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Comparison of Plantar Pressure in Patient with Hallux Valgus and Healthy Control and Effect of Demographic Characteristic on it: A Pixel Based Approach

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Abstract: There is no detailed information available about the differences in plantar pressure distribution between hallux valgus and healthy feet. The goal of this study was to evaluate the plantar pressure of the left and right feet in hallux valgus patients against healthy controls. The current research also looks at the impact of demographic factors on plantar pressure distribution. Furthermore, a correlation between the hallux valgus foot and radiographic measures such as the hallux valgus angle and intermetatarsal angle is investigated. There were 50 patients with hallux valgus (HV group) and 55 healthy matched controls (C group) who did not have hallux valgus in the research. Age, height, weight, and body mass index did not differ significantly between the HV and C groups. The CAD WALK open access database is used to obtain dynamic plantar pressure measurements. Using manual masking, the plantar region of the foot was divided into eight sections. When compared to healthy controls, the hallux valgus foot has three abnormal pressure patterns in the left foot and two abnormal plantar pressure patterns in the right foot in various regions. The comparison is done using the region of interest's peak pixel intensity. According to our findings, when the hallux valgus angle increases, plantar pressure characteristics change from the medial to lateral side of the forefoot. Demographic characteristics like age, height, and shoe size were discovered to be important considerations during a plantar pressure study. We may conclude from our findings that manual masking on 2D plantar pressure footprints is quite reliable.
Keywords: hallux valgus deformity, hallux valgus angle, intermetatarsal angle, peak plantar pressure, plantar pressure distribution

I. INTRODUCTION

The pressure at the point where the plantar surface of the foot meets the ground is known as plantar pressure. Plantar pressure measurements are used to assess foot and ankle function during walking and other functional activities.

Plantar pressure measuring technology is being used to research hallux valgus. The term “Hallux Valgus” means a turning outward of the big toe. Hueter introduced the term in 1871 to describe lateral deviation and subluxation of the first metatarsophalangeal (MTP) joint in conjunction with medial deviation of the first metatarsal (4). The tendons of the extensor hallucis longus, flexor hallucis longus, and sesamoids are shifted laterally with the great toe's phalanx (2). The great toe's pulp becomes non-functional due to the resulting imbalance, which causes dorsiflexion and pronation. Hence, lowering foot pressure under the first ray may cause insufficiency in the first ray, causing the lesser rays to be overloaded (3).

To evaluate biomechanical abnormalities related with hallux valgus, the distribution of plantar pressure was studied. The majority of plantar pressure measurement techniques are done on a group level. Recent years have seen a surge in the popularity of region of interest studies over group level studies. Because group-level studies have limitations, cluster-based analytic approaches and, more recently, machine learning algorithms have been employed to categorise an individual's plantar pressure measurement into patient or healthy control groups (4). This work describes a pixel-level imaging approach for revealing abnormal pressure patterns on the foot caused by hallux valgus abnormalities.

Hard et al. presented a significant study in 1951 that compared a group of hallux valgus patients to a control group. The traditional approach of measuring the hallux valgus angle (HVA) and intermetatarsal angle (IMA) before surgery is based on the findings of this study (5). An HVA is the angle formed by the longitudinal axis of the first metatarsal bone and the proximal phalanx of the big toe, while an IMA is formed by the longitudinal axes of the first and second intermetatarsal bones. The physiological mean HVA was 15.7°, while the physiological mean IMA was 8.5°, according to these researchers(5).

The goal of this study is to identify abnormal pressure patterns in hallux patients using a pixel-based analytic technique, as well as the demographic factors that influence the plantar pressure distribution of the foot. In addition, a correlation between foot hallux valgus and radiographic measurement like HVA, IMA is identified.

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II. MATERIALS & PATIENTS

A. Dataset

This study used dynamic plantar pressure measurement data from the CAD WALK open access database (Brian G. Booth, 2018, 2019). This dataset contains the raw dynamic plantar pressure measurements of 50 Dutch people with Hallux Valgus taken at Sint Maartenskliniek centres in the Netherlands prior to surgical surgery.

B. Data Collection Protocols

Plantar pressure measurements were taken with a 0.5 m footscan® plate (rsscan, Paal, Belgium; dimensions: 48.8 32.5 cm) on top of a Kistler force plate (9286AA,Kistler, Wintherthur, Switzerland) that was synchronised with an RS scan footscan® 3D interface box. The pressure data was collected using RS scan's footscan® software 7 gait 2nd generation, then exported and converted to nifti format with MATLAB version 2016b (The MathWorks, Natuck, USA)(6,7). At a frequency of 200 Hz, data was recorded.
After the 0.5 m plate, a 1.5 m RS scan footscan® plate (RS scan, Paal, Belgium; dimensions: 146.3 32.5 cm) was put to gather two more footsteps from the subject being measured (see below). The pressure data was collected using rs scan's footscan® software 9.5.1, which was then used to calculate the distance and time between consecutive footsteps. The pressure plates were levelled with the participant's walking surface using rubberized mats shown in Fig 1.

