PLANTAR FOOTPRINTS AND 3D FOOT SHAPE DIGITAL ANALYSIS FOR OVERWEIGHT TEENAGER – ONE CASE STUDY

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ABSTRACT. Nowadays, one of the most critical health problems among young people is obesity. Because teenagers are still in the growing process, the foot shape and plantar footprints are very important to be analysed and potential problems to be identified. Young adulthood is a risky period for the development of obesity. This study aims to analyse the plantar footprints, the biomechanical parameters obtained through plantar pressure measurements, and the 3D shape of the foot and anthropometrical parameters obtained from scanning. By comparing the results, both feet have been demonstrated to be high arched, as well as high pressures were identified and differences from left to the right foot. With these results, prophylactic footwear and components can be designed, adapted to the subject's feet.

KEY WORDS: plantar pressure, Body Mass Index, anthropometrical measurements

ANALIZA DIGITALĂ A AMPRENTELOR PLANTARE ȘI A FORMEI 3D A PICIORULUI PENTRU ADOLESCENTUL SUPRAPONDERAL – STUDIU DE CAZ

REZUMAT. În zilele noastre, una dintre problemele critice de sănătate în rândul tinerilor este obezitatea. Deoarece adolescenții sunt încă în proces de creștere, forma piciorului și amprentele plantare sunt foarte importante pentru a fi analizate și eventualele probleme de identificat. Acest studiu își propune să analizeze amprentele plantare, parametrii biomecanici obținuți prin măsurători ale presiunilor plantare, forma 3D a piciorului și parametrii antropometrici obținuți în urma scanării. Prin compararea rezultatelor, s-a demonstrat că ambele picioare sunt scobite, s-au înregistrat presiuni mari și diferențe de la piciorul stâng la cel drept. Folosind aceste rezultate, pot fi proiectate modele de încălțăminte și componente profilactice, adaptate la picioarele subiectului.

CUVINTE CHEIE: presiune plantară, indicele de masă corporală, măsurători antropometrice

L'ANALYSE NUMÉRIQUE DES EMPREINTES PLANTAIRES ET DE LA FORME 3D DU PIED POUR L'ADOLESCENT EN SURPOIDS – ÉTUDE DE CAS

RÉSUMÉ. De nos jours, l'un des problèmes de santé les plus critiques chez les jeunes est l'obésité. Comme les adolescents grandissent encore, la forme du pied et les empreintes plantaires sont très importantes pour analyser et identifier d'éventuels problèmes. Cette étude vise à analyser les empreintes, les paramètres biomécaniques obtenus en mesurant les pressions plantaires, la forme 3D du pied et les paramètres anthropométriques obtenus après le balayage. En comparant les résultats, il a été montré que les deux pieds sont creux, qu'il y a des pressions élevées et des différences du pied gauche au pied droit. A partir de ces résultats, des modèles de chaussures et des composants prophylactiques peuvent être conçus, adaptés aux pieds du sujet.

MOTS CLÉS : pression plantaire, indice de masse corporelle, mesures anthropométriques

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INTRODUCTION

Teenagers and child obesity have increased considerably in recent years. Around 12.7 million, or 17 percent of adolescents and children are overweight or obese. Obesity is one of the easiest medical issues to recognize but most difficult to treat. An increased weight gain due to poor diet and lack of exercise is responsible for more than 300,000 deaths each year. One way to manage children's and adolescents' obesity is to include the increase of physical activity (for example walking) and have a more active lifestyle, eating meals as a family instead of while watching television or at the computer [1-3].

Authorities reported that, for children and adolescents aged 2-19 years, in 2017-2018 [4]:

• The prevalence of obesity was 19.3% and affected about 14.4 million children and adolescents.

• Obesity prevalence was 21.2% among 12 to 19-year-olds. Childhood obesity is also more common among certain populations.

• Obesity prevalence was 16.1% among non-Hispanic white children.

