European Review for Medical and Pharmacological Sciences 2022; 26: 6236-6241

Abnormal foot pressure in older adults with knee osteoarthritis: a systematic review

P. PANYARACHUN[1], C. ANGTHONG[1], P. JINDASAKCHAI[1], P. RAJBHANDARI[2], N. RUNGRATTANAWILAI[3]

[1]Faculty of Medicine, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
[2]Department of Orthopaedic Surgery, RIPAS Hospital, Bandar Seri Begawan, Brunei
[3]Department of Orthopaedics, Queen Sirikit Naval Hospital, Royal Thai Navy, Cholburi, Thailand

Abstract. – OBJECTIVE: Knee osteoarthritis (KOA) is a progressive disease affecting the biomechanics of the knee and other parts of the lower extremities, such as the ankle and foot. Little is known about the pathophysiology of plantar pressure in patients with KOA, which could lead to foot disability. This review aimed to provide more in-depth information regarding the pathophysiology of plantar pressure patterns and their related parameters in older adults with KOA.

MATERIALS AND METHODS: Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, the PubMed database was searched with the keywords "foot pressure and knee osteoarthritis" and "center of pressure and knee osteoarthritis". The eligible articles were evaluated based on five characteristics: KOA stages, sample size, country, study tool, and findings. The primary outcomes were plantar pressure and center of pressure (COP) in each area. Other outcomes were also evaluated, such as knee flexion angle, knee abductor moment, and clinical scores.

RESULTS: Nine full-text articles were eligible for review, including 495 participants (256 patients with KOA and 239 healthy individuals). The mean age of patients with KOA was 60.2-77 years. Patients with KOA had a higher tendency for pronounced plantar pressure on the medial forefoot, mid-foot, or the foot's central area. The COP patterns were shorter and more lateralized in patients with KOA, reflecting the functional ability, pain, and well-being of patients with KOA.

CONCLUSIONS: Abnormalities in plantar pressure and COP were observed in older adults with KOA. This information could be a basis for designing biomedical devices, orthoses, and other realignment osteotomies of the lower extremities that could relieve symptoms at the knee or foot, or reduce KOA progression.

Key Words:
Knee osteoarthritis, Plantar pressure, Center of pressure, Foot.

Introduction

Knee osteoarthritis (KOA) is a progressive disease affecting older adults worldwide. Globally, the incidence of KOA is 203 per 10,000 person-years[1] and shows an increasing trend owing to the increasingly aging population and obesity prevalence. KOA is a long-term degenerative joint disease characterized by cartilage destruction, which results in osteophytes, inflammation, and pain[2,3]. This leads to limited knee joint motion, and stiffness results in functional disabilities, affecting patients' quality of life. In addition to the alterations in knee biomechanics that create knee disability in patients with KOA, it is important to address the changes in plantar pressure for the comprehensive evaluation of the patients' lower extremities.

Although KOA has been studied extensively, little is known about the pathophysiology of plantar pressure in patients with KOA, which could lead to foot disability. This systematic review aimed to provide more in-depth information regarding the pathophysiology of plantar pressure patterns and their related parameters in older adults with KOA.

Materials and Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) g uidelines (Figure 1)[4]. The literature search was conducted using the PubMed database using the keywords "foot pressure and knee osteoarthritis" and "center of pressure and knee osteoarthritis". The reference lists of the identified trials and reviews were also manually searched for further references. The searched articles were subject to the following in-

