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Review Article

An insight into the plantar pressure distribution of the foot in clinical practice: Narrative review

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ABSTRACT

Introduction: In clinical practice and within the scope of research studies, foot pressure distribution as measured by plantar pressure analysis is widely used to diagnose foot pathologies. Although plantar pressure data have been recognized as an important element in the assessment of patients with various foot problems, an in-depth knowledge of the plantar pressure distribution of the foot is lacking in literatures.
Aim: This article presents a review of literature on plantar pressure distribution and factors that may affect plantar pressure among patients with foot pathologies and healthy population.
Material and methods: A literature search was conducted in Science Direct and PubMed databases for articles published from January 2000 to August 2012. Medical Subject Headings (MeSH) and other keywords for search were plantar pressure, age, body weight, gender, reliability, instrument and healthy subjects.
Results and discussion: This paper reviews on the factors influencing plantar pressure distribution. Factors such as the gender, age, body weight, foot type and footwear proved to have a significant effect on plantar pressure distribution of the foot. The paper also reports on the plantar pressure distribution of the foot and the reliability of the measurement. Studies were excluded from this narrative review if they did not meet the above criteria.
Conclusions: This review has added sufficient knowledge on plantar pressure distribution of the foot in clinical practice. Data obtained from a plantar pressure distribution can be used by the physical therapist in the evaluation and management of patients with a wide variety of foot and lower extremity disorders.

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1. Introduction

The human foot plays an important role in maintaining the biomechanical function of the lower extremities which includes provision of balance and stabilization of the body during gait.[1,2] The anatomical and physiological characteristics of the foot not only change with gait development, motor control of the lower limb and age related skeletal growth but can also lead to alteration in foot pressure distribution during gait.[3,4] In clinical practice and research studies, foot pressure distribution as measured by plantar pressure analysis is widely used to diagnose foot pathologies. The altered plantar pressure distribution of the foot can also provide additional insight into the etiology of various lower limb musculoskeletal problems.[2,5] However, the interpretation of plantar pressure distribution is confounded by various factors such as age, gender, body weight, etc.

Studies have reported that factors such as gender, body weight and foot joint range of motions can affect plantar pressure distributions of foot.[4,6,7] Furthermore, past studies postulated that the distribution of pressure under the foot varies between walking speed and anatomical regions of the foot.[7,8] In normal gait, the ground reaction force must be equal to the body weight of the subject.[9] However, in abnormal gait pattern, inadequate force and pressure is distributed on the foot.[2,6,10] In addition, higher ground impact force and load at heel strike has been reported among older subjects compared to younger subjects.[4] Thus, several of the above said factors could influence the interpretation of plantar pressure analysis. Therefore, a knowledge of the factors that influences the plantar pressure distribution is important for clinicians and researchers for meaningful interpretation of the plantar pressure analysis. However, published in-depth review of literature on plantar pressure is lacking. This article provides vital information on plantar pressure distribution with regard to the factors affecting the measurements in patients with foot pathological problems and healthy populations. In addition, this paper reports on the reliability of plantar pressure measurement and the clinical usefulness of the techniques.

2. Aim

This review aimed to substantiate knowledge for the researchers and clinicians on the plantar pressure distribution of the foot in clinical practice. Such knowledge may be helpful to apply and analyze the plantar pressure distribution of foot to choose an appropriate treatment strategy.

3. Material and methods

3.1. *Data sources*

A literature search of published articles from January 2000 to August 2012 in Science Direct and PubMed databases was conducted. Medical subject headings keywords for search were [[(plantar pressure) OR (foot pressure) OR (foot load)] AND [(measurement) OR (assessment) OR (evaluation) OR (distribution)] AND age AND body weight AND [(gender) OR (sex)] AND patient AND healthy subject AND [(repeatability) OR (reliability)]]. The search strategy attempted to retrieve all relevant studies in a conventional review manner.

3.2. *Article selection*

Articles were included for review if they met the following inclusion criteria. Firstly, articles were included if the studies presented foot pressure distribution using plantar pressure analysis. Secondly, studies that reported on the relationship between plantar pressure distribution and age, gender, body weight, foot type and footwear was considered. Thirdly, studies that had reported on the reliability of the measurement was also included. Only those articles which were published in the English language were considered.

3.3. *Data extraction*

Reference lists of literatures identified were examined to see if further literature existed. Identification of full article was conducted if literatures are relevant to the study. Titles and abstracts of all identified studies were examined. Full copies of the articles were gathered and examined if the study was appropriate.