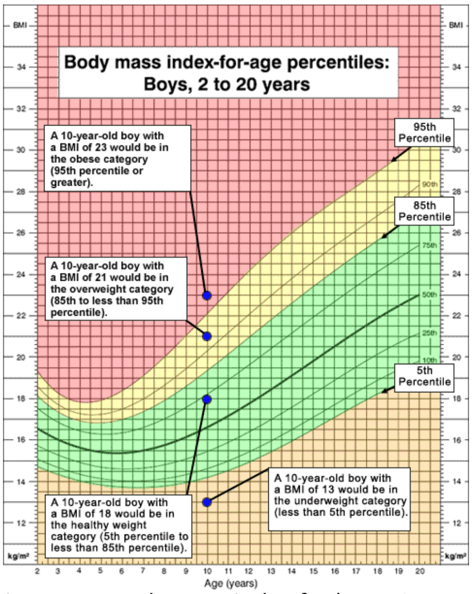

Figure 1.a. Body mass index for boys. Source: https://www.cdc.gov/healthyweight/assessing/bmi/childrens_bmi/about_childrens_bmi.html

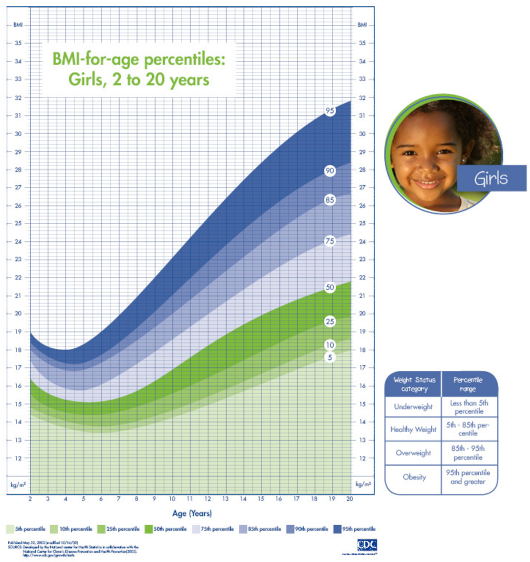

Figure 1.b. Body mass index for girls. Source: https://www.obesityaction.org/get-educated/understanding-childhood-obesity/what-is-childhood-obesity/girls-bmi-for-age-percentile-chart/

Based on probabilistic models, it is highly likely that overweight and obese adolescents suffer from obesity and other related illnesses – such as diabetes, orthopaedic (flat, high arched, or Hallux-Valgus feet), and psychological problems [5, 6]. Functional and structural limitations resulting from the additional load on the locomotor system by excess fat, resulting in wrong mechanics of movements [7, 8].

In a study undertaken by Jiménez-Ormeño, E. *et al.*, it is demonstrated that excess weight affects the feet structure of children. There are changes which show that the foot of overweight and obese children follows a distinct growth pattern, different than children with a normal-weight. Using those results, the footwear manufacturers can design and produce shoes for children taking into consideration their age and weight [9].

EXPERIMENTAL

Materials and Methods

The BMI of a child tells us if their weight is appropriate for their height. Instead of using the BMI categories used for adults, a child's BMI is given as a percentile [9]. Because children are constantly growing until around the age of 18, their age and whether they are a boy or girl is also used to work out their BMI percentile. A small change in weight or a few months' difference in age can change the percentile score. The BMI calculator works out if a child or young person is:

- underweight: on the 2nd percentile or below
- healthy weight: between the 3rd and 91st percentile
- overweight: 91st percentile or above
- very overweight: 98th percentile or above

Our subject has recorded a value of 99th percentile, meaning that he is VERY OVERWEIGHT.

Scanning the Foot

All experimental protocols were approved by a named institutional review board. The subject has been informed and consented to participation in the study. All methods were carried out following relevant guidelines and regulations.

The subject (9-year-old, male) was accompanied by a parent during testing, the parent has signed a consent form. He has been previously diagnosed with over-pronation. Several initial stages of structural modification related to his condition have been identified, in this case, especially in the rearfoot area.