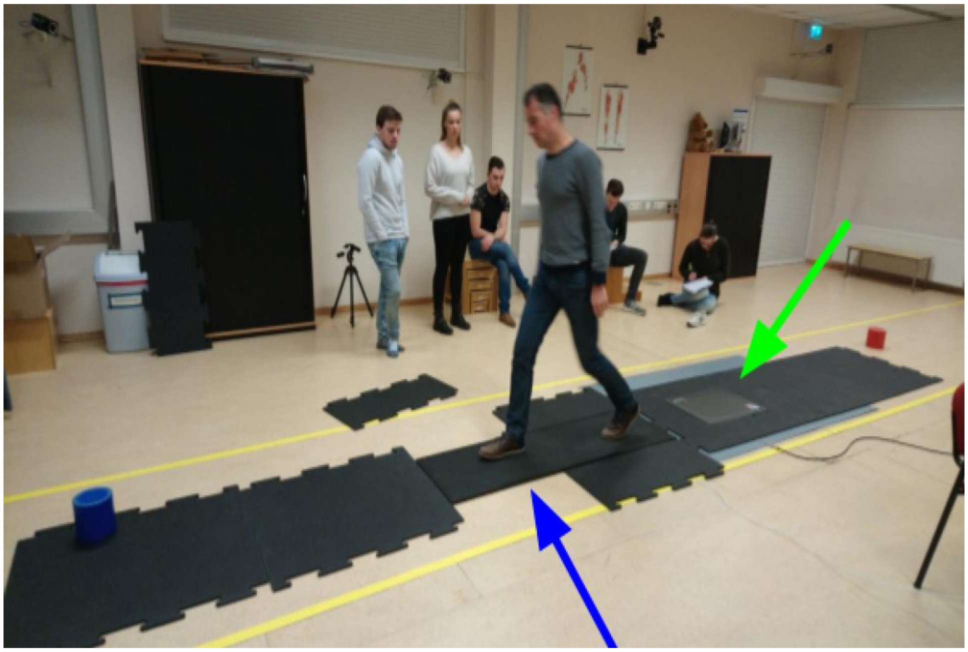

Fig 1- Plantar pressure measurement plate (Image by Brian G. Booth)

C. Hallux Valgus Patient

A total of 54 people were measured, however four were removed due to various gait-related problems (e.g., diabetes, Parkinson's disease) (7). For each person, 8-15 dynamic plantar pressure readings for both feet are provided. 15 trials were gathered from 46 of the 50 people in this collection.
Healthy Controls
A total of 55 people were measured. For each person, 24 dynamic plantar pressure measurements for both feet are provided (6). They had no previous injuries to their feet or lower limbs. Before the study, the subjects' feet and gait were examined and determined to be normal.

D. Demographic Characteristics

The demographic characteristics of the healthy controls and hallux valgus group are shown in Table 1. The mean and standard deviation are shown, with the range in parenthesis. The Manne Whitney U test was used for statistical processing, with a significance threshold of $p < .05$. There were no significant differences in age, height, weight BMI, or shoe size between the C and HV groups.

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TABLE I
Demographic Characteristics of the Control and Hallux Valgus Groups

	Healthy Group(n = 55)	Hallux Valgus Group(n = 50)	P value
Age (years)	42.30±16.82 (18-70)	54.52 ± 16.14 (18 -74)	0.25
Sex	Female (33), Male (22)	Female (44), Male (6)	0
Height(cm)	175.02±9.75(159-195)	170.3±7.87 (149-180)	0.12
Weight(kg)	74.8±12.17 (50.6 - 103.2)	70.2±12.34 (42.4-96.9)	0.087
BMI (kg/m)	24.4 ± 8.7	24.3 ±11.02	0
Shoe size (EU)	40.8±2.95 (36.5 - 48)	40±2.48 (35- 48)	0.29

III.METHODS

A. Data Pre-Processing

The sensor dimensions of the footscan® pressure plate utilised for data collection aren't square (7.62 mm 5.08 mm), each footstep seems compressed in the anterior-posterior direction. Therefore, each measurement is up sampled to a 3 × 3 grid using 3D linear interpolation to restore the foot shape. Each Plantar Pressure images is then normalized. The entire mean pressure image was used to normalise each plantar pressure measurement. The sum of all pixel values in the 2D mean pressure image is divided by each plantar pressure sample. A rectangular bounding box is created for foot detection. After the normalisation, multiple images of the single foot is aligned and averaged to get the foot peak pressure image.

B. Footprint Masking

Masking the footprint into regions of interest is a typical way for analysing plantar pressure parameters (ROIs)(8). The foot was divided into eight regions of interest in this study using manual masking Fig. 2. Manual masking is examining the footprint visually and selecting sub-areas based on subjective identification of areas that are thought to correlate to anatomical features of interest (8,9). Using the Novel 10 region mask, the foot region is manually divided in 10 region. Great toe, 2-3 toes, 4-5 toes, medial forefoot, central forefoot, lateral forefoot, midfoot, and hindfoot, with certain regions merged, such as medial and lateral hindfoot and metatarsal.

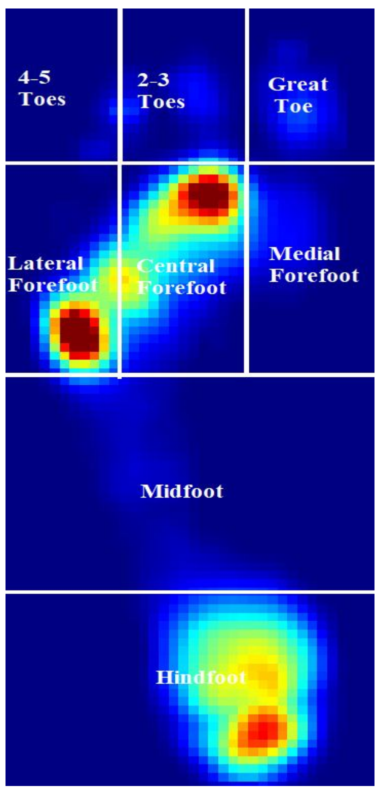

Fig. 2 Manually Masking Image of plantar foot pressure

IV. RESULTS

The pixel intensity in different regions is used to make a comparison between the two groups.

A. *Pixel Intensity Comparison*

The aberrant pressure pattern most commonly detected in our hallux valgus cohort in the medial forefoot, 4-5 toes, and hindfoot region of the left foot, as well as the great toe and hindfoot region of the right foot. The chart below shows a considerable disparity in this area.