4. Results

The literature search identified 32 relevant studies. Among the 32 studies, 19 assessed the factors influencing plantar pressure distribution. Among the remaining 13 studies, 4 studies reported on the standard parameter used in plantar pressure analysis,[10–13] 5 studies specifically looked at the reliability of plantar pressure measurements[14–18] and 4 studies reported on the clinical implications.[2,3,6,19]

Among the 19 studies conducted on the factors, 3 studies observed gender influence,[11,20,21] 2 studies observed the influence of age on plantar pressure distribution,[4,22] 4 studies observed the influence of body weight,[5,23–25] 5 studies observed the effect of walking speed,[8,9,26–28] 3 studies reported on the foot type[29–31] and 2 studies reported on the footwear.[32,33] The particulars of the study findings are stated in Tables 1 and 2.

5. Discussion

The plantar pressure distribution is a common aspect that clinicians look among patients with foot pathological problems. By understanding the plantar pressure distribution, the foot function and the pressure distribution at foot can be addressed in clinical practice.

5.1. *Factor influencing the plantar pressure distribution*

There are several factors that may influence the plantar pressure distribution. Clinicians have to carefully consider these factors for a better interpretation of the results from the plantar pressure distribution. The discussion below suggests

Table 1 – Factors influencing plantar pressure distribution.

Factors	Study	Participants	Results
Gender	Periyasamy et al.[7] Putti et al.[21]	n = 28	Foot contact areas were higher in males than females.
	Murphy et al.[20]	n = 50	There were no differences among genders in the midfoot contact area and plantar pressure.
Age	Hessert et al.[4]	n = 15	Elderly people use less pressure and force under the medial masks of the foot.
	Bosch et al.[22]	n = 104	With increasing age, the peak pressure under the total foot increases. Toddlers have a higher arch index than the other age groups.
Body weight	Teh et al.[5]	n = 120	The total plantar force and total contact area increase as BMI increases.
	Birtane et al.[24]	n = 50	The forefoot peak pressure is higher in obese subjects.
	Hills et al.[23]	n = 35	Peak plantar pressure increased in obese subjects when compared with non-obese subjects.
	Periyasamy et al.[25]	n = 22	Midfoot pressure distribution parameter — power ratio (PR) value and contact area increased in pre-obese subject compared to non-obese.
Walking speed	Burnfield et al.[27]	n = 20	Faster walking results in higher maximum force, peak and mean peak pressure under the heel, central and medial metatarsals and toes.
	Taylor et al.[26]	n = 20	Walking speed does influence plantar pressure patterns when using the two-step gait initiation protocol.
	Ko et al.[8]	n = 18	People with diabetes have a slower walking speed than people without diabetes.
	Pataky et al.[26]	n = 10	Midfoot and proximal forefoot peak pressures decrease as walking speed increases.
	Drerup et al.[9]	n = 20	Speed reduction causes a general reduction of the peak pressures.
Foot type	Syed N et al.[30]	n = 628	Relationship exists between foot arch height and foot pressure.
	van Schie et al.[31]	n = 34	Arch height of the foot has a small effect on dynamic plantar pressure.
	Chuckpaiwong et al.[29]	n = 50	Foot types do influence the contact area in the medial midfoot. Maximum force and peak pressure in the lateral forefoot.
Footwear	Wiegerinck et al.[33]	n = 37	The result demonstrated a significant difference between training shoes and racing flats in terms of peak pressure, maximum force and contact area.
	Queen et al.[32]	n = 34	The maximum force and peak pressure are significantly greater in racing flat than in a traditional training shoe when running at a self-selected running speed.

Table 2 – Reliability of plantar pressure.

