD (local public hospital) Tugurejo for research purposes were duly followed. All subjects had no pain in the foot apart from calcaneal spur. Pain test is done by pressing certain points on the heel area by using a rigid stick with 1.0 cm or more in diameter and when the test was done, the subjects did not consume medicines/painkillers. The purpose of inspection is only to identify the location in heel area that results the minimum compressive pressure which can be known from the patient's facial expression (can be rated on a scale of 0 to 10 qualitatively, Fig. 2a) [17].

In this study, the pain test is conducted by using Algometer (FDIX 25, Wagner Instruments, Greenwich CT, USA), as shown in Fig. 2b [18]. This device consists of a flat rubber tip probe of 1 cm in diameter, which is applied perpendicular to the skin and the pressure is transmitted to a load cell and a voltage output is produced. The signal is transduced and amplified and the output is displayed in newtons or kilograms (pressure is equal to force divided by the probe area). Pressure threshold is lower than 2 kg/cm^2 at the insertion of the plantar fascia at the medial tuberosity of the calcaneus expresses quantitatively the degree which is considered abnormal [19]. There are five pain compressive points specified in this study where the 5th point is set at the base of the spur and 4th point is at the end of a spur, another 3 points are made to be around the spur with the radius equal to spur length is added with 1 cm as shown in Fig. 2c [20].

There are 5 steps of pain test to follow: 1) mark the 5 pressure points around spur growth with marker (Fig 2c), 2) press the skin at 5th point which has set first, 3) increase the pressure gradually and stop until the patient's face expression looks like level 6 or 7 (Fig 2a), 4) take a note on the pressure value that causes pain; 5) apply the same pressuring procedure at point 4; point 3; point 2 and point 1. From the record of quantitative data of pain test results at those 5 points of pressuring can be revealed the pain minimum compressive pressure (PMCP) and the point location in each patient. Suppression at the end of spur should produce a minimum pain compressive pressure because it is identical to the cantilever beam construction. All the pain tests were carried out at the orthopaedic sub-section of RSUD Tugurejo.

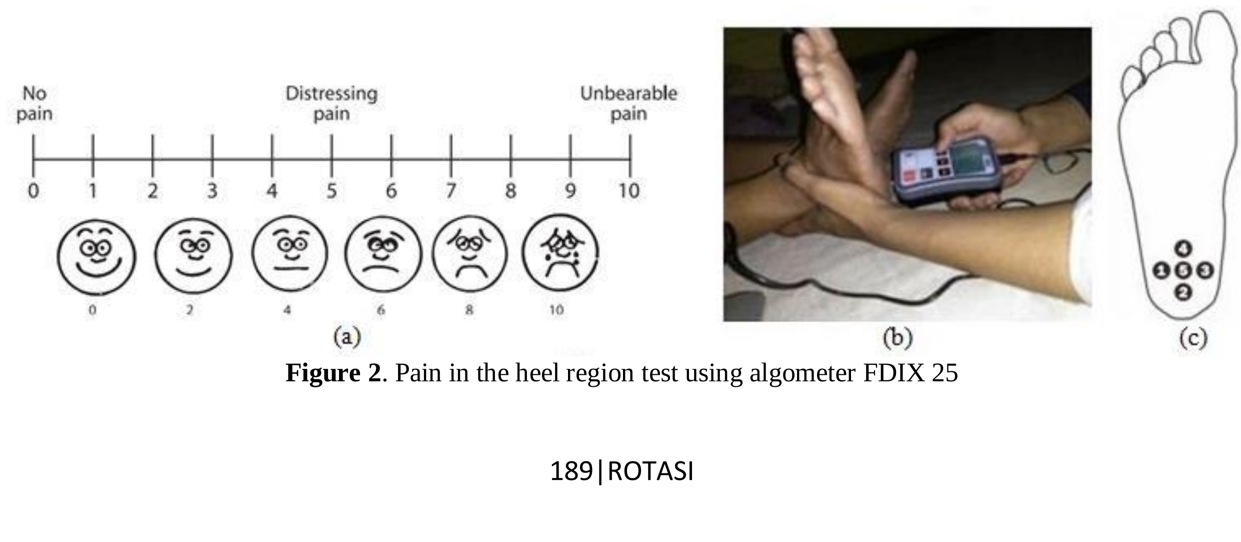

Figure 2. Pain in the heel region test using algometer FDIX 25

Foot area contact (FAC) is the entire foot area of footprint image from digital footprint result (Fig. 1b) after the part which is not in contact with the platform is removed. Calculating the FAC (in mm^2) is done by using *bwarea* function in MATLAB software with the scanner resolution of 200 dpi (default setting of the scanner). This instrument is made by itself as a modified flatbed document scanner which is capable of measuring in addition to FAC, foot length (FL), foot width (FW), shoe size and foot type (high arch, normal, flat foot) and has obtained a patent with No. IDS000002253 [21].