1) *Left Foot*

The Fig. 3 shows high pixel intensity in medial left forefoot of HV group when compared to healthy control. The Fig 4 below shows top five hallux valgus patient with abnormal high peak pressure in the medial forefoot of the left foot. The patient with hallux valgus has low pixel intensity on the 4-5 toes and hindfoot, but high pixel intensity on the medial forefoot of the left foot, as shown in the chart and images above. Some healthy patients have abnormal pressure in one or more areas as several demographic factors have an impact on plantar pressure, which will be discussed later.

Fig 5 shows low pixel intensity in left hindfoot of HV group when compared with healthy individuals. Fig 6 shows five lowest pixel intensities in hindfoot of the HV group. This pressure is occasionally seen in HV patient

Fig 7 shows abnormal low pixel intensity in left 4-5 toes of HV group when compared to healthy. The Fig 8 shows low plantar pressure at Toes 4-5. Usually the pressure at Toes 4-5 is low but some cases the toes do not touch the ground so the pressure at that point is zero.

2) *Right Foot*

The chart below shows the abnormal intensity of hallux valgus in the great toe and hindfoot region of the right foot. Because of the deformity, the hindfoot and great toe have lower pixel intensity than healthy subjects. Some of the hallux valgus patients in the study have normal intensity, much like the healthy controls as, in addition to the deformity of the foot, there are additional factors that influence plantar pressure.

Fig 9 shows low pixel intensity in the right hindfoot of the HV group when compared to healthy controls. Fig 10 shows the image of top five patients with low plantar pressure in the right hindfoot of HV group.

Fig.11 shows the low pixel intensity in the right great toe of the HV group which is consistent to the previous studies. The Fig 12 shows the image of top five patients with low plantar pressure in the right great toe of the HV group.

The results discussed in the pixel intensity comparison section are consistent with the prior study, which used the same database as ours (4). They exhibit unusually high peak pressure in five HV group regions. Because they create a left foot model for plantar pressure analysis, the results are indistinguishable between the left and right feet. Our findings show that the HV group had unusually high or low peak pressure in three regions of the left foot and two regions of the right foot.

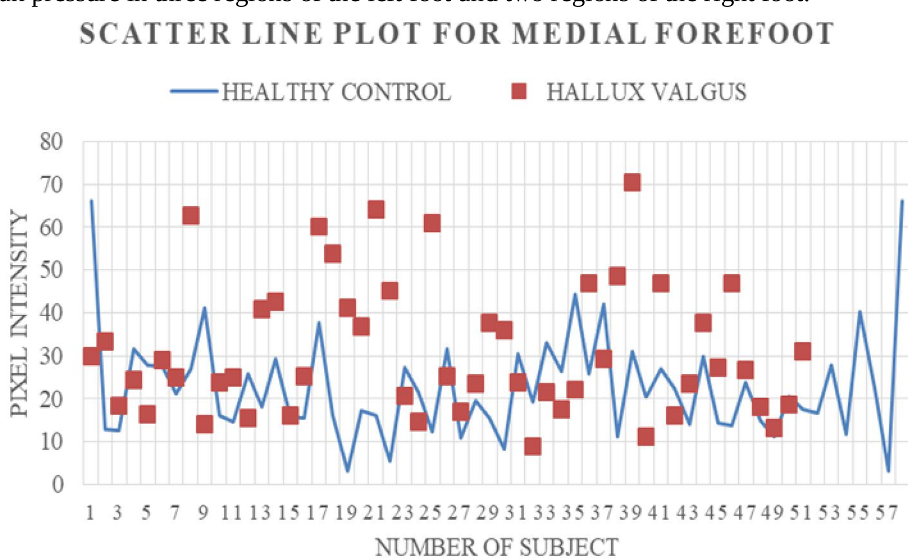

Fig 3 - Abnormal high pixel intensity in medial left forefoot of HV group.

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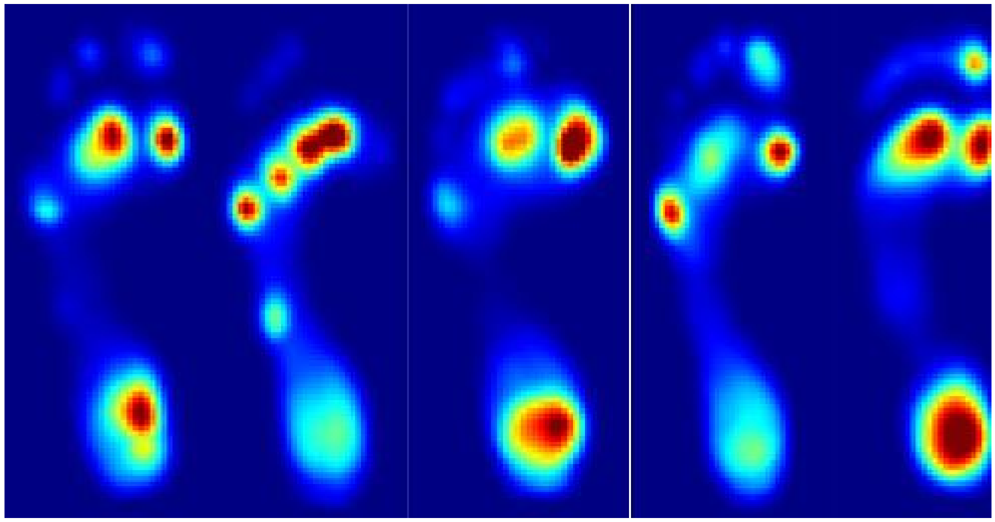

