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Plantar pressure changes in normal and pathological foot during bipedal standing

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Background : Plantar pressure measurement during bipedal standing provides an important information of loading of human body on foot under various postural activities. Therefore, the objective of the present work was to monitor the plantar pressure during bipedal standing in normal and pathological conditions. Use of orthotics in attenuating the peak pressure to distribute it uniformly on plantar surface of the foot was also examined.

Methods: The pedobarographs of 66 subjects were recorded using computer assisted indigenously developed optical pedobarograph. The pedobarographs were evaluated using Asha 3-D software developed during present study. Standard size universal orthotics (Footmaxx™, Canada) was used to determine the effect in attenuating the peak pressure.

Results: Results showed distribution of plantar pressure in the right and left foot of normal subject under the various regions was not equal. It was observed that among the normal subjects 17% experienced equal pressure on the both feet, 7% showed greater pressure on left foot and 76% found higher load on the right foot. Similarly the pathological subjects were analyzed and noticed the changes in the pedobarographs depending upon the type and location of pathology. It was found that orthotics improved the plantar pressure and distributed it uniformly to make the person standing comfortably.

Conclusion: Plantar pressure measurement techniques are useful in the analysis and understanding of the biomechanics of human foot. It was found that orthotics attenuated the peak pressure and distributed it uniformly on the plantar area of the foot. The data seem to be useful in understanding the biomechanics of bipedal standing.

Key-words: Foot; Plantar pressure; pedobarograph; Stance phase; Orthotics.

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Introduction

The study of plantar pressure measurements has received a considerable attention in the assessment and treatment of various orthopedic disorders[1-3]. The normal foot in bipedal standing exhibits contact across the heel, forefoot and usually the lateral border of foot. There have been reports of normative plantar pressure studies, but quantitative studies have produced contradictory results in terms of a normal pressure position, pattern and value[4]. Some investigators found that the heel experienced twice or three times of the forefoot weight[4,5] and other found equal load on the heel and the forefoot[6-8]. These results seem to be contradictory to each other. Although there are studies on normal barefoot standing using different pressure measuring systems, but the standard normal pressure distribution to compare the result is yet to be established. Hence, analysis of the results is mostly based on the experience of the user. Patil and Srinivasan studied leprotic feet where loss of sensation and irreversible nerve damage caused paralysis in muscle leading to physical deformity[9]. Static studies are quite useful in studying the basic information of prosthesis, leprotic feet and in many other clinical situations where it is suspected that one foot is weaker than other.

Different orthotic materials were investigated by Brown et al to demonstrate the beneficial effect of orthotics in relieving high pressures[10]. Foot orthosis reduces the strain on injured structure in the foot and lower extremity, allowing them to heal and become less painful. It also helps to prevent the occurrence of future problems in the foot and lower extremity by reducing abnormal forces acting on these areas[11]. There is a wide variation of the threshold described by earlier researcher, which could vary from 500 kPa to 1000 kPa[12,13]. It seems to be more confusing and may lead to incorrect interpretation of the clinical observations. The diversity of commercially available systems to measure plantar pressure has established that different measuring systems produce different results. Therefore, we used the technique of percentage pressure normalized to peak pressure instead of absolute value of pressure.

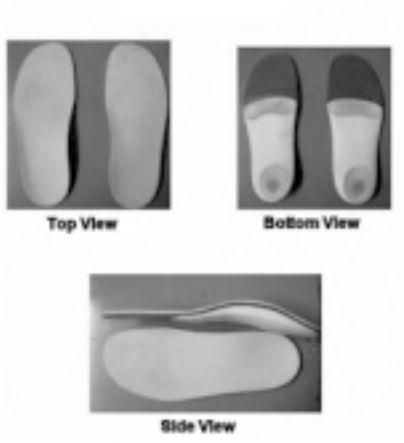

Fig 1. ***Different views of orthotics***

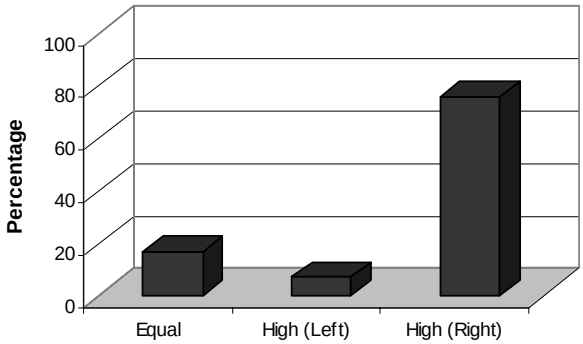

Fig 2. ***Comparison of peak pressure on right and left foot in normal subjects***

In the present study, an attempt has been made to study the pedobarographs of left and right foot in normal and pathological subjects during bipedal standing. Percentage pressure profiles were plotted to see the distribution of loading on the plantar surface of the foot. The effects of universal orthotics on pressure points in normal and pathological subjects were also evaluated.