Heel pad compressibility index (HPCI) is defined as the ratio of the heel pad thickness in loaded conditions (LHPT) to unloaded positions (ULHPT) [10] [22]. If HPCI is close to 1 then the heel pad presents a high stiffness. ULHPT is the distance from the unloaded skin line (YU) to the line of the plantar tuberosity of the calcaneum (YO), while LHPT is the distance from the loaded skin line (YL) to YO (Fig. 3). Distance from YU to YL indicates the amount of heel pad deformation due to own weight. Both ULHPT and LHPT are measured by using lateral x-ray imaging of the region from skin to bone [10]. ULHPT was measured in a recumbent position. To measure the heel pad thickness under static loads, the subjects were instructed to stand on a flat bench which 50 cm in height by crossing the legs (the right leg is in the front first and the left leg is behind). By using lateral x-ray, both ULHPT and LHPT can be measured.

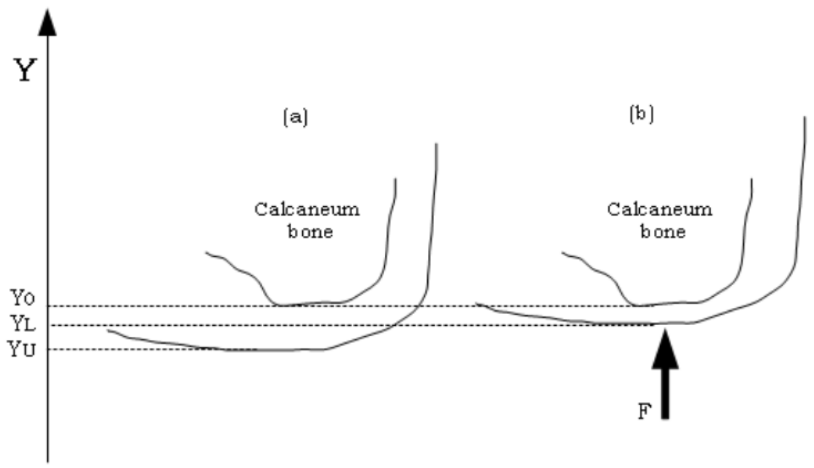

Figure 3. Schematic illustration of unloaded (a) and loaded (b) heel pad

3. Results and Discussion

3.1. Results

A general description of the study population is given in Table 2. From 13 patients, there are 7 patients who suffer calcaneal spur on two feet. Testing pressure of pain in these patients is done in both right and left foot so that there are a total of 20 sets of testing tap pain. Only the smallest pressure pain recorded from patients who suffer calcanea spur on two feet is used as the basis for the evaluation of pain.

The results demonstrated that the average length of spur of all subjects is 5.0 mm (range 1.5-7 mm). The amount of PMCP is varying, the smallest one is 1.17 kg/cm^2 and the largest one is 3.30 kg/cm^2 while the average is 1.99 ± 0.67 kg/cm^2. From 13 patients, there are 7 patients whose PMCP is below 2 kg/cm^2. The location points of PMCP at 1st point are 5, at the 2nd point is 1, at the 4th point are 11 and 3 are at the 5th point.

The average of the FAC of adults and elderly is quite the same but males have averages of FAC is 14% greater than females. The average of LHPT of elderly is greater than adults and males have averages of LHPT which is 20.8% greater than females. The average of HPCI of elderly is also greater than adults, which is 21.4%, but the average of HPCI in males and females are quite the same.