Reliability of plantar pressure	Study	Participants	Equipment	Results
Inter- and intra-observer reliability of masking in plantar pressure measurement analysis	Deschamps et al.[14]	n = 56	Footscan pressure platform (RS Scan, Olen, Belgium)	In single masking, interclass correlation (ICC) values for the peak pressure were only 0.79 and 95% lower confidence limit (LCL) values were 0.59, which implies that inter-observer reliability is poor. Single masking could be classified as good, but the clinical impact represented by the peak pressure, showed only a poor reliability. The results of multi-masking showed a poorer reliability from the peak pressure value. The experienced observers had the best intra-observer reliability for multi-masking that may indicate that experience is an important factor.
The validity and reliability of PressureStat for measuring plantar foot pressures in patients with rheumatoid arthritis	Firth et al.[16]	n = 10	The PressureStat footprint mat (Bailey Instruments Ltd., Manchester, UK)	The validity of pressure data obtained using PressureStat is poor, particularly at the lower end of the range.
Between-day reliability of replaced plantar pressure distribution measurements in a normal population	Gurney et al.[15]	n = 9	Emed-AT (Novel GmbH, Germany)	The interclass correlation (ICC) and coefficients of variation (CoV) analysis show a generally good level of reliability.
Normal pressure values and repeatability of the Emed-ST2 system	Maetzler et al.[17]	n = 23	Emed-ST2 system, model-ST2 (Novel GmbH, Germany)	Peak pressure is the most reliable parameter. The Emed1-ST2 foot pressure system was found to be repeatable.
Normal pressure values and repeatability of the Emed-ST4 system	Putti et al.[18]	n = 53	Emed-ST4 system, model-ST4 (Novel GmbH, Germany)	Emed1-ST4 foot pressure system was found to be repeatable.

how these factors were reported to influence the plantar pressure distribution of the foot.

5.2. Gender

The size and shape characteristics of men and women's foot are different mainly at the lateral side of the foot, arch, metatarsal and hallux.[7] These differences were shown to cause a variation in foot pressure distribution in men and women during standing.[7] Men have higher foot contact areas and pressure distribution than women.[7] Also, men showed a larger contact area in all regions when compared to women, however there was no differences in peak pressure between genders in any of the regions.[21] Murphy et al. compared the midfoot contact area and plantar pressure and found no significant differences in the midfoot contact area and plantar pressure between the two genders.[20] Thus, there is a mixed opinion which requires further research for a better understanding on the effect of gender in influencing the plantar pressure distribution.

5.3. Body weight

Obesity is another significant factor that tends to influence the plantar pressure values.[5] People with higher body mass index (BMI) were reported to have increased total contact area and total surface area when compared to non-obese subjects.[5] Two other studies also showed a significant higher value in forefoot peak pressure and contact area in obese subjects when compared to non-obese subjects.[5,24] Hills et al. investigated the plantar pressure differences during standing and walking in obese and non-obese subjects and reported increased peak plantar pressure values while walking in all sections of the foot among obese subjects.[23] Thus, initial evidences support that obesity is a factor that can influence the plantar pressure distribution of the foot.

5.4. Age

Age is another significant factor that influences plantar pressure of the foot. Two studies showed differences in plantar pressure distribution between younger and older subjects.[4,22] Age was found to be independently associated with reduced pressure under the heel, midfoot and hallux.[4] Medial pressure values and force values are lower in older subjects compared to younger subjects.[4] Also, older people have a tendency for greater weight bearing on the lateral mask of the foot.[4] Another study found a significant increase in peak pressure with increasing age.[22] In general, the elderly subjects showed a decrease of peak pressure and force under the hindfoot and forefoot and, longer contact times in the midfoot area when compared to the younger subjects.[22]

5.5. Walking speed

The influence of walking speed on pressure parameters in normal populations was addressed in different studies.[8,18,26] While using the Emed-F and Emed-SF2 pressure plate system (Novel GmbH, Munich, Germany), a linear increase in force and pressure under the whole foot was observed when patients walked in slow, medial and fast cadences.[18] Also, the mean foot-to-floor contact durations reportedly decreased and mean peak pressures increased with increasing cadence.[26] Similarly, elderly subjects presented with higher mean and peak pressure with increased speed.[27] Another study showed that people with diabetes have a significantly slower walking speed compared to healthy subjects, with reduced peak plantar pressure on the forefoot and rearfoot during barefoot walking.[8] Thus, it is important to consider the walking speed when measuring the plantar pressure at foot since changes can be seen in plantar pressure measurements even at a slower walking speed.[26]

5.6. Foot type

There are three different types of feet, pes planus, pes cavus and normal foot, which could influence the pressure loading on the feet.[29,30] A previous study revealed that a relationship exists between foot type and foot pressure.[31] It indicates that people with pes planus have a higher foot pressure compared to pes cavus when walking barefoot.[31] Another study indicated that loads under the midfoot were reduced in the pes cavus foot type due to the lack of foot deformity and no medial shift existed in forefoot loading in pes planus foot type.[29]