Fig 4 High peak pressure in medial forefoot of five different HV patients

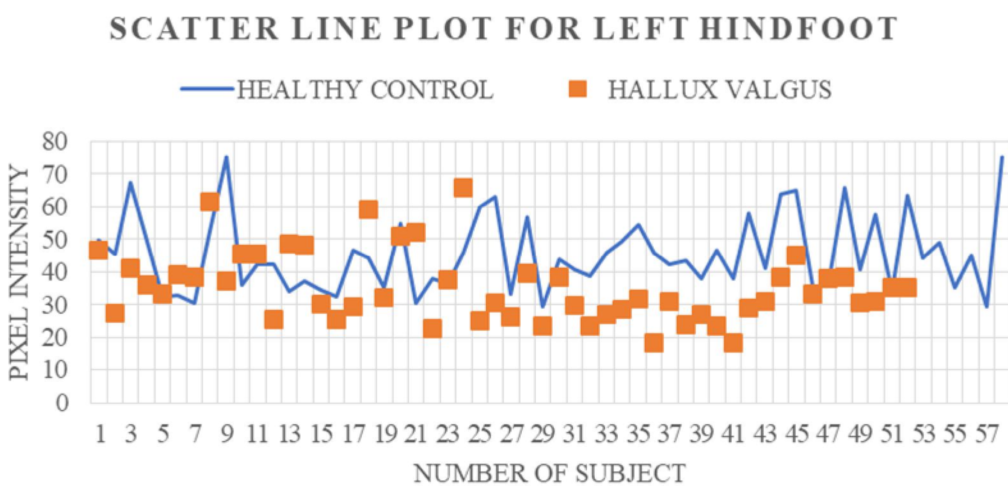

Fig. 5 Abnormal low pixel intensity in left hindfoot of HV group

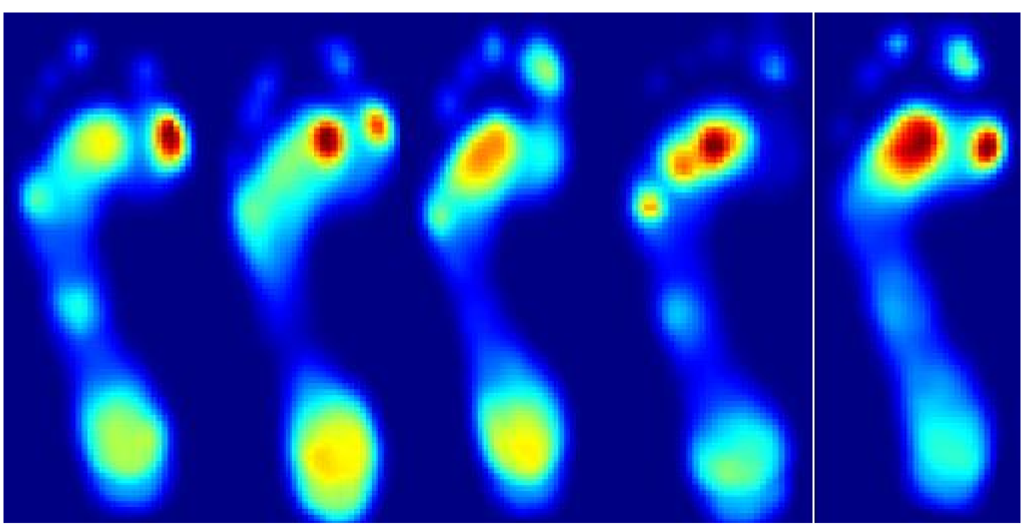

Fig.6 Low peak pressure in the Hindfoot of five different HV patient

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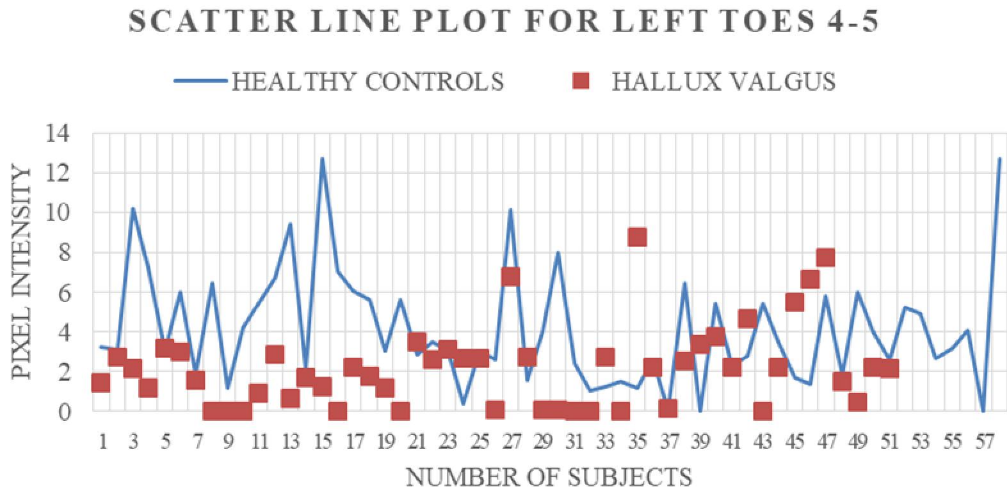