Table 2: Characteristics of the study population

Subject Factors	Age (years)	FAC (mm^2)	ULHPT (mm)	LHPT (mm)	HPCI	Length of Spur (mm)	PMCP (kg/cm^2)
All Subjects							
Mean	56	11173	20.18	12.85	0.64	5	1.99
SD	10	2201	2.44	2.18	0.11	2	0.67
Range	38–73	8800–14317	17.10–24.50	9.9–17.5	0.50–0.84	1.5–7.0	1.17–3.30

Adults							
Mean	46	11260	20.98	11.47	0.55	4.0	1.83
SD	5	1917	2.89	1.78	0.06	1.6	0.43
Range	38–50	9206–13529	17.50–24.50	9.9–14.2	0.50–0.63	2.0–6.0	1.24–2.32
Elderly							
Mean	63	11119	19.68	13.71	0.70	4.8	2.09
SD	6	2489	2.17	2.03	0.09	1.9	0.80
Range	54–73	6777–14317	17.10–23.30	11.0–17.5	0.61–0.84	1.5–7.0	1.17–3.30
Males							
Mean	61	12518	22.50	15.30	0.69	5.0	2.13
SD	13	987	1.47	1.91	0.13	2.0	1.08
Range	47–73	11379–13112	20.80–23.40	14.2–17.5	0.61–0.84	3.0–7.0	1.17–3.30
Females							
Mean	55	10769	19.48	12.12	0.63	4.0	1.95
SD	9	2336	2.26	1.71	0.10	2.0	0.58
Range	38–68	6777–14317	17.10–24.50	9.9–14.9	0.50–0.76	1.5–7.0	1.19–2.95

(N = 13, adults=5 and elderly=8, males=3 and females=10)

Table 3 shows the relationship between age and heel pad deformation (YU-YL), age and HPCI, BMI and FAC, BMI and PMCP, length of spur (LOS) and PMCP, and PMCP and HPCI. The results indicated that there is no correlation in age and FAC, age and PMCP, BMI and HPCI, and FAC and HPCI. The relation between age and heel pad deformation can be presented by linear regression with correlation coefficient of 0.77 which shows that the higher the age, the lower its heel pad deformation. The relation between age and HPCI can be presented by order 2 polynomial regression with correlation coefficient of 0.78 which shows that the higher the age, the higher its HPCI value.

There is a significant correlation between BMI and FAC with correlation coefficient of 0.73 which shows that the higher the BMI, the higher its FAC value. The same results are also shown in the correlation between PMCP and HPCI which shows that the higher the PMCP, the higher its HPCI value. For the relation between BMI and PMCP, it shows that the higher the BMI, the lower its PMCP. For the relation between LOS and PMCP shows that the longer the spur, the lower its PMCP.

Table 3: The relationship between age, BMI, FAC and HPCI for calcanea spur

Correlation Between	Regression Equation	Correlation coefficient (r)	Results
Age (years)			
Age, x vs (YU-YL), y	$y = -0.209x + 19.12$	0.77	↑Age, ↓(YU-YO)
Age, x vs HPCI, y	$y = 1E\text{-}04x^2 - 0.0002x + 0.459$	0.78	↑Age, ↑HPCI
BMI (kg/m^2)			
BMI, x vs FAC, y	$y = 429.4x + 209.6$	0.73	↑BMI, ↑FAC
BMI, x vs PMCP, y	$y = 0.005x^2 - 0.418x + 8.630$	0.60	↑BMI, ↓PMCP
LOS (mm)			
LOS, x vs PMCP, y	$y = -0.275x + 3.233$	0.71	↑LOS, ↓PMCP
PMCP (kg/cm^2)			
PMCP, x vs HPCI, y	$y = 0.116x^2 - 0.412x + 0.954$	0.72	↑PMCP, ↑HPCI

The relations are calculated for all subjects. YU, unloaded heel pad thickness in mm; YL, loaded heel pad thickness in mm; (YU-YL), heel pad deformation in mm

3.2. Discussion

The results of pain pressure tests in 13 patients shows that the smallest pain pressure occurs mostly at the location of the point 4 (55%). This is consistent with the REALITY that the compressive on the end of spur produces the smallest pain pressure. From the relation between LOS and PMCP is also consistent with the REALITY that the longer the spur, the greater the bending moment occured at the base of the spur. The result also shows that there are 7 patients which are indicates as abnormal presented by the PMCP which is smaller than 2 kg/cm^2 [19].

