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ROLE OF DETERMINATION THE ACTIVE CONTACT AREA OF FOOT IN EVALUATION OF PES PLANUS AND DESIGN THE INSOLE

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Abstract: *Pes planus (flat foot) is more then 10% from the active population. The aim of the study is to research how could be make the plantar correction using insoles in flat foot. Biomechanics evaluation consists in determination of active area contact like percent from total plantar area. The conclusions of our research open the new way for approach the flat foot in the perspective of how could be the workflow for design the insole for flat foot. Also evaluation of morphologic indexes and correlate with plantar pressure distribution and active contact area correction limit the evolution of flat foot, the unwanted effects under the lower limb. Also, the check of insole using scanner method help to adjust the design process.*

Key words: *Biomechanics, flat foot, 3D models, insole, active contact area.*

1. INTRODUCTION

1.1 Problem description

The feet are only 5% from body surface, sustain 95% from body weight and reduce the shock during the gait. Dynamic and static of foot needs, sometimes, to produce corrective insoles that are fit and could help for improve the life quality and locomotion, according to the person needs.

By this way is possible to reduce and control the foot pain due to corrective pressure distribution under the plantar side of the foot.

Pes planus (flat foot) is one of the most frequency pathology of the foot that means morphologic disorders of foot that could be find at more then 10% from the active population. In the last 10 years we find an increase the number of the persons that come for make specific assessment and are diagnosed with *pes planus*, especially children. In the same time we can observe that the technology of evaluation the gait, the foot gives us the possibility to discuss about the pattern of pressure distribution under the plantar side.

Even if exists a reach of literature in field of evaluation the *pes planus*, we have to recognize that the informations about these patterns are not enough and this involve a lack of knowledges about accurate diagnostic and also about the design of assistive system like insoles.

1.2 Application field

This study has application in field of clinical orthopedic and rehabilitation, because it gives a lot of informations and also an algorithm for identify the overuse of plantar side regions, that need correction and also help the clinician to monitoring the evolution and prescription the insoles.

Much more could help in create the prognosis about the possible injuries of the foot in the context of spine static disorders and also impact under the lower limb [1], [2].

1.3 Research stages -state of the art in *pes palnus* (flat foot) biomechanic assessment

The problem of the *pes planus* (flat foot) is approached in many studies which are focused on two aspects of *pes planus*: medial plantar arch and valgus heel, because both influence the development of *pes planus*. So, the medial arch is the main morphologic change of the foot, but also are numerous factors that could contribute to the development of *pes planus* [3], [4], [5], [6].

Understanding how is possible to correct the *pes planus*, means to know specific aspects of this foot, the plantar arches, such longitudinal arch which has to be at no more then 3mm under the ground. The authors speak about two types of *pes planus*: functional pes planus and structural pes planus, which is the problem because the foot arch does not recover even not charged [7].
Australian Podiatrists Association shows that in the last 10 years, 91% from the insoles prescriptions like prefabricated insoles, are used by the persons suffer from *pes planus* (flat foot).
However are many questions about how make the prescription and about the biomechanic mechanisms that have to take in consideration regarding the best prescription. This because the problem is that even if is possible to evaluate the foot posture, is not enough informations about what means normative data.
In this way are many authors that studied how the plantar pressure is influenced by the plantar arch [8]. They propose to use the *Gabor wavelet* method for evaluate the plantar arches on footprints. Using the mathematic methods and include the energy evaluation, the perimeter of the footprint and entropy of the dates, they identify some specific elements that could be associated with the points on the footprint perimeter.
The questions are about the accurate of the footprint, due to lack the informations about development the compensatory mechanisms, and this problem is discussed in [9]. Much more are many discussions about the insoles prescription start from a lot of variables [10], [11], [12], and no consensus in this way [13], [14]. From this point of view some authors describe the "clusters" of insoles based on prescription criteria and variables.
Hunt and al. [15] study the loading of the plantar side and how the pressure distribution could be improve using the wedges insoles, but the lack of this research consists in how the authors male the evaluation of the results using the questionnaires for pain and radiological evaluation without objectives informations.
Because are a lot of shortcomings it seems that the most important thing is to contoured insoles which have a better effects then flat insoles, because the discharge is not enough, it is a point. In this context using the informations about the surface contact under the plantar regions could help to design the insoles that action under the plantar edges [16]. Much more this approach the thalo-calcanean eversion decreases.

