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Conceptual Analysis of Correspondence between Plantar Pressure and Corrective Insoles

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***Abstract*—**Some theoretical and experimental aspects related to the conceptual analyses concerning the direct correspondence identification between the shape, area and orientation of plantar pressure and obtaining adequate corrective insoles by rapid prototyping are presented in this paper. In the first part of the paper there is the theoretical-correlative concept, which is the fundament of correspondence deduction between plantar surface characteristics and respectively corrective insoles. In the second part of the paper the experimental equipment used to analyze and perform the correspondence stages and then the integral ones between the analyzed foot shapes and the ones with corrective insoles is presented. In the final parte the results used to adapt the insoles obtained by rapid prototyping but also some specific aspects and conclusions of the conceptual analysis of direct and rapid correspondence are shown.

***Keywords*—**Insoles, plantar surface, rapid prototyping, correspondence concept

I. Introduction

THE concept, upon which the research developed within this application, consists of creating a correlation between the recordings of the plantar pressures of different subjects by help of the Footscan pressure plate and respectively constructive shapes of orthopedic insoles for two of the most encountered sole abnormalities, namely the “hollow foot” and “flat foot”. In many research studies it was shown that most people (approx. 60-70% of the population) suffer from excessive pronation due to flat feet when walking, running and standing. When the human subject sits down the foot may appear normal, with a clear arch present under the foot, *over-pronation* becomes noticeable when he stands or walks. The arches collapse with every step he makes, and the ankles roll inwards. This is called *over-pronation*, a biomechanical imbalance that can lead to many painful foot conditions such as heel pain, plantar fasciitis, heel spurs, tendonitis, and can even affect other parts of the body such as the knees and lower back also. *Over-pronation action* has different causes like obesity, pregnancy, age or repetitive pounding on a hard surface. These activities can weaken the arch, leading to over-pronation, but it is also a very common situation for athletes, especially runners, who most of them, nowadays, use orthotics inside their sport shoes.[2]

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Orthopedic operations, a usual way of obtaining improvements of the foot shape include a large range of procedures meant to try to correct the locomotion malfunctions, but in spite of these there are little researches done to highlight the post-operation changes occurred as a result of these types of interventions. Most of them are concentrated upon the changes presented at X-rays level and/or study only the patients’ comfort and satisfaction, neglecting the measurement of the sole functions before and after operation. Computerized systems of measuring sole pressure became during the last years smaller, easier to transport, cheaper and more accurate, offering to researchers more useful and objective methods to measure plantar pressures but they are limited only to measurements performed with special shoes, not taking into account the fact that the subject walks using different types of gait. [3]

The sole is essentially a complex structure supporting the entire weight of the human body and/or of the clothing or working accessories. In order to study the manifestations of the plantar pressure as well as the effects upon the entire anatomical structure, a lot of technologies were developed, including force platforms (plates), pressure plates and devices that are introduced inside the shoes, trying to provide safe and reproducible methods for recording the distribution of the plantar pressure to improve the understanding of sole functionality, both for healthy subjects and for pathological situations.[4]

„Taking proper care of the feet is extremely important action, because they play a vital role in supporting human body weight, and also allow an incredibly flexible range of movement. Each one of human subject desires to have feet that are free of pain, feel good, look good and smell good as well. Taking preventive foot health care to correct biomechanical conditions such as flat feet and over-pronation, and pampering the skin helps quite a bit in preventing many of the most common foot ailments. Any biomechanical imbalances in the feet can be managed by wearing orthotic insoles. This approach is effective in alleviating symptoms as well as preventing bunions from worsening.” [6]

„The foot is „designed” to adapt to different types of surfaces and absorb shock and impact during walking, running or jumping. At the same time, the foot must be capable of changing into a rigid structure to stabilize and move the body forward and this is known as *normal foot function*. However, most of the people suffer, at different degree of abnormal foot function which can throw the whole body off, causing pain and injury all the time.