The subject's foot is scanned by using a 3D foot scanning system; namely the INFOOT USB Standard Model IFU-S-01. INFOOT scans a foot and positions the anatomical landmarks, which are used to measure automatically/ calculate up to 20 measuring items. The subject stands with one barefoot inside the scanner and one foot outside the scanner, and the entire mass of the subject is equally distributed on both feet [11, 12].

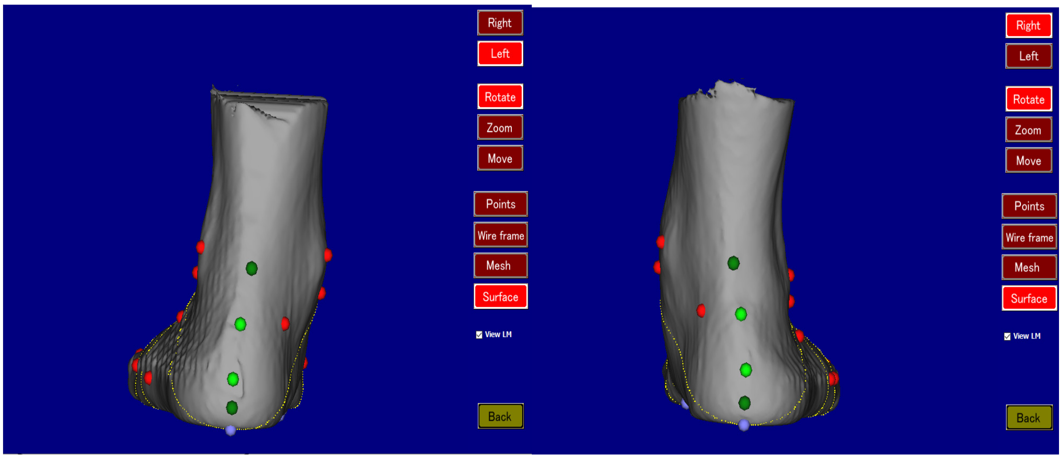

Figure 2. 3D Shape of the scanned feet

The scanned foot data can be used for foot morphological analysis, footwear/last selection, and also for designing new lasts or re-designing existing ones, especially in case of customized footwear.

It can be seen from Figure 2 that the feet are over-pronated, and the left foot is more pronated than the right one. These images show valgus feet, with a postural deformity characterized by exaggerated dorsiflexion of the foot.

Plantar Pressures

The RSScan 2D plate of 0.5 m and its associated software, namely Footscan Gait Scientific, have been used. The experimental task that was followed up comprises measurements in:

- Statics – the subject was required to find his balance on the pressure plate having his weight equally distributed on both feet. Then a capture of the plantar pressure has been taken.
- Dynamics – the subject was required to walk, passing on the pressure plate with the left foot. One capture in dynamics has been taken. The subject repeats this movement stepping with the right foot on the plate. Three measurements on each foot have been taken to obtain reliable and comparable sets of data.

RESULTS AND DISCUSSIONS

Anthropometrical Measurements

Accurate positioning of the anatomical points influences the value of anthropometric parameters. For the hereby-presented study case, the mapping of the anatomical points suggested by the scanner's producer – INFOOT was used [13]. The landmarks are automatically given by the software in a few seconds. Because several problems and structural modifications against the normal foot have been identified for this case, each anatomical point is checked, and it is moved (if necessary) in its right position. After correct positioning of anatomical points, the anthropometrical chart is automatically generated, the results can be seen in figure 3.

Dimension	Left	Right
Foot length	230.6 mm	229.6 mm
Ball Girth circumference	220.4 mm	216.2 mm
Foot breadth	87.4 mm	83.2 mm
Instep circumference	219.8 mm	217.6 mm
Heel breadth	60.7 mm	61.0 mm
Instep length	168.3 mm	155.6 mm
Fibular Instep length	138.8 mm	134.6 mm
Height of Top of Ball Girth	41.9 mm	44.9 mm
Height of Instep	57.8 mm	58.6 mm
Toe #1 angle	1.3 °	0.4 °
Toe #5 angle	0.7 °	2.7 °
Height of Toe #1 joint	23.3 mm	24.6 mm
Height of Toe #5 joint	18.3 mm	19.2 mm
Height of navicular	39.1 mm	33.1 mm
Height of Sphyrion fiburale	59.1 mm	48.1 mm
Height of sphyrion	52.6 mm	58.6 mm
Height of the most lateral Point of lateral malleolus	69.6 mm	58.6 mm
Height of the most medial Point of medial malleolus	68.1 mm	69.1 mm
Angle of heel bone	7.5 °	8.2 °
Heel Girth circumference	320.9 mm	299.9 mm
Horizontal Ankle circumference	268.7 mm	248.6 mm
Calf circumference	- - - . - mm	- - - . - mm
Foot size	23.0 C	23.0 C