Material and Methods

Barefoot pressure measurement was carried out on 66 subjects (46 males and 20 females). Height and weight of all the subjects were recorded and all of them were asked to fill the questionnaire to get the information about type and preference of footwear used and any present/past injury, which affects the gait.

Fifty-eight subjects who participated in this study had normal gait and 8 had abnormal gait. Subjects were in the age group of 11 to 59 years (mean age 29±13 years). Normal subjects included in the present study had no major musculoskeletal or neurological pathologies that affected gait. The locally designed optical pedobarograph was used to collect plantar pressure information. The pedobarographs obtained by optical pedobarograph were evaluated using the Asha 3-D software developed during this study. The software maps the entire pedobarograph and calculates the value of intensity for every pixel. These values could be displayed in terms of percentage of normalized point pressure or absolute pressure at any point.

Before taking final readings, all the subjects were trained to stand on the platform. Prior to pressure measurements, subjects familiarized themselves with the testing procedure and details of the procedure were explained to them. The subjects were told to look straight ahead, while standing on the platform. The subjects were told to stand on the optical pedobarograph with both the feet separated, based on their normal style of standing. Pedobarograph were recorded using the CCD camera (National Panasonic M9500). Pressure measurements were also carried out with standard size (Fig. 1) universal orthotics (Footmaxx^{TM}, Canada) by placing it under the foot of the subject.

To reduce the error due to posture sway, three readings for every individual subject were taken. The most useful information for interpretation of clinical analysis is the peak pressure plots. Highest pressure in each part of the foot that occurred during any point of the contact is recorded in relation to the reference maximum peak pressure.

Results

Figure 3 shows the distribution of peak pressure in right and left foot of the normal subjects. It was found that intensity patterns among normal subjects were not uniformly distributed on the plantar surface. It was also observed that

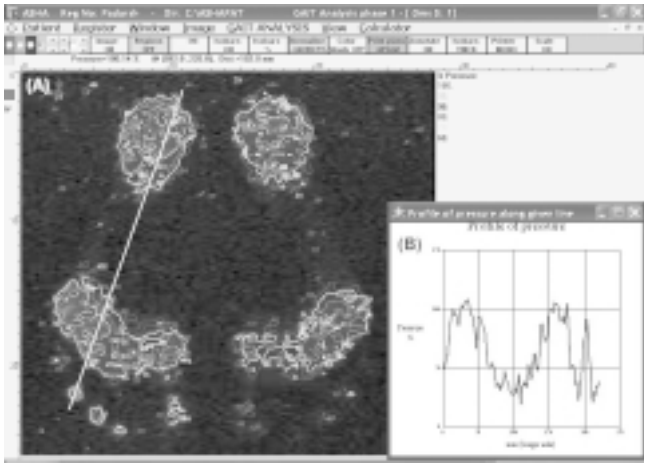

Fig. 4. ***Distribution of plantar pressure in normal subject*** **b.** ***Pressure profile from heel to forefoot showing equal pressure on heel and forefoot in right foot***

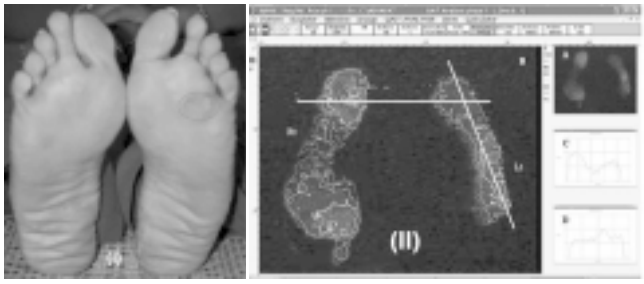

Fig 4 (I) ***Photograph of pathological left foot showing callus at forefoot (II) (A) Image obtained with optical pedobarograph, (B) Plantar pressure distribution of same foot, pressure profiles shows abnormal left foot (C) Pressure profile of heel to heel in both feet (D) Pressure profile of heel to toe in left foot***

among normal subjects 17% had equal pressure on both the feet, 7% showed greater pressure on left foot and 76% subjects experienced greater load on right foot. Figure 4 shows the pressure distribution in normal foot.

It was found that in normal foot the load is distributed equally on the heel and forefoot whereas the midfoot experienced minimum load (50.66%±16.55). It was also observed that in right foot, pressure on heel, metatarsal regions (Mt-1, Mt-2, Mt-3, Mt-4) and toe was also equally distributed (with in 10%). However, under the 5th metatarsal the pressure was lower by 19.3%. The same pattern was found in left foot, but the variation was little higher than the right foot (Fig. 5).

Among the pathological subjects, there were wide variations in the pressure of right and left foot. In pathological subjects pressure varied depending upon the type and location of the pathology. Figure 6shows the plantar distribution in pathological foot having callus in heel and forefoot.

Figure 7 and 8 show the pressure distribution in pathological left foot and flat foot respectively. In flat foot the pressure is high in the midfoot. In pathological left foot the pressure was 30% at forefoot in comparison to the right forefoot where pressure was 95%. Figure 9 shows the effect of orthotics on plantar pressure. The pressure under the feet with orthotics is more uniform than without orthotics as it attenuated the peak pressure.