Corresponding Author: Chayanin Angthong, MD, Ph.D; e-mail: chatthara@yahoo.com

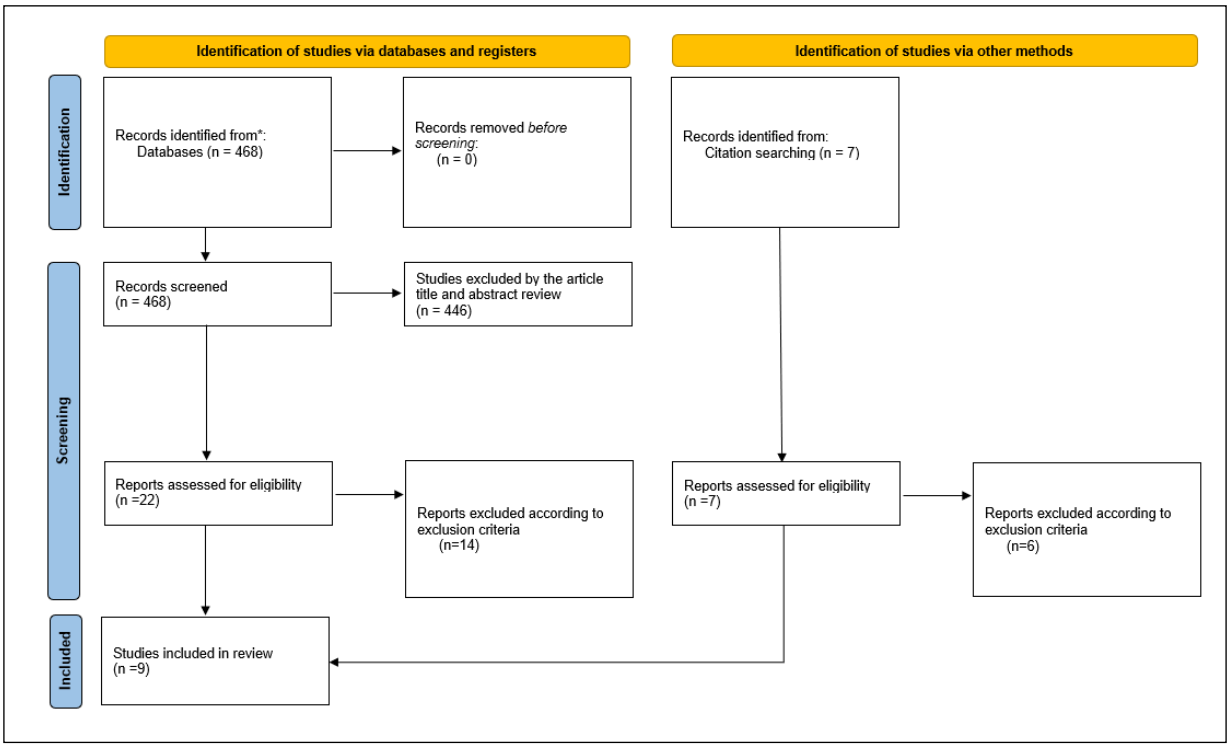

Figure 1. PRISMA flow diagram.

clusion and exclusion criteria. The inclusion criteria were: 1) articles including all search terms; 2) articles published after 2010; 3) articles of these study types: cross-sectional studies, randomized control trials, or cohort studies; 4) English language articles, and 5) the number of participants was >20. The exclusion criteria were as follows: 1) other sites of osteoarthritis (e.g., foot osteoarthritis), and 2) the full text was unavailable.

The eligible articles were evaluated for five characteristics: KOA stage, sample size, country, study tool, and findings. The primary outcomes were center of pressure (COP) and plantar pressure in each area. Other outcomes were also evaluated, such as knee flexion angle, knee abductor moment, and subscales of the Knee Injury and Osteoarthritis Outcome Scale (KOOS), which are activities of daily living (ADL) and quality of life (QOL). The quality of the included studies was assessed using the Newcastle Ottawa Quality Assessment Scale[5,6]. In addition, each eligible study was reviewed by two independent reviewers (PP and PJ). The findings represented a consensus in cases of similar agreements. The ultimate conclusion was made by the senior author (CA) if there was no agreement between the previous reviewers. Regarding the Ethical Committee approval, this paper did not involve the direct study of human subjects due to its design as a systematic review; therefore, it was not considered within the criteria to review and obtain approval *via* the authors' institutional Ethical Committees.

Results

A total of 468 studies were identified following an initial search using the outlined search strategy. Duplicate publications were excluded from this review. After reviewing the articles' titles and abstracts, 22 studies remained. These studies were then evaluated to identify those that matched the inclusion criteria. Nine full-text articles were eligible for the overall criteria and were included in the final review. Regarding the statistical analysis, this study presents the review data in general due to its form as a systematic review; therefore, a specific method of statistical analysis was not implemeted in this study. Nine studies were evaluated for five characteristics: KOA stage, sample size, country, study tool, and findings. The total number of participants was 495 (256 patients with KOA and 239 healthy individuals). The mean age of patients with KOA was 60.2-77 years. Various

Table I. Summary of comparisons for plantar pressure in knee osteoarthritis.