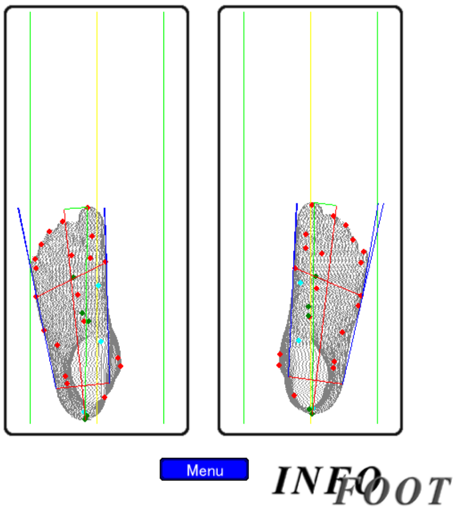

Figure 3. Feet anthropometrical measurements

Plantar Pressure Measurements

The static printout (figure 4.a.) gives the first information on the pressure distribution over the plantar area and the shape of the foot. For the investigated subject, both feet are high arched, with a peak of pressure under the heel. The contact areas between foot and ground are on the heel and only in a very small forepart area.

Figure 4.b. shows the distribution of pressures during all phases of rolling the feet on the ground. In this case, the high pressure is still on the heel, but the plantar shape is closer to normal, not so much high arched as in static position.

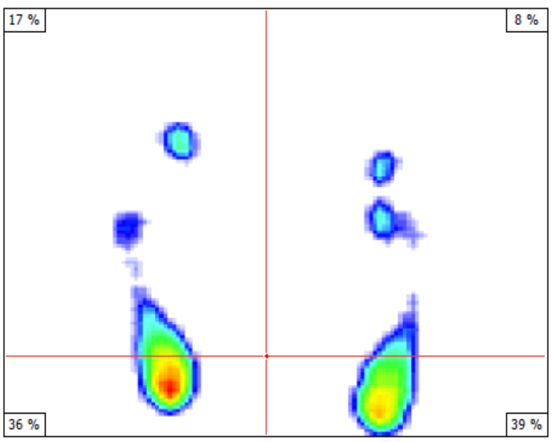

Figure 4.a. Static printout

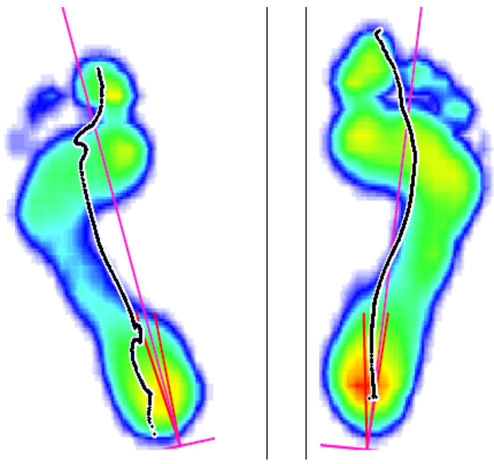

Figure 4.b. Dynamic printout

The gait cycle can be divided into three main stages: the first contact with the surface (impact), the stance stage when the entire foot is in contact with the ground, and the propulsion stage when the foot is pushing off the ground. Five phases of the gait cycle are presented for the left foot and 5 phases for the right foot (figure 5). For the herby study case, the left step time is 511 ms and the right step time is 575 ms, both values being under the average step time of 900-990 ms reported in other studies.

