Biomechanical Study of Foot Force Pattern in Hallux Valgus (HV) Patients

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Abstract

***Background*:** Hallux valgus is the angulation of the big toe of more than 15 degrees. Many people during their lives are challenged with this condition. The occurrence is 3 times more in women to men. However one of the causes of the condition is congenital but the other important factor is wearing narrow toe box and high heel shoes. There are some devices measuring the foot kinematic or sole pressure for identifying such condition but as there are lots of variations in foot kinematics and pressure the identification of the disease becomes more challenging. Many previous works are published regarding to foot sole pressure pattern but still early recognition of the condition is needed.

***Method*:** To see the existence of force pattern out of gait experiments, Rs-Scan device used to take the kinematic data of the one complete foot contact. 10 trials were conducted of each volunteer with the full right foot contact with the pressure mat. 3 valid trials have been chosen for final analyses. With this method the load/pressure measurement under the 10 anatomical regions of the foot have been recorded and used to recognise people with and without deformity. Furthermore, Motion Capture cameras were used to capture the first and the second metatarsal movements in HV and Non HV volunteers to see whether there is a joint laxity of the metatarsals in HV patients.

***Results*:** It was observed that the load pattern in forefoot in people with HV was significantly different compared to non HV volunteers .So independent sample T-Test done and the statistical difference less than 0.05 observed in Toe1,Metatarsal 1,Metatarsal 2, Metatarsal 3, Metatarsal 4 and Metatarsal 5. So just there was no difference load pattern on the Toe 2-5. Hence, the maximum load was on the 2nd and 3rd metatarsal heads in people with HV which is already published by previous authors but the walking speed showed a significant effect on the force variations in both group. The relative movements captured by 7 cameras in Motion Capture laboratory were monitored and it has shown the greater movement of first and second metatarsal heads in patients with HV.

***Conclusion*:** The observed force pattern was changing trial to trial in each individual to have a consistent reading they asked to walk 10 times over the pressure mat. After getting this, it was discovered that there is a relationship between walking speed and maximum load applied to the forefoot. Also there was rising load on the 2nd and 3rd metatarsal heads in HV patients. Hence, the 6

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regions on the forefoot including Toe1, Meta1, Meta 2, Meta 3, Meta 4, Meta 5 were statistically different while comparing HV and control group. It should be indicated that HV group also had more lateral movement of the first metatarsal head comparing to control group.

Keywords: Hallux valgus, Foot force pattern.

1 Introduction

Hallux valgus is the lateral deviations of the big toe of more than 15 degrees[1]. The statistics shows that 23% of the people developing this condition during their lives [2]. The measurement of articular surfaces of the foot showed that female bones had a potential for more movement to occur in the direction of adduction [3]. Also recent studies shown that women are more predisposed to HV than men by the ratio of 2 to 1[4].

Fig. 1. The foot with the HV deformity [5]

However one of the causes of the deformity is congenital but wearing narrow toe box shoe and high heels have direct effect on the formation of condition.

Changes in the force pattern underneath the foot can change the shape of the first metatarsal bone in individuals.

Inadequate distribution of forces under the sole of the foot can lead to the abnormal movements [6]. Accordingly in people with the normal feet, heel bears about 50% of the body weight while the first and second metatarsals can stand about 25% of body mass and the other metatarsals bear the rest 25% [7]. But people with HV have different pattern of applied force over their feet compared to Non HV individuals.

One study shows the plantar pressure was lower under the 1st and the 2nd toes and higher peak force under 3rd to 5th metatarsal heads but other studies show higher peak force under the 1st to 3rd and lower force under 4th and 5th metatarsal heads in HV patients [8].

One conducted study on plantar pressure and patients with Hallux valgus presents that the highest pressure are on the third, second, first, fourth and fifth [9].

In this study the RS-scan device has been used to analyse the force pattern in individuals with and without HV condition. Moreover, Motion capture laboratory has used to distinguish the laxity of the first metatarsal joint in HV compared to control group.

2 Methodology

2.1 Subjects

20 volunteers recruited to take part in the experiment with RS-scan device, 10 with deformity and 10 without. All HV were clinically diagnosed with HV by an HV specialist or the angle of their right foot was measured with the goniometer so people with the first metatarsal angle of more than 15 degrees counted as HV volunteers. ***Foot-scan advanced & hi-end system*** (RS-scan International NV, Belgium) has been used to collect force data.

Informed consent was obtained from each participant before data collection and the ethical committee of the Brunel University approved the experimental procedures.

2.2 Data Collection

Foot Scan Device

The plantar measuring system [Rs-scan Inc.] was used to measure the plantar force distributed over the right foot of each volunteer. The pressure plate was 578 mm x 418 mm x 12 mm in dimensions. And the active sensor area was about 488 mm x 325 mm. The pressure range is between 0 – 200 N/cm2.