1.4 The aim of the study

In this research we put the problem about how could be make the plantar correction using insoles in flat foot, in the same time with decrease the risk of pain and injuries or other imbalance foot problems that could be developed in time.
The aim of this study is to create a cluster which will include kinetic elements for insole prescription based on using the biomechanics evaluation. This cluster is based on active surface contact and morphologic parameters, because how we said before, in literature are many informations about these shortcomings.
Of course, the results of our proposal could be improve if the research will be include also a normal people like control group.

2.METHODS

The study included 10 patients, mean age 12yrs, height 155 cm, weight 47.36 Kg and body mass index (BMI) 19.15, right *pes planus* (flat foot). Biomechanic evaluation consists in determination of active area contact like percent from total plantar area. It depends on pressure distribution on plantar side. The evaluation is make using the RS Scan force plate at two moments in time T1 and T1 (after 6 months).

2.1 Morphologic assessment

First step includes morphologic evaluation using index *Chippaux* (ICS) and *Clarke angle* (IC), which give us informations about the longitudinal arch of the foot, and allows to qualifies the subjects in different types of flat foot. *Chippaux* index indicates the area of the midfoot on a smooth surface. It is measured by dividing the value of the narrower zone of the midfoot (CD) by the value of the parallel line on the wider zone of the forefoot (AB), and multiplying by 100 (Figure 1). There are three grade of flat foot: grade I ICS $\in$ [45.1%-50%]; grade II ICS$\in$ [50.1%-60%]; grade III ICS $\in$ [60.1%-100%] .

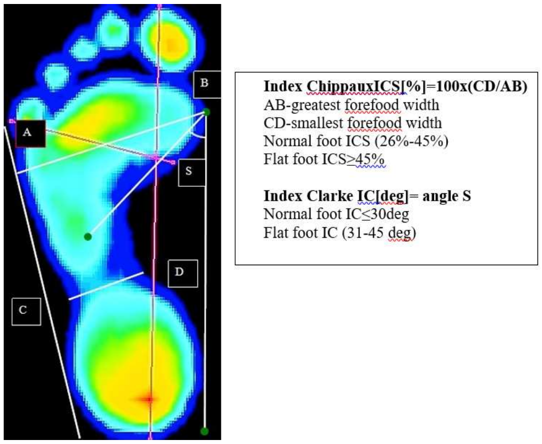

Fig.1. Indexes Chippaux (ICS) and Clarke (IC)

Clarke is the method for measuring internal longitudinal arch angle S between line, that joins the more internal point of the forefoot and the more internal point of the rearfoot, with line, that joins the more internal point of the forefoot with the deeper part of the footprint (Figure 1). References values are:

- Clarke Angle < 31° tendency to flatness and/or pronation;
- 31° < Clarke Angle < 45° normality range; Clarke Angle > 45° tendency to cavus foot (Figure 1).

2.2 Biomechanical assessment

Biomechanical assessment has been made using the RS Scan Scientific Version planting, RSScan International, Olen, Belgium, able to perform measurements with a frequency of 500 Hz in 2D for measure the force distribution and plantar pressure distribution and record the complete action of both plants. The platform was used to record the pressure distribution values in the lower limb at ground contact, in dynamic action-gait. The plant applied on the platform measures local pressure at full contact with the ground at high frequency, the operational substrate is represented by the total impact force measured at the level of a sensor matrix on a known surface. RS Scan force platform makes the gait analysis in terms of ground reaction force and the pressure developed during gait. The values are expressed in [N] for force and [N/cm2] for pressure. Data analysis includes: information about pressure distribution at plantar level, force distribution in each plantar region, the contact surface which is active. Both plants were recorded during two gait cycles, paying attention to alternative placement of the right/left lower limb (Figure 2).

Fig.2. Force plate measurement using RS Scan forceplate

In the present study, we grouped the eight stages of gait into three stages, namely:
- ground attack phase – the initial contact heel;
- midstance phase, in which the middle region of the plant is involved;
- propulsion phase, in which the load is higher in the metatarsals; this stage depends on the way the tibial-tarsal control is achieved.

Plantar regions are: contact toe-1; contact toe 2-5; contact metatarsian1; contact metatarsian 2; contact metatarsian 3;contact metatarsian 4; contact metatarsian 5; contact midfoot, medial and lateral heel contact (Figures 3a,3b).