Study	KOA stages	Sample size	Country	Tool	Findings
Muñoz-Organero et al[7]	Patients with KOA with no severe pain (a perceived pain score of 5 or less on the previous scale	28 (14 KOA patients and 14 healthy individuals)	United Kingdom	Insole sensor (Kinematix company)	Patients with KOA delay the pressure transition from the heel to midfoot loading. Also, there is less prominent peak pressure on the heel than that in healthy adults.
Saito et al[8]	Moderate to severe (KL grades 3 or 4)	144 (50 patients with KOA and 94 healthy individuals [50 young individuals and 44 older adults])	Japan	Insole sensor (F-scan)	Patients with KOA have lower partial foot pressures (%PFP) on the heel and hallux, whereas higher partial pressure on the central part of the foot. They also had shorter COP length and a limited range of knee extension than that of healthy adults.
Saito et al[9]	Severe, requiring total knee arthroplasty (TKA)	118 (64 patients with KOA and 54 healthy individuals)	Japan	Insole sensor (F-scan)	Patients with KOA exhibited low %PFP of the medial heel, lateral heel, hallux, and lateral toe before TKA. Also, a significantly higher %PFP was found in the central region compared with the control group. The anteroposterior length and transverse width of the COP path in the TKA groups were significantly shorter in patients with KOA.
Zhang et al[10]	Mild to moderate KOA (Lequesne Knee Score, 1-7)	46 (23 patients with KOA and 23 healthy individuals	China	Insole sensor (Novel Pedar-X system)	Patients with KOA have higher peak pressure on the midfoot and first and second MPJs.
Katoh et al[11]	KL grade 3 or 4	20 (10 patients with KOA and 10 healthy individuals)	Japan	Force plates (Unimec company)	The anterior and posterior centers of foot pressure displacement were significantly smaller in medial patients with KOA.
Lidtke et al[12]	Mild to moderate (Grade 1, 2, or 3 grades of KL score)	50 (25 patients with KOA [six men and 19 women] and 25 healthy individuals)	USA	Force plates	Patients with KOA had higher lateral loading. There is a correlation between the severity of pain and the COP index. The COP during gait is lateral to the midline of the foot in patients with KOA, while that in the control group was more medial.
Fukaya et al[13]	Moderate to severe (KL grades 3-4)	24 (14 patients with KOA and 10 healthy individuals)	Japan	Force plates (Kistler)	In patients with KOA, lateral shifts in the COP were correlated with knee flexion angle, the second peak of the knee extensor moment, and knee abductor moment.
Turcot et al[14]	Mild to severe (KL grades 1-4)	29 (20 patients with KOA [nine of KL grade 1-2 and 11 of KL grade 3-4] and nine healthy individuals)	Canada	Force plates (Kistler)	Patients with KOA exhibited lower COP velocity. A significantly higher range of knee acceleration was found in the KOA group, which correlates with the COP.
Sabashi et al[15]	Mild to severe (KL grades 1-4) Moderate-to-severe medial KOA (KL grade 3-4)	36 patients with KOA (29 females and seven males)	Japan	Force plates	Patients with KOA exhibited smaller COP movements during the transition from double-leg to single-leg standing. The smaller and slower COP movements correlated with poorer KOOS-ADL and KOOS-QOL.

KOA stages, ranging from mild to severe, were evaluated differently among the studies. The criteria used in seven studies involved the Kellgren-Lawrence (KL) grading scale, whereas the other two studies used the Lequesne Knee Score and subjective pain scale (ranging from 0-10).

The primary outcomes were center of pressure (COP) and plantar pressure in each area of the foot. Five studies measured the center of pressure, and four measured plantar pressure, two of which also analyzed COP. Apart from COP and plantar pressure, other outcomes were evaluated, including knee flexion angle, knee abductor moment, and quality of life (using KOOS-ADL and KOOS-QOL).