The start and the end point of walking has been defined for the volunteers, the distance was 6 meters and the pressure mat was located in the middle and before the actual test, they were asked to familiarise with the process by walking some times between the distance until they reached to consistent speed. Also they were requested to walk with the self- selected speed to avoid any adaptability while passing the mat until a full contact of the right foot with the mat achieved.

10 trials have been gained and inconsistency trial to trial in the same individuals observed so their force distribution under their feet was so varies among trials. So speed of walking showed to have the most important effects on the distribution of the force. It is investigated that individuals with steadier way of walking had more repeatable force distribution pattern. To achieve steadier walking pattern volunteers asked to walk with around 4.6 second speed when they are passing the pressure mat. So 10 valid trials collected from each volunteer. To complete each trial they should have had a full contact of the right foot from the heel to the toe off position with the mat.

For the next step they were asked to increase their walking speed by 20% of their normal speed for this stage also 10 valid trials have been achieved.

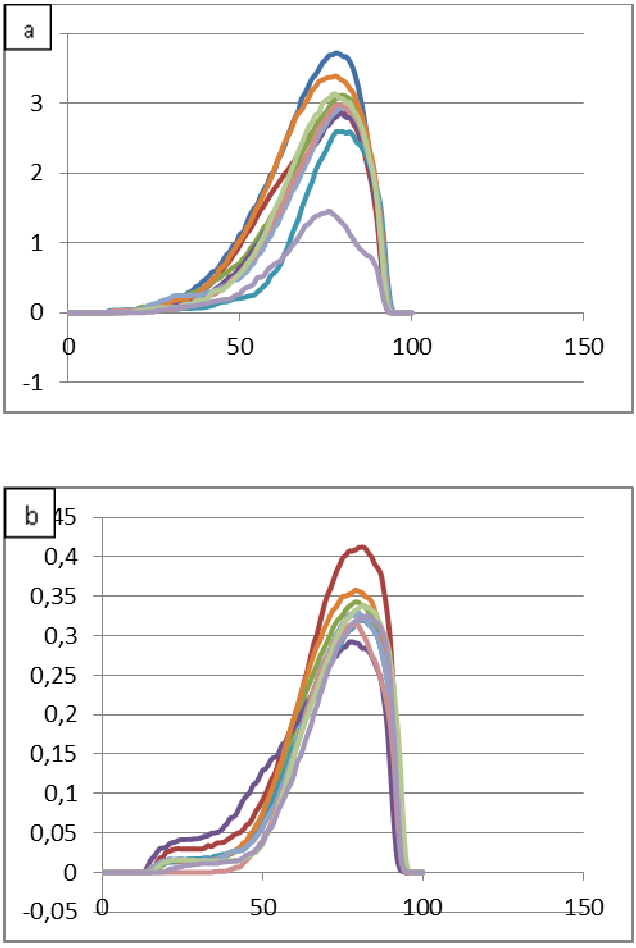

Fig. 2. Force distribution pattern on 2nd metatarsal (a) in the fast speed (b) in the normal speed

Motion Capture Cameras

10 volunteers with and without deformity took part in the experiment. Vicon Blade software has been used to calibrate the 7 cameras and the start and end point of walking has defined. The start and the end points were identified after calibration has done many times to find the best place in which individual could walk and camera had the best view in the space.

Two markers stick to the bare foot of the right foot of each individual.

To avoid any limitation in the natural walking style of each person the markers stick with the blue tag directly to the skin.

First marker located on the first metatarsal head and the second one on the 2nd metatarsal head.

The distance between the start and stop point was 3 meter. They walked 5 times before actual test for being familiarised with the experiment procedure to be constant in their speed.

10 valid trials have been achieved for each person and 3 valid trials have been selected for comparison among groups.

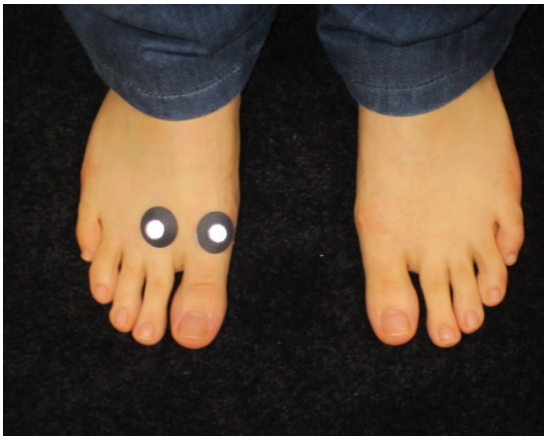

Fig. 3. The location of the markers on the right foot

3 Data Analyses

3.1 Foot Scan

The software, "foot scan", divides each foot to the 10 anatomical zones, the relative forces related to each region of the foot saved in excel sheets. In this case force option is chosen because pressure depends on the size of the region as well as the actual force value, whereas force value is the total force carried by each region which seems to be more meaningful. The force values recorded are normalised against the body weight. For each region the time axis was also normalised.