Fig.3.a. Plantar regions

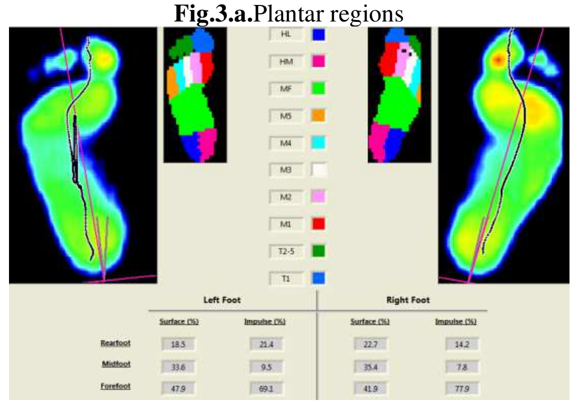

Fig.3.b. Footprint for flat foot

Start from the force plate dates about active contact area [%], was made the design of the insoles using CAD-CAM (CNC) method (Figure 4) and pelotation the plantar regions that needs discharge or sustain for make the plantar correction, which involves an uniform pressure distribution.

Fig.4. Final insoles (CNC)

We make a check of the insoles using the manual scan 3D, by Scanner ARTEC Eva and its software ARTEC V9. This method help to adjust the insoles and be more accurate. For this, the insole is fixed on rotated table and was scan (Figure 5).

Fig.5. Scan method using ARTEC Eva Scan

After the scan, the points cloud are processed by ARTEC V9, and the results is the 3D model, “as build” of the insole. (Figure 6).

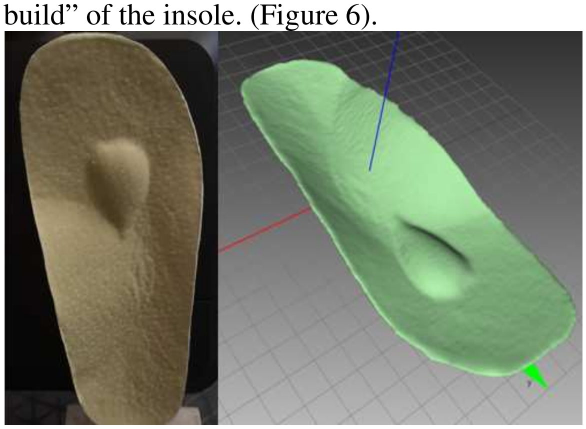

Fig.6. The 3D model of the insole obtained by scanning method

Using the scanner software we make transversal sections (Figure 7) and longitudinal sections (Figure 8) through 3D model.

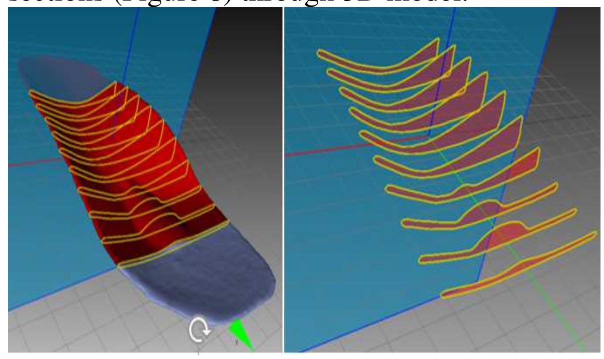

Fig.7. Transversal sections

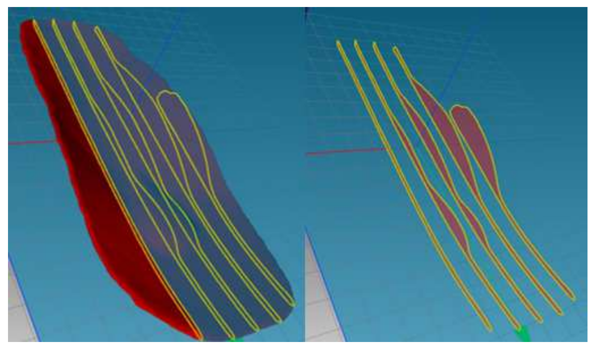

Fig.8. Longitudinal sections

In these sections we observe the pressure points in connection with active contact area for each plantar region. Based on this relationship between biomechanic force plate evaluation and 3D model, we can check if the design is in according with the subject needs and also we can measure the corrective values of the wedges during pelotation process. By this way will obtain much more accurate of the insole that could satisfy the needs for correction the plantar arches at different plantar regions (Figure 9).