Fig.7 Abnormal low pixel intensity in left 4-5 toes of HV group

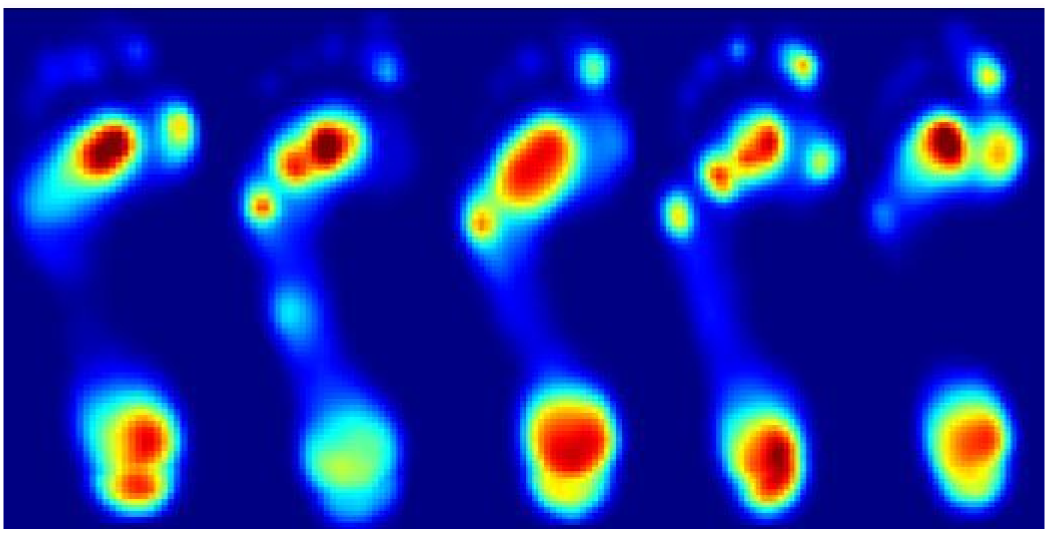

Fig.8. Low plantar pressure at Toes 4-5 in HV group

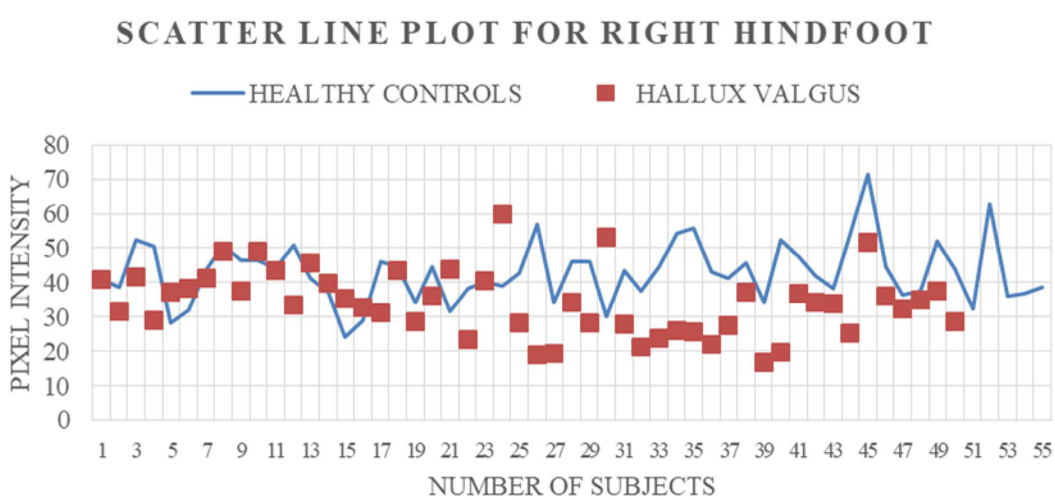

Fig. 9 Abnormal low pixel intensity in right hindfoot of HV group

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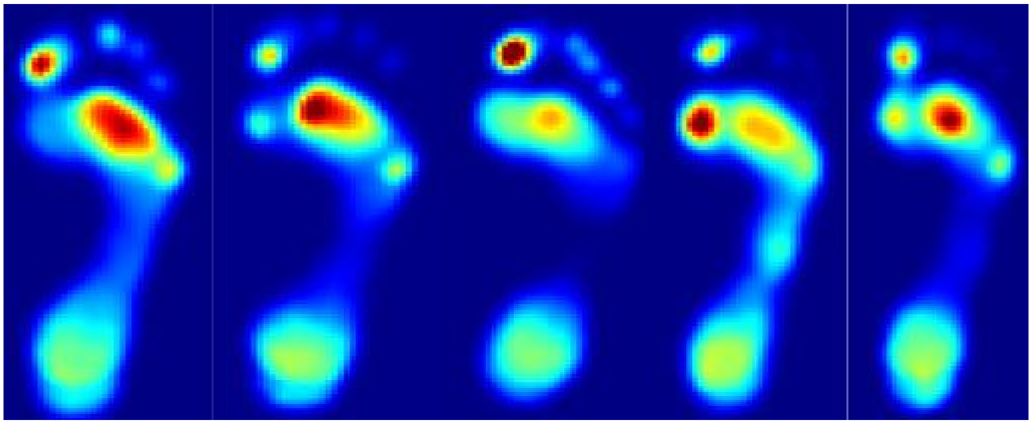