The maximum force are analysed and metatarsal 2nd and the 3rd bearing the most pressure in both groups but the peak force on these regions were higher in HV group compared to control group.

The amount of force in each region has changed by the changes in the speed of walking. By increasing the speed the force that applied to the foot is about 2 times body weight and more speed means more impact pressure that applies to the sole of the foot [10].

The IBM SPSS Statistics 20 was used to compare the applied forces in both groups to see the existence of significant differences.

Then the force data related to each region of the foot from excel sheets just copy and pasted in the Data View of the software. So in this stage importing the data was

completed and the final stage of the analysis was conducted. By going to Analyse toolbar and then Comparing Means Icon and clicking on Independent sample T-Test, the final results appeared in the created table.

The comparison has been done in forefoot which contains Toe1, Toe2-5, Meta1, Meta2, Meta3, Meta4, and Meta5.

The comparison between HV and Non HV groups has conducted to see whether the force pattern is different among groups. The results achieved from the software presents the statistical significance different of less than 0.05 in the First metatarsal in both groups.

The results indicate that there is a significant difference in Levene's Test for equality of variances and also for equality of means which was less than 0.05 in all forefoot regions except toe2-5 in which no significant difference was observed.

So the regions including 1st, 2nd, 3rd, 4th, 5th and Toe1 showed significant difference by less than 0.05 in HV group compared to control group. Just toe2-5 in both groups did not present any significant difference.

3.2 Motion Capture

Each participant's walking movements have been captured by Vicon cameras and the data related to the movement of first and second metatarsal heads were given by 3 coordinates (x, y, and z).

The two markers were glued to the right foot of individuals so in all cases the motion of the right foot had been analysed.

The start time that the software start recording was the same in all participants and in all trials. The X, Y and Z coordinates were saved with the (trc) format on the notepad file then the data just copied and pasted in the excel file to be able to do the analyses. To find out the relative movement of the first and second metatarsal heads regarding to each other the distance between these two regions has been achieved by the Pythagoras formula for each selected trial. And the graphs achieved based on the distance in millimetre (mm). Figure4 shows repetitive fluctuations while walking in HV volunteer.

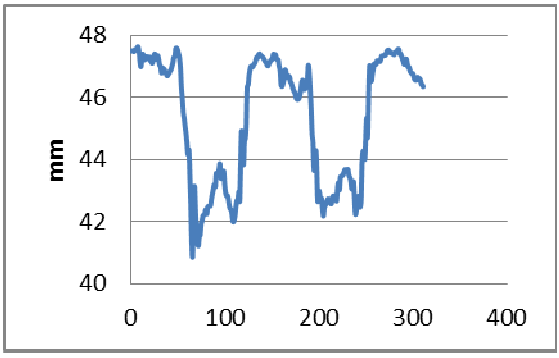

Fig. 4. The distance between markers while walking in HV patient

Other factors that may have impact on the data collection and the results were the way of walking of each volunteers, However they walked 3 times for the preparation for the experiment but still at some stages the error may happen due to the nature of motion but they tried to be steady for the experiments which were repeated10 times passing between start and the end points.

Furthermore, the way of sticking the markers on the barefoot was an issue because they shouldn't constraint the natural movement of the feet so they glued directly to the skin with blue tag.

For having comparison between HV and control groups the range between maximum distances in each trial minus the minimum distances in the same trial has been obtained and then the average of 3 selected trials was calculated. So for each volunteer one number was calculated for making the comparison between 2 groups.

4 Conclusion

Foot scan data regarding to the force distribution over the 10 anatomical regions of the foot shows to be varied in the same person trial to trial. So consistency is an essential issue that being achieved to get the less variable results in the same person. It is concluded that the speed of walking has an important effect on the variability of the force distribution pattern also the style of walking was another factor to have effect on the force pattern.

Consequently forces on the 2nd and the 3rd metatarsal regions are higher in HV group compared to control group. Moreover, by increasing the speed the magnitude of force rises considerably as many previous published studies neglected the importance of the speed of walking.

Also the relative distance between 1st and 2nd metatarsal heads is significantly higher in HV patients compared to non HV individuals and this an important indicator of lateral laxity of the first metatarsal heads' joint which can be the firm indication of the condition.

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