The value of PMCP pain test results vary from 1.17 to 3:30 kg/cm^2. This values are the minimum pressure that causes pain at certain points around the spur growth which are estimated based on the patient's facial expression (Fig. 2b) which were estimated based on the same patient's facial expression (at the level of the pain 6 or 7 equivalently) while were pressed by using algometer [17-18]. The results of this test can be made the level of the pain quantitatively. The type of pain is called worst when $PMCP<2.0$ kg/cm^2, is called severe when $3.0>PMCP\geq2.0$ kg/cm^2, is called moderate when $PMCP\geq3.0$ kg/cm^2 and is called minor when $PMCP\geq3.0$ kg/cm^2. Patients who categorized as worst pain are 7 persons, as severe pains are 5 persons and as moderate pain is 1 person.

The average of FAC of males is greater than females [6][23]. The correlation between BMI and FAC which is presented by linear regression (Table 3) is caused by the average of BMI of male (26.36 ± 0.65 kg/m^2) is greater than female (25.28 ± 4:27 kg/m^2) [24]. The correlation between BMI and PMCP which shows the higher the BMI, the lower its PMCP means the patients with excessive body mass will experience more pain [3].

This study proved that there is no relation between BMI and HPCI which is different from the result of the research conducted by Prichasuk et al. that compared HPCI to normal weight and overweight subjects [25]. In this study, there are 7 patients with BMI that is classified as normal weight, 5 patients as overweight and 1 patient as obese.

The average of ULHPT in males is greater than in females, which is 22.5 ± 1.47 mm and 19:48 ± 2.26 mm respectively [10]. The opposite condition occurs in adults and elderly groups, which is 20.98 ± 2.89 mm and 19.68 ± 2.17 mm respectively [9]. That is caused by the small number of research subjects. The average of LHPT of the elderly group is greater than the adult group, which is 13.71 ± 2.03 mm and 11.47 ± 1.78 mm respectively. The average of HPCI of the elderly group is also greater than the adult group, which is 0.70 ± 0.09 and 0.55 ± 0.06 respectively. These results, according to Kinoshita et al., indicated the loss of the elasticity of the heel pad in aged adults. According to the relationship between age and heel pad deformation (YU-YL), it is also indicated that the energy absorbed is less for the elderly than for the adults [9].

These results are consistent with the relation between age and HPCI which indicated the loss of the elasticity of the heel pad in aged adults [9]. According to the relation between age and heel pad deformation (YU-YL) is also indicated that the energy absorbed is less for the elderly than for the adults [9]. The average of PMCP is increased along with the increasing value of HPCI. These results are consistent with the research carried out by Somchai P. which proved that HPCI were all significantly greater in patients with plantar heel pain than in normal subjects [10].

4. Conclusion

The HPCI increased with age and HPCI of the elderly is greater than the adult which is indicated the loss of the elasticity of the heel pad in aged adults. The heel pad deformation decreased with age, it is also indicated that the energy absorbed is less for the elderly than for the adults. The HPCI increased with PMCP indicated HPCI are all significantly greater in patients with plantar heel pain than in normal subjects.

The BMI increased with FAC due to BMI and FAC of males is greater than females. The PMCP decreased with BMI indicated that patient with excessive body mass will experience more pain.

Pressure algometry can objectively and quantitatively document the improvement that corresponds to relief of pain which indicated that there is abnormality showed by the PMCP value is lower than 2 kg/cm^2. From the result of pain test, it can be determined a quantitatively pain level: worst when PMCP< 2.0 kg/cm^2, severe when 3.0> PMCP ≥ 2.0 kg/cm^2 and moderate when PMCP≥3.0 kg/cm^2. These pain levels are very beneficial for orthopedic doctors in determining the dosage of pills/injections of pain killer and for *orthotic* shoes designer to modify the pressure in heel area.