5.7. Footwear

Footwear also affects foot loading characteristics.[33] Two studies which compared the racing flat and traditional training shoe indicated that the maximum force and peak pressure are greater in the racing flat footwear.[32,33] In another study, different footwear conditions such as leather soled oxford shoe, running shoes and barefoot on plantar pressure were investigated; results showed that running shoes presented with lower walking plantar pressure compared to barefoot conditions.[27]

5.8. Reliability of plantar pressure measurement

Reliability of foot pressure measurement is important to establish the trustworthiness of the data collected on the foot pressure analysis.[18] The reliability of the plantar pressure measurement is influenced by three factors which are the technical aspect of the equipment used, regions of the foot analysis and the numbers of trials collected.[14,15] The above-mentioned factors should be standardized, controlled or at least monitored during data collection to assure reliability of the measurements.

Reliability was reported to vary among different equipments to measure the plantar pressure distribution of the foot.[14] One of the most common measurement systems to measure plantar pressure is the Emed (Novel GmbH, Munich, Germany).[18] Both the studies on the repeatability of the Emed-ST2 and Emed-ST4 found that the peak pressure to be the most reliable parameter when compared to other variables.[17] Another study using the Emed-AT in a normal population based on between-day reliability suggested a good level of reliability between testing days in normal subjects.[15]

The plantar pressure distribution in the various anatomical parts of the foot is important to understand foot function.[6]

In order to standardize pressure measurements, the footprint is usually divided into different anatomical regions or the masking of the foot surface.[14] Two studies have divided the foot sole into 9 anatomical regions which consists of medial calcaneus, lateral calcaneus, medial midfoot, lateral midfoot, first, second, third metatarsal, hallux and toes.[3,4] Three studies divided the foot sole into 10 anatomical regions.[2,5,7] As for reliability, a previous study suggested that single-masking has a high inter-observer reliability in the medial–lateral direction and a good reliability in the proximal–distal direction.[14] On the other hand, multi-masking was shown to have the highest inter-observer reliability in medial–lateral direction and the lowest in the distal–proximal direction.[14]

The numbers of trial taken in each test have a significant influence on the reliability of the plantar pressure distribution.[18] There is a significant increase in the reliability of the pressure data collected with the number of trials collected.[15] Previous studies suggested that a minimum of three measurements in each test is sufficient to obtain a good level of consistency.[15,18]

Therefore, reliability trials on plantar pressure distribution are necessary prior to any data collection. As the application of foot pressure measurement systems widens, it becomes increasingly necessary to determine their reliability and to establish a range of normal values for reference and comparison purposes. Thus, it is important for the clinicians and researchers to be aware of the reliability of the system that is selected for use.

5.9. *Plantar pressure distribution of the foot and its clinical implication*

The plantar pressure measurement of the foot is being increasingly used in both research and clinical practice.[5,9,26] Researchers and clinicians have utilized the plantar pressure measurements for the management of the lower extremities and foot problems.[34] For example, an abnormal plantar pressure distribution during walking might provide information that may result in tissue damage among patients with diabetic foot complications.[8] Patients with ankle osteoarthritis showed decreased maximum force and smaller contact area.[19] Hence, by understanding the plantar pressure distribution of the foot, the contact surface area, force distribution, plantar pressure and the effects of loading on foot can be addressed in clinical practice. Moreover, measurement of foot pressure distribution is clinically useful as it can identify anatomical deformities and pathological disorders of the foot thereby guiding the diagnosis and treatment of gait disorders and falls.[34]

One of the earliest applications of plantar pressure measurements was the evaluation of footwear and to investigate the effect of various materials used to cushion the footwear.[34] Moreover, literatures have reported that loading characteristics can be modified by the conditions of the shoe's midsole or the cushioning properties of the shoe.[32,33,35] For example, shoes with a softer midsole are reported to produce higher ground reaction forces[33] and running with a harder midsole shoes causes decreased in impact force.[32] Thus, information attained from these studies can be beneficial to clinicians in identify the appropriate amount of pressure reduction that can be expected when using various types of insole materials.[34]

6. Conclusions

Plantar pressure measurement is used to evaluate the changes related to foot pressure during human gait. Thus, clinicians and researchers may consider using it an effective outcome measurement tool in clinical practice for various lower extremity and foot problems. However, several factors highlighted in this review warrant a watchful understanding on the interpretation of the plantar pressure readings in practice.

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