An estimated 70% of the population suffer from over-pronation - or rolling inwards of the feet and ankles, and collapsing of the arches. For that orthotic insoles are specifically designed for managing over-pronation and restoring the normal function of our feet and entire lower body. In operation of restoring the biomechanical features (stability, balance or equilibrium) of the human body, the orthotic insoles play an important role. Orthotic insoles are designed to control over-pronation and to restore the natural foot function. Orthotic insoles re-align the foot and ankle bones to their natural position, thereby restoring proper foot movement."[6]

The theoretical-correlative concepts consists of establishing a deduction procedure of the corrective insoles shape and dimensions starting from the plantar pressure recordings in various gait situations or stability in different environmental or displacement conditions (open eyes, closed eyes, temperature variation, influence of sounds or light stimuli). From previous research the team was able to find a connection between the insoles shape and the foot model obtained by layout techniques, but this does not entirely match the requirement of getting a very accurate shape of the corrective insoles.

II. EXPERIMENTAL SETUP

The working concept for optimization of the model creation mechanism for a corrective insole required the use of several anthropometrical measurements equipments, recording, scanning and rapid prototyping equipments so that each step is independent but also integrated for comparison in the general structure.

In this respect the methodology consisted of the following steps:

- Selecting the subjects' sample;
- Obtaining anthropometrical dimensions of sole for each subject;
- Identifying the subjects respectively the plantar surfaces with morpho-functional deviations (hollow foot and flat foot);
- Recording plantar pressures, forces and motion evolution developed by the foot;
- 3D scan of plantar surface;
- Digital modeling of these shapes;
- Plantar pressures transfer upon the virtual model of insoles;
- Virtual comparison of insoles shape with the foot virtual model;
- Insoles manufacturing by rapid prototyping;
- Checking the obtained insoles on the corresponding subject's foot.

This methodology was applied and checked for the two types of feet with morpho-functional deviations, namely hollow foot and flat foot, followed by an optimization operation that allows the procedures simplification or allow the use of other equipments in the primary phase, without distorting the final result, which is the construction of a correct corrective insole, comfortable and effective.

In order to perform the measurements and analyze plantar pressure data, the *Footscan®3DGaitScientific* system was chosen, respectively a set of anthropometric devices to establish foot dimensions and also to observe anatomical abnormalities. The equipment used for recording and interpretation of dynamical quantities of subjects' displacements (forces, plantar pressures, walk duration, contact duration, trajectory) consists of a 2m long and 0,4m wide plate, with 16384 piezzo-electric sensors set in matrix form and of a data acquisition module that connects the computer and the software dedicated for measurements.

Fig. 1 Footscan® 3D Gait Scientific system

The software dedicated to footscan type recordings is a *LabView* application and offers the opportunity of getting pressure and displacement duration measurements as soon as possible.

Using *footscan®gait* software it is possible to perform plantar pressures measurements both for a shoe wearing subject and for a barefoot one, statically or dynamically. Besides the static and dynamic pressure during the sole rolling on the ground, *footscan® gait* system allowed delivering necessary information about temporal and spatial parameters of sole rolling during gait, these are helping to gait interpretation as a whole for human subjects.

Dynamic measurement of this type on the plate records the distribution of pressure developed on the patient's sole during rolling upon the contact surface, strating with the initial contact between sole and *footscan®* plate to the end moment of sole rolling. Dynamic measurement is performed individually for each foot, the subject has to go or run on the plate according to the selected recording variant.

For the next stage, the one of obtaining the foot virtual model by 3D scan, the portable scanner with laser source *EXA Scan 30144* was chosen. The operating principle of the scanner is based upon the mechanism for *time of flight* measurement (TOF) or laser pulsed (LP). In this case the distance between the instrument and the object is determined according to the time required to travel the distance or the time between the emission and receiving of laser radiation.

Fig. 2 3D scan system *EXA Scan 30144*

According to the complexity of the scanned surface one of the following configuring ways was used, first *manual configuration*, that assumed a manual setup, more intuitive of the optimal scanning distance, corresponding to an adequate light intensity of the beam emitted by the scanner.