Abnormal plantar pressure patterns were found in patients with KOA compared with healthy indi-

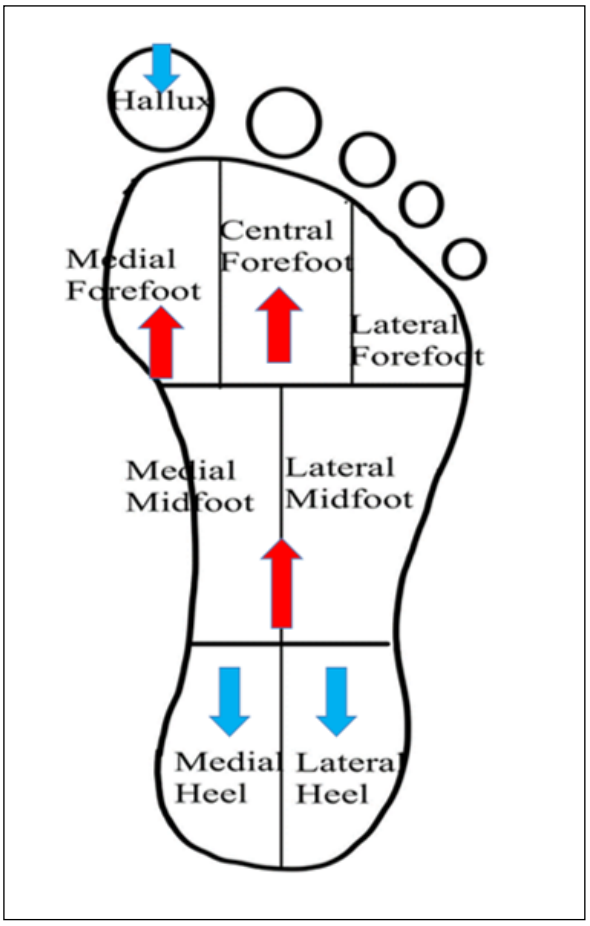

Figure 2. Summary of plantar pressure in knee osteoarthritis.

viduals (Table I and Figure 2). Lower peak pressure was found in the heel of patients with KOA[7]. This result was in accordance with another study that identified patients with KOA at KL grade 3 or 4 exhibiting lower partial pressure on the heel and hallux area[8]. In addition, patients with KOA exhibited limited knee extension, which could be due to the underlying mechanism of low pressure on the heel during the heel-contact phase. Atypical plantar pressure is not only found in the heel and hallux areas, but higher pressure was also observed in the central part of the foot in patients with KOA compared to healthy subjects[8]. Another study investigated plantar pressure in patients with severe KOA who required total knee arthroplasty[9]. Apart from similar results to previous publications, lower partial pressure was found on the lateral toe, both medial and lateral sides of the heel, and hallux. In addition, higher pressure was also found on the mid-foot and first metatarsophalangeal joint in patients with mild-to-moderate KOA stage categorized by the Lequesne Knee Score[10].

The COP was also evaluated in patients with KOA, who tend to have shorter COP lengths[8,9]. Another study also stated that anterior and posterior COPs were significantly shorter in patients with medial KOA[11]. Apart from COP length, patients with KOA also exhibited COP shifts. The COP was more lateral in patients with KOA, whereas it was more medial in healthy individuals[12]. Moreover, the lateral COP shift was correlated with the knee flexion angle, second peak of knee extensor moment, and knee adductor moment[13].

In addition, other notable points regarding the COP of patients with KOA have been addressed in several studies[14,15], and slower COP movement has been observed in patients with KOA[14]. The correlation between slower COP and QOL was also evaluated[15]; the results showed that a small COP and slower COP movement correlated with poorer QOL (as assessed by KOOS-ADL and KOOS-QOL). The quality of the included studies was assessed and showed good Newcastle-Ottawa Quality Assessment Scale scores (mean=8.8)[5,6].

Discussion

This systematic review highlights the changes in plantar pressure and other parameters in patients with KOA. Plantar pressure had a higher tendency to be pronounced in the mid-foot or central area of the foot, and COP patterns were shorter and more lateralized in patients with KOA. Abnormal plantar pressure patterns may occur due to irregular knee alignment. Varus knee was commonly found in patients with medial KOA and was shown to increase the risk and progression of KOA[16]. The foot has a compensatory mechanism for varus knee alignment, becoming everted. It was found that people with KOA exhibited a more pronated foot type than controls, allowing increased medial foot contact[17]. This led to an abnormal load on the medial foot, mid-foot, and second metatarsophalangeal joint (MPJ)[10].