References

1) James L. Thomas, Jeffrey C. Christensen, Steven R. Kravitz, et al. The Diagnosis and treatment of heel pain: a clinical practice guideline – revision 2010. The The Journal of Foot & Ankle Surgery, Vol. 40, No. 5, pages 329-340, 2010, Elsevier
2) D. Scot Malay. Plantar fasciitis and heel spur syndrome: A retrospective analysis. Book Chapter – Chapter 7, The Podiatry Institute, 1996
3) James J. Hill and Paul J. Cutting. Heel pain and body weight. Foot ankle int, 9:254-255, 1989
4) M. A. Turlik, T.J. Donatelli, M.G. Veremis. A Comparison of Shoe Inserts in Relieving Mechanical Heel Pain. The Foot (1999), 9: 84 – 87
5) Asanka S. Rodrigo, Ravindra S. Goonetilleke and Shuping Xiong (2013). Load distribution to minimize pressure-related pain on foot: a model. Ergonomics, 56:7, 1180-1193, DOI: 10.1080/00140139.2013.797111
6) R. Periyasamy, A. Mishra, Sneh Anand, et al. Preliminary investigation of foot pressure distribution variation in men and women adults while standing. The Foot 21 (2011) 142-148
7) Bavornrit Chuckpaiwong, James A.Nunley, Nathan A.Mall, et al. The effect of foot type on in-shoe plantar pressure during walking and running. Gait & Posture 28 (2008) 405 – 411, Elsevier
8) Mary M. Rodgers. Dynamic biomechanics of the normal foot and ankle during walking and running. Physical Therapy 68 (12): 1822-1830, 1988
9) Kinoshita H., Francio P.R., Murase T., et al. The mechanical properties of the heel pad in elderly adults. European Journal of Applied Physiology. Vol. 73, pp. 404-409, 1996.
10) Somchai Prichasuk. The heel pad in plantar heel pain. J Bone Joint Surg [Br] 1994; 76-B: 140-2.
11) Keith Rome, Robert Campbell, Allison Flint, et al. Heel pad thickness – a contributing factor associated with plantar heel pain in young adults. Foot & Ankle International. Vol. 23, No. 2, February 2001, DOI:10.1177/107110070202300211
12) Medical Record Sub-Section RSUD (Local Public Hospital) Tugurejo Semarang, 2016

13) Narelle Wyndow, Amy De Jong, Krystal Rial, et al. The relationship of foot and ankle mobility to the frontal plane projection angle in asymptomatic adults. Journal of Foot and Ankle Research (2016) 9:3, DOI: 10.1186/s 13047-016-0134-9
14) Tzu-Hsuan Chen, Li-Wei Chou, Mei-Wun Tsai, et al. Effectiveness of a heel cup with an Arch Support Insole on The Standing Balance of The Elderly. Clinical Intervention in Aging, 2014: 9 351-356
15) Dwi Basuki Wibowo, Gunawan Dwi Haryadi, Achmad Widodo, Sri Puji Rahayu. Correlation of loaded and unloaded foot area with arch index in younger flatfoot. International Conference on Mechanical and Manufacturing Engineering (ICME2016), Jogjakarta
16) Peter R. Cavanagh and Mary M. Rodgers. The Arch index: a useful measure from footprints. J. Biomechanics Vol. 20, No. 5, pp. 547-551, 1987
17) Holy Redeemer. Pain Level Chart. (https://lane.stanford.edu/portals/cvicu/HCP_Neuro_Tab_4/0-10_Pain_Scale.pdf)
18) Wagner Instruments. Wagner FPTX Series Economy Manual Pain Threshold Testers. PAIN TEST™ ALGOMETER, USA
19) David S. Butler and G. Lorimer Moseley. Explain pain. Noigroup Publication; Adelaide, Australia, 2003
20) Wibowo, DB.; Suprihanto, A.; Widodo, A.; Rahayu, SP. Methods for designing orthotic shoes for inferior calcanea spur patients. Patent No. IDS000002663, 3 Dec 2019
21) Haryadi, GD.; Wibowo, DB.; Ariyanto, M.; Suprihanto, A.. Digital scanning method for evaluation of dimensional parameters and identification of foot type. Patent No. IDS000002253, 2 April 2019
22) Sara Matteoli, Jens E. Wilhjelm and Soren Torp-Pedersen. Some of the factors influencing the heel pad compressibility index (HPCI). The international conference on the Ultrasonic Measurement and Imaging of Tissue Elasticity, 2009
23) Yu-Chi Lee, Gloria Lin and Mao-Jiun J Wang. Comparing 3D foot scanning with conventional measurement method. Journal of Foot and Ankle Research 2014, 7:44
24) Roshna E. Wunderlich and Peter R. Cavnagh, 2001. Gender differences in adult foot shape: Implications for shoe design. Med. Sci. Sports Exer., 33: 605-611.
25) Somchai Prichasuk, Pornchai Mulpruek and Pimjai Siriwongpairat. The heel pad compressibility. Clinical Orthopaedics and Related Research, Vol. 300, pp. 197-200, 1994.