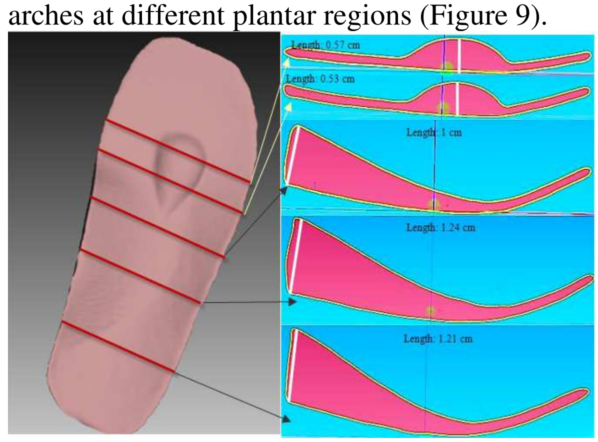

Fig.9. Transversal section measurement of wedges

3. RESULTS

First we present the values and average values of indexes *Chippaux* and *Clarke angle*, in table 1a, 1b, for the two moments T1 and T2 of evaluation.

Table 1.a

Index Chippaux and Clarke angle, moment T1 (values and average values)

No.	Right foot Index Chippaux	Left foot Index Chipp-aux	Right foot Index Clar-ke	Left foot Index Clar-ke
1	43.65	40.57	47.15	44
2	19.95	30.12	48.49	19.42
3	30.28	28.3	52.89	54.87
4	54.29	67.59	21.85	17.53
5	61.23	54.77	28.07	42.67
6	47.37	59.79	41.7	19.58
7	65.57	63.83	29.83	25.06
8	41.31	40.52	54.49	46.7
9	40.89	35.66	56.6	61.7
10	47.78	56.39	35.14	28.02
11	62.88	62.79	41.68	35.31
12	59.89	54.1	15.12	42.75
13	50.13	64.89	66.3	4.86
14	42.9	54.37	55.39	32.57
15	56.86	45.94	26.67	44.97
16	45.57	33.91	41.75	45.24
17	29.34	62.46	38.34	22.77
18	30.23	22.94	39.49	46.15
Averages values	46.11	48.83	41.16	35.23

Table 1.b

Index Chippaux and Clarke angle, moment T2 (values and average values)

No	Right foot Index Chippaux	Left foot Index Chippaux	Right foot Index Clarke	Left foot Index Clarke
1	40.51	45.57	47.68	55.73
2	28.52	36.8	51.67	16.22
3	31.38	26.26	52.79	58.06
4	42.56	56.11	54.25	16.44
5	75.47	66.84	32.49	28.66
6	56.57	47.38	34.68	42.1
7	52.9	60.73	49.16	24.57
8	30.35	35.31	42.12	52.08
9	36.62	37.87	54.3	60.44
10	43.88	44.32	32.56	44.35
11	51.48	55.48	51.31	38.68
12	65.5	55.81	20.19	39.53
13	47.75	46.84	25.55	28.31
14	37.52	42.26	66.61	46.48
15	43.59	45.43	43.71	39.16
16	41.87	33.41	41.56	46.9
17	35.05	19.97	54.03	44.82
18	42.99	37.93	52.43	38.07
Averages values	44.69	44.12	44.83	40.03

The results show us that dosent exist any convergence of the values, but we see to average values we can observe that for index *Chippaux* the values decrease for both feet and also the main important observation is that acquired a symmetry right–left. *Clarke angle* has not significantly changes between two moments. The conclusions are that these indexes have not a specific importance and they describe only the foot morphology but can not be use for monitoring the evolution as well as the biomechanic parameters.

In the same context, Buldt at all. [17] observed that different foot posture are associated with different kinematic changes of the foot that have impact during the gait and in flat foot this means decrease the midfoot mobility during the swing phase.

Regarding active contact area evolution, the results are presented like average values on table 2a for right foot and on table 2b for left foot, at two moments T1 and T2. Also, the coefficient of variation (CV) is presented on table 3a for right foot and table 3b for left foot. The value of CV are less then 28%.

Table 2.a

Average values of active contact area, moments T1 and T2 right foot

Plantar regions	Right foot-T1 med	Right foot-T2 med	Average [%]
Contact Toe 1 [%]	6.54	5.92	9.56
Contact Toe 2-5 [%]	6.50	5.86	9.97
Contact Meta1 [%]	6.84	6.63	3.13
Contact Meta2 [%]	6.09	5.96	2.28
Contact Meta3 [%]	4.76	4.87	-2.33

Contact Meta4 [%]	4.94	5.09	-3.16
Contact Meta5 [%]	4.30	4.14	3.72
Contact Midfoot [%]	23.95	21.51	10.18
Contact area medial heel [%]	8.49	8.53	-0.51
Contact area lateral heel [%]	7.36	7.33	0.45