Fig. 10 Low planter pressure in hindfoot of the HV patient

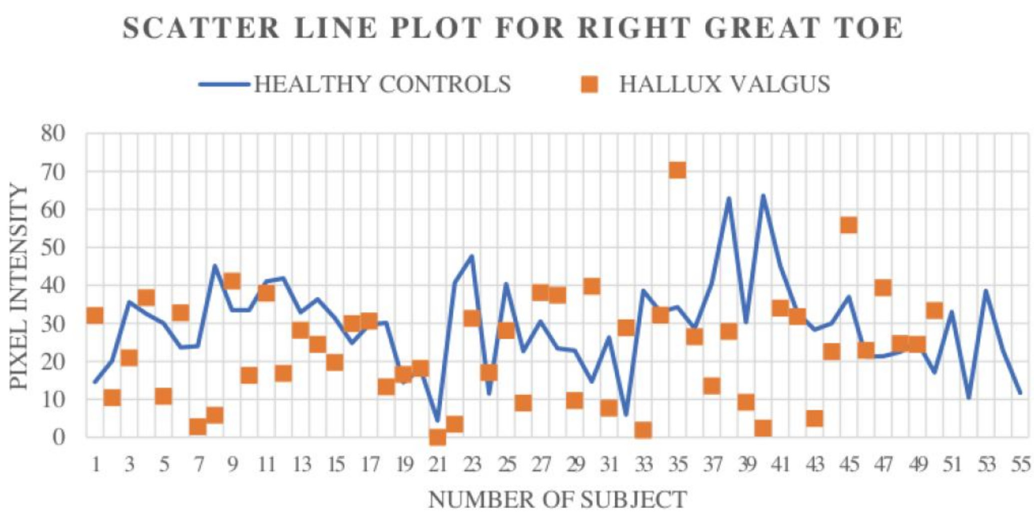

Fig. 11 Abnormal low pixel intensity in right great toe of HV group

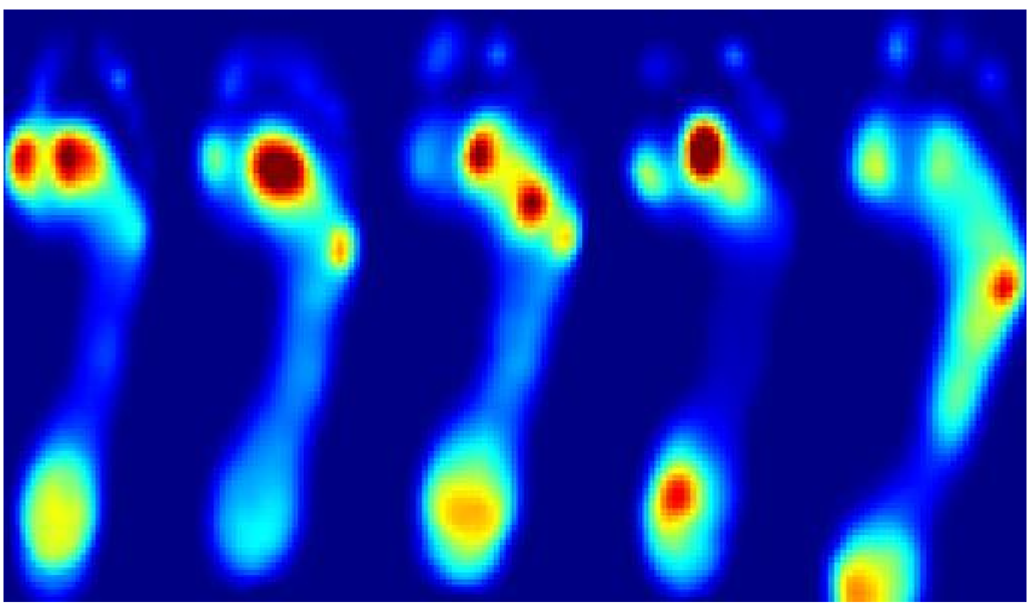

Fig. 12 Low plantar pressure in right great toe of HV group

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B. Correlation between HVA,IVA & Plantar Pressure

Table 5.1 shows all significant correlations in different regions between radiological data (hallux valgus angle and intermetatarsal angle) and pixel intensity. After analysing the data, it was shown that the hallux valgus angle and intermetatarsal angle are linked to pressure changes in the toes 2-3, medial forefoot, and hindfoot.

The Pearson's Correlation Coefficient was used to calculate the correlations (r). The significance level was set at 0.05. (HVA stands for Hallux Valgus Angle, while IMA is for Inter Metatarsal Angle.)

The great toe and the IMA, HVA of both the right and left foot were found to have a negative correlation. Toes 2-3 of both feet, we found a positive correlation between toe 2-3 and HVA angle. The IMA and 2-3 toes were found to have a negative correlation. For Toes 4-5 The IMA, HVA of both the foot and toes 4-5 were found to be negatively correlated. Medial Forefoot in both feet, we discovered a favourable relationship between the medial forefoot and the HVA angle. The IMA and 2-3 toes of the left foot were found to have a negative correlation. In Central Forefoot we found a correlation between the toe Central forefoot and the HVA, IMA of the left foot. In the right foot, there was a negative correlation between the central forefoot and the IMA, HVA. Lateral Forefoot of both the right and left feet had a negative correlation between lateral forefoot and IMA, HVA. In Midfoot we found a correlation between the midfoot and the right foot's HVA, IMA. In the left foot, there was a negative correlation between midfoot and IMA, HVA. Hindfoot of both the right and left foot showed a positive correlation between hindfoot and IMA, HVA.

C. Demographic Characteristic effect on Plantar Pressure

This research looks on the impact of demographic factors on planter pressure patterns. The demographic features of the individuals differed significantly amongst them. The Pearson correlation approach was utilised to determine the relationship between plantar pressure and demographic factors such as height, weight, age, and shoe size.

In most of the regions studied, such as Toe 2-3, Toe 4-5, medial and lateral forefoot, we found a significant positive correlation between age, weight, and shoe size. In the left foot with hallux valgus, age has a positive correlation in all of the above-mentioned areas, and height and shoe size have a modest positive correlation in the lateral forefoot as shown in the Table 2. Age correlates with most of the regions of interest in the right foot with Hallux valgus, and height and shoe size correlate with toes 4-5, medial and lateral forefoot. Results are shown in the Table 3. Age has a positive correlation with toe 2-3, lateral forefoot, and midfoot in healthy controls' left feet. Toes 2-3 and midfoot are minimally correlated with weight and height as shown in Table 4. In Healthy controls right foot, Toes 2-3, toes 4-5, central and lateral forefoot have a positive correlation with age. Toes 2-3 are highly correlated with weight, height, and shoe size. Results are shown in Table 5.