Discussion

The changes were observed in peak plantar pressure of right and left foot and this was in agreement with the earlier studies[14]. Whereas these results do not coincide with the findings of Tuna et al[15], who found no significant difference between static pressure values for the right and left foot. The

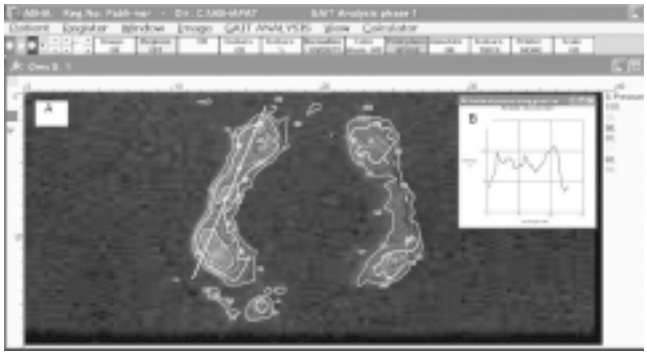

Fig 7. ***Flat foot A) Plantar pressure distribution in flat foot B) profile showing variation in pressure from heel to forefoot in right foot***

difference in plantar pressure may be because of the standing posture, which has become part of their habit. Cavanagh et al found approximately 2.6 times higher heel pressure against forefoot pressures in symptom-free feet of 107 subjects during bipedal standing[4]. The highest forefoot pressures were located under the second and third metatarsal heads. They also found no load sharing by the toes during standing position. Contrary to this, in the present study, variation in heel and forefoot pressure was minimal (figure-5) and the toe equally shared the pressure. Equal pressure on heel, forefoot and toe indicates normal and stable standing posture. Higher peak pressure observed by Cavanagh et al under metatarsal 2 and 3 was in agreement with this study[4].

Furthermore, in agreement the Cavanagh et al peak plantar pressures did not show a significant relationship to the body weight of subjects[16]. The peak pressures beneath the one to four metatarsal heads were higher than the 5th metatarsal region. No differences in plantar pressures were found between the male and female subjects. Only 3.45% subjects showed high pressure in the midfoot indicating that in normal subjects with normal arch height there is minimal pressure in the mid foot region.

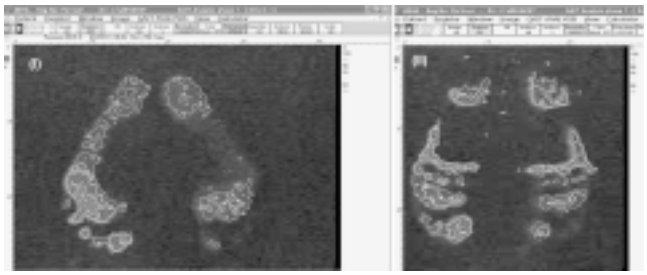

Fig 8. ***Comparison of plantar pressure with and without universal orthotics (I) Plantar pressure distribution with bare foot (II) Plantar pressure distribution with universal orthotics***

The wide variation in the plantar pressure of pathological subjects was in agreement with the clinical evaluation. One of the pathological subject was not able to apply any load on heel and toe of the left foot. Whereas, heel to heel profile of right and left feet showed high pressure on right foot as compared to left foot (Figure. 6 C). The heel to toe pressure profile of left foot showed more pressure on left midfoot (Fig. 6 D). In flat foot the pressure is high in the midfoot (Fig. 7). In pathological left foot there was no visible difference but the loading of pressure was less (30%) at forefoot in comparison to the right forefoot where it was 95% (Fig. 8)

Evaluation of the questionnaire showed that the soft innersole of the shoes was preferred by 93% of the subjects. For comfortable walking, 60% of the subjects were using sports shoes in routine. It was also found that if given a choice, subjects preferred branded sports shoes (Nike, Adidas, Reebok, etc) than locally manufactured ones (Bata, Action, etc). Ninety percent of the subjects agreed that choice of shoes is important from health point of view. Seventy percent of the subjects agreed that shoes are fashion and life style accessories, but if not comfortable they could be harmful. It was also observed that all the subjects felt more comfortable with universal foot orthotics as it uniformly distributed the plantar pressure. Figure 9 clearly shows the effect of orthotics on plantar pressure. The pressure under the feet with orthotics is more uniform than without orthotics.

The study suggests that the bipedal standing guarantee a stable support of the body. The human foot attenuates potentially harmful impact shocks, and provides a sensory information regarding the contact with the ground. Pressure distribution measurement techniques are useful in the analysis and understanding of the biomechanics of human foot in bipedal standing. Orthotics are useful for the uniform distribution of plantar pressure. It was found that orthotics attenuated the peak pressure and distributed it normally on the plantar area of the foot. Various disorders related to muscloselkelatal system and nervous system could be analyzed using plantar pressure technique. Plantar pressure distribution instrumentation could be used as a standard clinical tool for diagnostic and therapeutic interventions.

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