Table 2.b

Average values of active contact area, moments T1 and T2 left foot

Plantar regions	**Left foot-T1 med**	**Left foot-T22 med**	**Average [%]**
Contact Toe 1 [%]	7.81	7.50	3.91
Contact Toe 2-5 [%]	6.94	5.42	21.82
Contact Meta1 [%]	4.64	3.85	17.02
Contact Meta2 [%]	5.26	5.33	-1.18
Contact Meta3 [%]	4.51	4.35	3.40
Contact Meta4 [%]	4.85	4.73	2.51
Contact Meta5 [%]	5.90	6.34	-7.52
Contact Midfoot [%]	24.31	23.16	4.72
Contact area medial heel [%]	7.47	7.51	-0.61
Contact area lateral heel [%]	6.44	6.66	-3.35

Table 3.a

Average values of coefficient of variation, moments T1 and T2 right foot

Plantar regions	**Right foot-T1 CV**	**Right foot -T2 CV**	**Average [%]**
Contact Toe 1 [%]	44.55	29.23	34.39
Contact Toe 2-5 [%]	53.87	45.43	15.66
Contact Meta1 [%]	35.14	21.05	40.09
Contact Meta2 [%]	28.12	16.16	42.54
Contact Meta3 [%]	28.02	13.37	52.27
Contact Meta4 [%]	28.93	15.10	47.82
Contact Meta5 [%]	31.66	26.98	14.77
Contact Midfoot [%]	22.36	20.01	10.53
Contact area medial heel [%]	22.67	13.29	41.36
Contact area lateral heel [%]	22.30	13.55	39.24

Table 3.b

Average values of coefficient of variation, moments T1 and T2 left foot

Plantar regions	**Left foot-T1 CV**	**Left foot-T2 CV**	**Average [%]**
Contact Toe 1 [%]	22.66	35.81	-57.99
Contact Toe 2-5 [%]	46.74	57.28	-22.54
Contact Meta1 [%]	37.51	31.42	16.25
Contact Meta2 [%]	17.15	19.83	-15.64
Contact Meta3 [%]	14.20	14.63	-3.04
Contact Meta4 [%]	14.82	17.95	-21.09
Contact Meta5 [%]	24.75	13.05	47.26
Contact Midfoot [%]	16.95	18.25	-7.66
Contact area medial heel [%]	18.31	17.23	5.91
Contact area lateral heel [%]	19.59	15.52	20.76

Analysis of the results indicates that on the right foot we record a high difference between two moments, that means the active contact area decrease on midfoot approximately with 10% and also the same evolution is for metatarsian 1 and toe 2-5 regions. Otherwise the corrective effect of the insole is demonstrated also by increase the loading on the heel region.
On left foot we observe the same tendency but the decrease of active contact area is more significantly on metatarsian 1 and toe 2-5 region. Also on the heel the contact area increases. Difference between right and left could be explain because all subjects have right dominant and even at normal foot we find different loading on the plantar regions.
On metatarsian region the active contact area decreases and this is in according with Muller at all. [18], that speaks about the possibility to decrease the pressure on the head metatarsians 2-5 about with 16-24% in the presence of the insoles.
Our approach by follow up the behavior of each plantar region is in according with Gostke at. all. [19], which underline the importance of metatarsian region and toe 2-5. These regions seem to take over the pressure in flat foot even in the orthostatic or sitting position.

3.1 Further research

Further research is need for have good correlations between morphologic indexes and biomechanic parameters, so could be possible to make an alignment correction of the foot or also ankle. In this context we consider that is need to develop the research regarding how the plantar arches could influence the subtalar angle and vice versa, but also how is the role of this in restore the thalocalcanean joint balance by increase the eversion moment or decrease the inversion moment.

4. CONCLUSIONS

The conclusions of our research open the new way for approach the flat foot in the perspective of how could be the workflow for design the insole for flat foot. One of the conclusions referee to the importance of using the morphologic indexes and correlate with plantar pressure distribution.

Correction of pressure distribution through the active contact area correction limits the evolution of flat foot, the unwanted effects under the lower limb.

Also, the check of insole using scanner method help to adjust the design process.

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ROLUL DETERMINARII ARIEI ACTIVE DE CONTACT LA NIVELUL PICIORULUI PLAT IN PROIECTAREA INSOLELOR

Rezumat: *Pes planus* il intalnim la peste 10% din populatia activa. Scopul studiului nostrum este Acela de a corecta piciorul plat folosind insole proiectate pe baza evaluarilor biomecanice ce constau in determinarea ariei active de contact raportat la suprafata plantara totala. Concluziile studiului deschid cai noi de abordare a piciorului plat si a modului de proiectare si fabricare a insolelor corective utilizand evaluari biomecanice si tehnologia de scanare

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