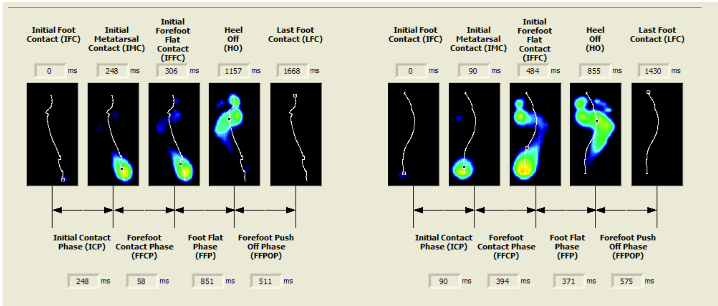

Figure 5. Gait cycle

The Footscan software gives the pressure graphs depending on the foot areas (figure 6). Therefore, the foot is divided into 10 areas (toe 1, toe 2 to 5, metatarsal 1 to 5, medium foot, medial heel, and lateral heel), each of them being differently coloured. The same legend of colours is kept for pressure graphs, to easily recognize how the pressure varies for each area of the foot.

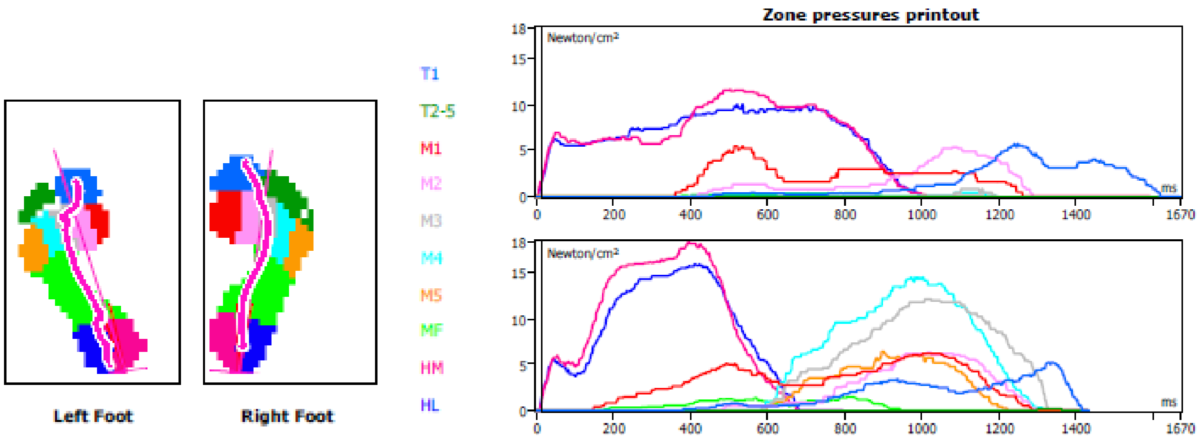

Figure 6. Pressure graphs depending on the foot areas – left foot and right foot

Each pressure graph can be divided into 3 phases: heel contact, foot contact, and push off. Two pressure peaks are visible on each graph: one during the heel contact stage and one during the pushing off stage. For a normal gait pattern, these two peaks have appropriate values.

The maximum pressures, impulse, contact, and time are extracted for both subject's feet. The values are analysed using a T-test to identify if there are significant differences between the right and left foot.