However, there were some variations in the findings among the different KOA stages; patients with mild-to-moderate KOA exhibited significantly lower pressure on the heel and hallux. This pattern was also found in patients with severe KOA, but more areas of the foot were affected. For instance, patients with severe KOA had lower plantar pressure at the lateral toe area[9], whereas those with mild to moderate KOA did not exhibit

significantly lower pressure in that area. This evidence reflects more alterations in plantar pressure and possible foot disabilities in patients with severe KOA.

A shorter COP length was one of the main characteristics of patients with KOA, and both anterior and posterior displacements were shorter. This could be the result of a limited range of knee motion. In addition, the limited range of knee extension during the heel-contact phase was probably associated with the low pressure on the heel[8]. In summary, COP length was shorter in patients with KOA than in healthy individuals. Moreover, patients with moderate-to-severe KOA have slower COP movements[14]. These changes have been associated with diminished functional abilities and lower QOL[15]. In addition, a lateral COP shift was found in patients with KOA, and a high lateral COP is correlated with pain[12].

Based on this review, the evaluation of plantar pressure and COP is vital for the comprehensive evaluation of patients with KOA. It could also be implied that the COP pattern reflected the functional abilities, pain, and well-being of patients with KOA. Therefore, combining the COP information with the pressure profile in different foot areas could provide an in-depth perspective of the alterations of foot biomechanics in patients with KOA. This information may be useful for determining foot disabilities and could also be used to design dynamic and static biomedical devices, such as wedge insoles, which could improve knee or foot symptoms and slow down the progression of KOA. The concept of alternating COP has been used to develop non-invasive biomechanical devices. The effects of using such a device for 6 months in patients with KOA were assessed[18], and a significant improvement was found in gait patterns, pain, function, and QOL[18]. Moreover, these data provide benefits for developing future KOA evaluation tools, such as sophisticated insole pressure sensors that can detect improper plantar loading as early as possible to increase the chances of better treatment outcomes. This is consistent with a previous study in which foot pressure measurement might be used for the early diagnosis of some condition[19]. In addition, the pre-existing conditions of the foot, such as pronation, pes planus, and hind-foot valgus, should be considered before realignment osteotomies for KOA treatment that could affect the plantar pressure and the related symptoms at the foot.

A limitation of this study was that only one database was searched. Therefore, other studies may have been overlooked. In addition, the criteria for KOA grades were not similar in every study; the most frequently used measure was the KL score. Lastly, the included studies used different tools to assess plantar pressure, mainly measured using force plates and insole sensors. Different measurement methods may lead to variations in the outcomes. Despite these limitations, the quality of the included studies was assessed and showed good scores on the Newcastle-Ottawa Quality Assessment Scale (mean=8.8)[5,6]. It could be inferred that this study can serve as a good platform for providing information regarding the pathophysiology of plantar pressure patterns and their related parameters in older adults with KOA.

Conclusions

Abnormalities in plantar pressure and COP have been substantially demonstrated in older adults with KOA. This information could form a basis for designing biomedical devices, orthoses, and other realignment osteotomies for the lower extremities that could relieve symptoms at the knee or foot, or reduce KOA progression.

Acknowledgments

None.

Funding

None.

Authors' Contribution

PP collected, reviewed and analyzed the data, and drafted a manuscript. CA reviewed and analyzed the data, supervised the research, and drafted a manuscript. PJ reviewed and analyzed the data. PR reviewed and drafted a manuscript. NR reviewed a manuscript.

ORCID ID

Dr. Chayanin Angthong: https://orcid.org/0000-0002-1104-8945

Conflicts of Interest

The authors declare that they have no conflict of interest.

Ethical Committee Approval

Regarding the Ethical Committee Approval, this paper did not involve the direct study of human subjects due to its design as a systematic review; therefore, it was not considered within the criteria to review and obtain approval via the authors' institutional ethical committees.