TABLE II
Significant Correlations Between Pixel Intensity of Each Region of Interest and Hallux Valgus-, Intermetatarsal-Angle

Foot region	IMA Angle		HVA Angle	
	LEFT	RIGHT	LEFT	RIGHT
Great Toe	-0.13	-0.08	-0.11	-0.15
2-3 Toes	-0.01	0.03	0.1	0.06
4-5 Toes	-0.15	-0.07	-0.05	-0.01
Medial Forefoot	-0.01	0.07	0.04	0.09
Central Forefoot	0.24	-0.22	0.1	-0.13
Lateral Forefoot	-0.13	-0.1	-0.17	-0.12
Midfoot	-0.22	0.08	-0.18	0.29
Hindfoot	0.18	0.16	0.18	0.25

TABLE III
Significant Correlations Between Demographic Characteristics and Each Region of Interest in HV Left Foot

Foot region	Demographic Characteristic			
	Height	weight	Age	Shoe Size
Great Toe	-0.07	-0.09	-0.33	-0.15
2-3 Toes	-0.19	-0.3	-0.06	-0.02
4-5 Toes	-0.17	-0.12	0.21	-0.05
Medial Forefoot	-0.03	-0.19	0.19	-0.03
Central Forefoot	-0.12	-0.47	-0.1	-0.13
Lateral Forefoot	0.14	-0.05	0.21	0.29
Midfoot	0.05	-0.03	0.01	0.01
Hindfoot	-0.29	-0.38	-0.16	-0.26

TABLE IV
Significant Correlations Between Demographic Characteristics and Each Region of Interest in HV Right Foot

Foot region	Demographic Characteristic			
	Height	weight	Age	Shoe Size
Great Toe	0.18	-0.02	-0.25	0.05
2-3 Toes	-0.04	-0.18	-0.11	-0.09
4-5 Toes	-0.39	-0.35	0.13	-0.13
Medial Forefoot	0.07	-0.26	-0.04	-0.05
Central Forefoot	-0.12	-0.43	-0.07	-0.22
Lateral Forefoot	-0.01	0.02	0.05	0.05
Midfoot	-0.45	-0.25	-0.19	-0.29
Hindfoot	-0.1	-0.22	-0.12	-0.16

TABLE V
Significant Correlations Between Demographic Characteristics and Each Region of Interest in Healthy Controls Right Foot

Foot region	Demographic Characteristic			
	Height	weight	Age	Shoe Size
Great Toe	-0.27	-0.17	-0.13	-0.47
2-3 Toes	0.01	0	0.03	0.11
4-5 Toes	-0.13	-0.03	0.02	-0.09
Medial Forefoot	-0.21	-0.22	-0.37	-0.29
Central Forefoot	-0.35	-0.38	0.06	-0.42
Lateral Forefoot	-0.09	-0.16	0.16	-0.22
Midfoot	-0.35	-0.29	-0.05	-0.4
Hindfoot	-0.18	-0.48	-0.2	-0.28

V. DISCUSSION

The purpose of this study is to look at how plantar pressure is distributed in individuals with hallux valgus and healthy controls. The comparison was made using the pixel intensity in the region of interest of both the left and right feet of two groups. The researchers also investigated for a relationship between the hallux valgus angle, intermetatarsal angle, and plantar pressure in the hallux valgus group to examine how the angles affected pressure distribution. The research also looked at demographic factors and how they influence plantar pressure. The research demonstrates the subject characteristic that must be chosen as a key component during the plantar pressure study modelling.

The dynamic plantar pressure distribution measurements of 55 healthy and 50 hallux valgus feet were compared in 8 regions of the foot using the Foot Scan® plate and the two-step data collecting technique (Booth et al., 2020). Despite the fact that the groups are gendered, the results should not have been affected because plantar pressure measurements have been shown to differ little between men and women (Lord et al., 1986).

The association between hallux valgus and healthy feet in terms of foot pressure distribution is still debatable. According to Resch et al., the Peak-P of the great toe was lower in hallux valgus than in controls, however Martineze Nova et al.(Martínez-Nova et al., 2010) and Bryant et al.(Bryant et al., 2005) found that the Peak-P of the great toe was higher in hallux valgus(Hida et al., 2017). Furthermore, no changes were detected between hallux valgus and control feet by Mickle et al.(Mickle et al., 2011). Differences in the severity of hallux valgus deformity are one of the possible explanations of these inconsistencies (Hida et al., 2017).

Differences in the severity of hallux valgus deformity and functional dysfunction of the foot across patients, as well as examinations with non-optimally matched controls, are possible explanations of these inconsistencies. To our knowledge, only one study has examined the association between symptomatic moderate-to-severe hallux valgus patients and healthy matched controls in terms of plantar pressure distribution (Hida et al., 2017). They discovered that the pressure in the great toe was substantially lower in the HV group than in the control group. In this study, Low pressure was detected in the great toe area of both feet with HV. When compared to healthy people, the pressure in the right foot is significantly lower. Previous study shows that the medial foot pressure is significantly higher in HV group (Bryant A, 1999). The medial forefoot pressure in hallux valgus feet was considerably greater than in healthy feet in this study. The position of the peak intensity, however, will change between people. Individual differences will be reduced as a result of the average over participants following normalisation. These findings show that in hallux valgus deformity, the great toe's function is reduced while the mechanical stress on the medial forefoot increases.

The study's second portion describes the plantar pressure characteristics of various regions of the hallux valgus foot and compares them to the radiological parameters HVA and IMA. Our results of the study conducted three key results. First, we identified a positive correlation between the toes 2-3, medial forefoot, and hindfoot with the IMA, HVA of both the right and left foot. Second, we observed a negative relationship between the great toe and both foot HVA, IMA. Finally, we identified a positive correlation between the medial forefoot and HVA in the right foot, as well as the negative correlation between central forefoot and HVA in the left foot.