Table 1: Biomechanical parameters on different areas of the foot and T-Test

	Start Time	End Time	% Contact	Max P	Impulse	Contact area
Left	ms	ms	%	N/cm²	Ns/cm²	cm²
Toe 1	459	1619.5	69	5.7	2.1	12.4
Toe 2-5	2	1668	100	0	0	7.1
Meta 1	360.4	1263.6	54	5.4	2.3	5.6
Meta 2	420.7	1289.3	52	5.3	1.8	8.6
Meta 3	1082.5	1185.5	6	0.8	0.1	6.4
Meta 4	1082.5	1167.5	5	0.4	0	6.8
Meta 5	2	1668	100	0	0	9
Midfoot	403.1	889.8	29	0.3	0.1	29.2
Heel Medial	5.1	1012.9	60	11.6	7.1	13.9
Heel Lateral	6.5	1001.1	60	10	6.9	12
Right	ms	ms	%	N/cm²	Ns/cm²	cm²
Toe 1	381	1417.5	72	5.2	2.1	12.8
Toe 2-5	1299	1365	5	0.2	0	12.8
Meta 1	148.5	1287.4	79	6.2	4	12
Meta 2	482.8	1299.2	57	6.3	2.5	10.1
Meta 3	584.6	1329.6	52	12.1	5.5	8.2
Meta 4	584.6	1315.4	51	14.4	6	7.9
Meta 5	596.7	1223.3	44	6.4	2.3	9.4
Midfoot	176.3	946.8	54	1.5	0.6	30
Heel Medial	10.4	676.9	46	18.3	7	13.9
Heel Lateral	10.3	683.1	47	15.9	6.3	12
T-TEST	0.398828	0.05769	0.42365025	0.0079721	0.029962	0.0178
	>0.05	>0.05	>0.05	<0.05	<0.05	<0.05

The anthropometrical parameters are extracted for both subject's feet. The values are analysed using a T-test to identify if there are significant differences between the right and left foot.

Table 2: Anthropometrical parameters of the foot and T-Test

Dimensions		Left	Right
1.	Foot Length	230.6 mm	229.6 mm
2.	Ball Girth	220.4 mm	216.2 mm
3.	Foot breadth	87.4 mm	83.2 mm
4.	Instep circumference	219.8 mm	217.6 mm
5.	Heel breadth	60.7 mm	61.0 mm
6.	Instep length	168.3 mm	155.6 mm
7.	Fibular instep length	138.8 mm	134.6 mm
8.	Height of Top Ball Girth	41.9 mm	44.9 mm
9.	Height of Instep	57.8 mm	58.6 mm
10.	Toe 1 angle	1.30	0.40
11.	Toe 5 angle	0.70	2.70
12.	Height of toe 1 joint	23.3 mm	24.6 mm
13.	Height of toe 5 joint	18.3 mm	19.2 mm
14.	Height of navicular	39.1 mm	33.1 mm
15.	Height of Sphyrion fibulare	59.1 mm	48.1 mm
16.	Height of Sphyrion	52.6 mm	58.6 mm
17.	Height of lateral malleolus	69.6 mm	58.6 mm
18.	Height of medial malleolus	68.1 mm	69.1 mm
19.	Angle heel bone	7.50	8.20
20.	Hell Girth	320.9 mm	248.6 mm
21.	Foot size (French)	23	23
T-TEST: p = 0.087> 0.05			

Based on the human body symmetry, the initial hypothesis is that there are no significant differences between left and right foot. For testing this hypothesis, a T-Test is conducted for a pre-set probabilistic limit of p=0.05. If the result of the T-Test is inferior to p, then the hypothesis is rejected.

For the biomechanical analysis, the calculated value for Student test is lower than p=0.05 for maximum pressure, impulse, and contact area. Thus, the initial hypothesis is rejected and there are significant differences between left and right foot.

For the anthropometrical analysis, the calculated value for Student test is 0.087, which is lower than p=0.05. Thus, the initial hypothesis is accepted and there are no significant differences between left and right foot.

Even if the investigated subject doesn't have visible differences on anthropometrical values, the difference in the position of the foot (seen in 3D), the pressure distribution between left and right foot in statics, the analysis of values in dynamics demonstrates that there are significant statistical differences and prophylactic footwear and orthoses are recommended.

CONCLUSIONS

By comparing the results, both feet have been demonstrated to be high arched, as well as high pressures were identified. For orthopaedists, it could be a very good example of establishing the typology of the foot to suggest special devices to be introduced inside the shoe or customized soles and insoles. A T-Test is conducted for anthropometrical and biomechanical parameters. The result of this test is that there are significant differences between the pressures of the two feet, and the need to design separately the bottom components. An analysis of gait time was made, the result being a normal distribution on each area of the foot.

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