Data Availability Statement

All data were available in the authors' record and able to be accessed as appropriate.

References

1) Cui A, Li H, Wang D, Zhong J, Chen Y, Lu H. Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. EClinicalMedicine 2020; 29-30: 100587.
2) Loeser RF. The Role of Aging in the Development of Osteoarthritis. Trans Am Clin Climatol Assoc 2017; 128: 44-54.
3) Loeser RF, Goldring SR, Scanzello CR, Goldring MB. Osteoarthritis: a disease of the joint as an organ. Arthritis Rheum 2012; 64: 1697-1707.
4) Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021; 372: n71.
5) Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available from: URL: http://www.ohri.ca/programs/clinical_epidemiology/ oxford.htm.
6) Li P, Xiong T, Hu Y. Hypertensive disorders of pregnancy and risk of asthma in offspring: protocol for a systematic review and meta-analysis. BMJ Open 2020; 10: e035145.
7) Muñoz-Organero M, Littlewood C, Parker J, Powell L, Grindell C, Mawson S. Identification of Walking Strategies of People With Osteoarthritis of the Knee Using Insole Pressure Sensors. IEEE Sens J 2017; 17: 3909-3920.
8) Saito I, Okada K, Nishi T, Wakasa M, Saito A, Sugawara K, Takahashi Y, Kinoshita K. Foot pressure pattern and its correlation with knee range of motion limitations for individuals with medial knee osteoarthritis. Arch Phys Med Rehabil 2013; 94: 2502-2508.
9) Saito I, Okada K, Wakasa M, Abe H, Saito A. Foot pressure pattern, hindfoot deformities, and their associations with foot pain in individuals with advanced medial knee osteoarthritis. Gait Posture 2018; 59: 83-88.
10) Zhang Z, Wang L, Hu K, Liu Y. Characteristics of Plantar Loads During Walking in Patients with Knee Osteoarthritis. Med Sci Monit 2017; 23: 5714-5719.
11) Katoh H. Effect of lateral-wedge insole on the center of foot pressure and lower extremity muscle activity at gait initiation in patients with medial knee osteoarthritis. J Phys Ther Sci 2019; 31: 776-779.
12) Lidtke RH, Muehleman C, Kwasny M, Block JA. Foot center of pressure and medial knee osteoarthritis. J Am Podiatr Med Assoc 2010; 100: 178-184.
13) Fukaya T, Mutsuzaki H, Okubo T, Mori K, Wadano Y. Relationships between the center of pressure and the movements of the ankle and knee joints during the stance phase in patients with severe medial knee osteoarthritis. Knee 2016; 23: 631-636.
14) Turcot K, Hagemeister N, de Guise JA, Aissaoui R. Evaluation of unipodal stance in knee osteoarthritis patients using knee accelerations and center of pressure. Osteoarthritis Cartilage 2011; 19: 281-286.
15) Sabashi K, Ishida T, Matsumoto H, Mikami K, Chiba T, Yamanaka M, Aoki Y, Tohyama H. Dynamic postural control correlates with activities of daily living and quality of life in patients with knee osteoarthritis. BMC Musculoskelet Disord 2021; 22: 287.
16) Sharma L, Song J, Dunlop D, Felson D, Lewis CE, Segal N, Torner J, Cooke TD, Hietpas J, Lynch J, Nevitt M. Varus and valgus alignment and incident and progressive knee osteoarthritis. Ann Rheum Dis 2010; 69: 1940-1945.
17) Levinger P, Menz HB, Morrow AD, Feller JA, Bartlett JR, Bergman NR. Foot kinematics in people with medial compartment knee osteoarthritis. Rheumatology (Oxford) 2012; 51: 2191-2198.
18) Miles C, Greene A. The effect of treatment with a non-invasive foot worn biomechanical device on subjective and objective measures in patients with knee osteoarthritis- a retrospective analysis on a UK population. BMC Musculoskelet Disord 2020; 21: 386.
19) Fang F, Wang YF, Gu MY, Chen H, Wang DM, Xiao K, Yan S, Yao LL, Li N, Zhen Q, Peng YD. Pedobarography – a novel screening tool for diabetic peripheral neuropathy? Eur Rev Med Pharmacol Sci 2013; 17: 3206-3212.