Sesamoid subluxation was linked to higher peak pressure under metatarsal heads three to five in previous study. Peak pressure increased beneath the metatarsal head five as the hallux valgus angle increased and reduced under the hallux (Koller et al., 2014). Our findings are consistent with those of the prior study.

The study's third portion investigates the effect of subject demographic characteristics on plantar pressure in various areas. The features of the individuals differed significantly. The research included both hallux valgus patients and healthy controls. The change in plantar pressure is highly correlated with age in both groups. The highest correlation coefficient values with subject characteristics were found under the Toe 2-3, Toe 4-5, medial, and lateral forefoot pressure. Previous study shows that plantar pressure is influenced by both body weight and foot size. When studying variations in plantar pressure across groups, analysis or adding subject variables as covariates is necessary (Keijsers et al., 2014)

VI. CONCLUSION

To the best of our knowledge, only one previous study evaluated plantar pressure utilising CAD WALK Plantar pressure data. Brian G. Booth et al. developed a left foot model for personalised plantar pressure analysis in patients with hallux valgus. The model uses healthy controls as a baseline to compare the hallux valgus group and demographic characteristics. In our study, we compared the plantar pressure of each foot individually in the hallux valgus and healthy groups. In addition, a correlation between the HVA, IMA, and the foot with hallux valgus is identified. Plantar pressure characteristics are shifted from the medial to the lateral side of the forefoot when the hallux valgus angle increases, according to our results. The influence of demographic characteristics on plantar pressure distribution is also investigated. During a plantar pressure analysis, age, height, and shoe size were shown to be relevant factors to consider. Manual masking is used in this study to divide the foot into distinct regions. In comparing the plantar pressure distribution in both groups, the current study's findings are compatible with the PAPPI statistical model. Based on our findings, we can conclude that manual masking on 2D plantar pressure footprints is very reliable in this study.

VII. ACKNOWLEDGMENT

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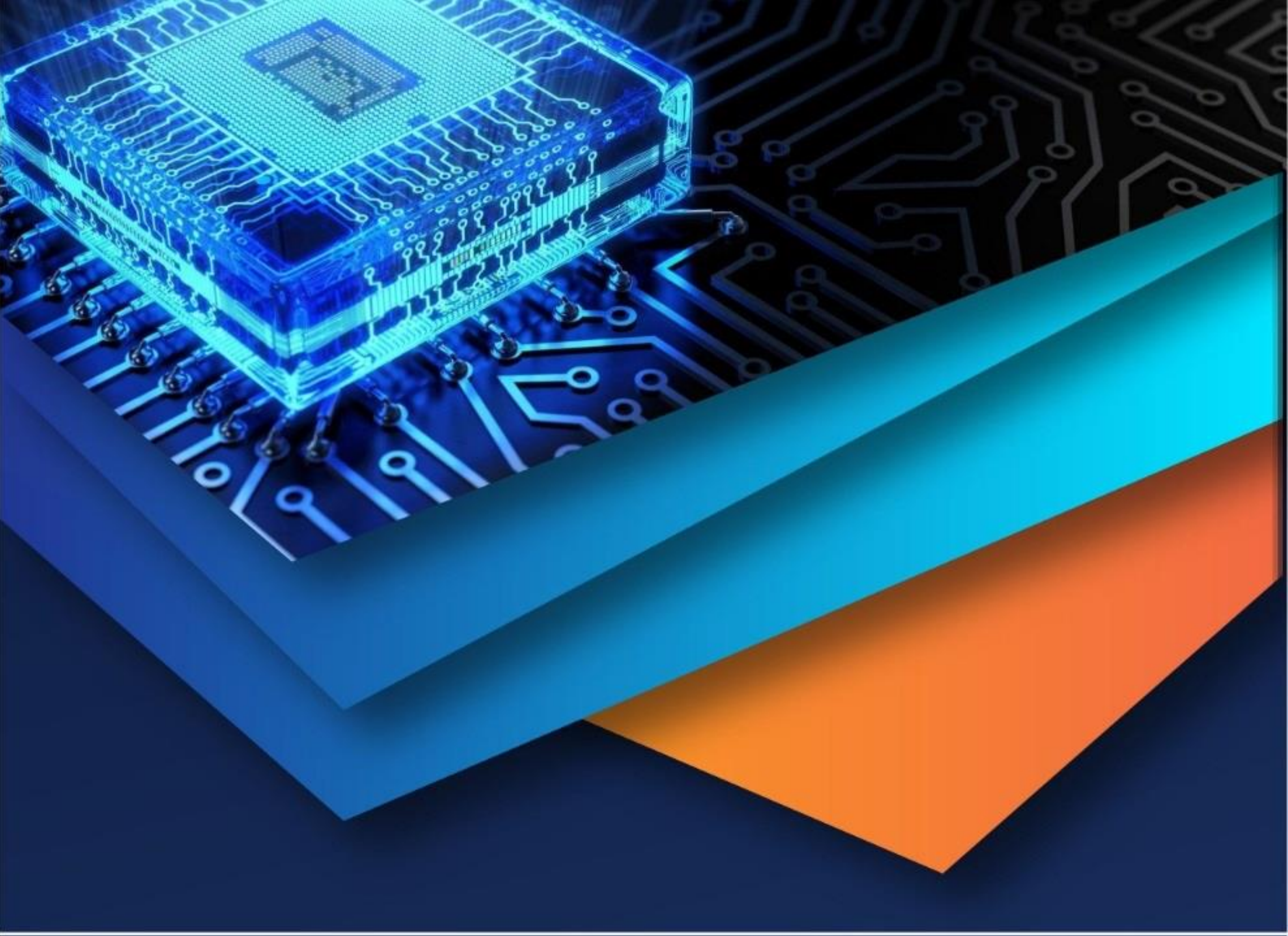

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