This method has the benefit of the fact that it allows scanning parts with more complex surfaces, but the disadvantage that the configuration operation is more difficult and requires more time. Configuration in *automatic manner* involves accessing of some adjusting options after following the necessary operations sequence to start the configuration setup. This configuration method presents the benefit of an easier and faster procedure, as well as the one of a better scanning resolution, but the main disadvantage is the fact of not being very effective in scanning surfaces with complex geometry, as the foot sole. This is why, in this situation when we establish by efficiency analysis which is the best method to use, the manual configuration of the 3D scanner with laser radiation was chosen.

Another equipment used in the procedure developed within this concept was the rapid prototyping machine, *Dimension Elite Printer* type**.** The operating principle of Dimension Elite Printer equipment is based upon heating the material to be deposited near its melting point and then the deposition of the fused material where this is necessary, in order to obtain the required model. The secret of a successful procedure consists in a thorough control of temperature of material heating and maintaining during depositing process. The used material may be a wire (filament) made of special wax, nylon, polyamide or plastic *ABS Plus* (Styrene Acrylonitrile Butadian). *ABS* plastic heating is performed for a 270 Celsius degrees temperature, when the material remains in a semi-liquid state and it can be further extruded through a very small diameter nozzle (0,178mm or 0,254 mm) and is immediately deposited where the part configuration requires it.

III. Results and Conclusions

In order to check the applied methodology and define the technological concept of obtaining corrective insoles, two shapes of plantar surfaces with anatomic abnormalities were analyzed, namely hollow foot and flat foot, this shapes being identified in a subjects' sample with no other medical problems, aged between 22-24 years, 7 males and 3 females, with different anthropometrical measurements (dimensions, weight).

Plantar pressures recording operation highlighted both the values of the forces developed in each part of the foot sole and the trajectories or plantar pressures distribution in each area.

After the measuring and recording operations on the pressure plate, an extremely important stage was represented by scanning as accurate as possible the foot shape with the corresponding deviations and obtaining the virtual model by CATIA processing. In order for the operation to succeed, the subjects were instructed to set the foot in a black background (calibration plate) with a number of markers (tracking markers). A major disadvantage of this operation is the fact that for the slightest motion of the subject, scanning cannot be correctly performed, which lead to an increased number of markers, up to 20, in order to obtain the required shape.

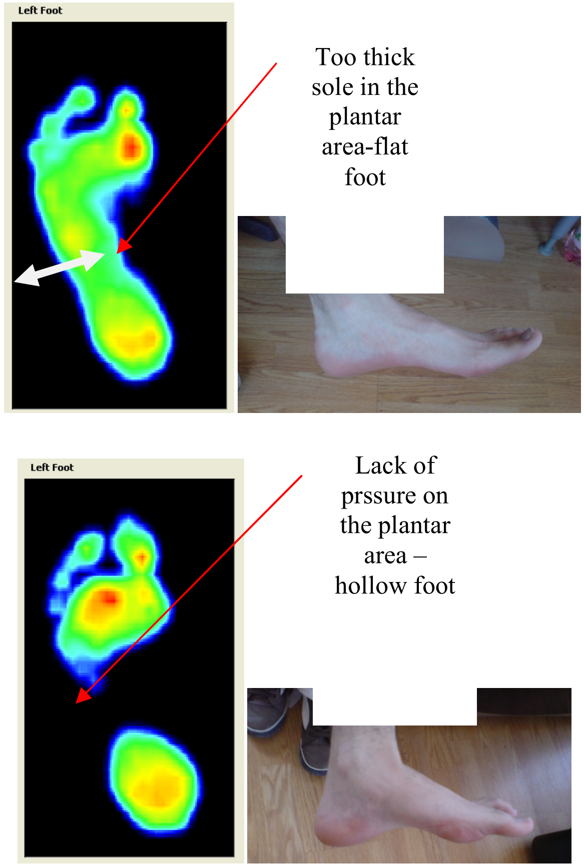


Fig. 3 Recordings of plantar pressure for the two variants of morpho-functional deviations (flat foot (up) and hollow foot (down)

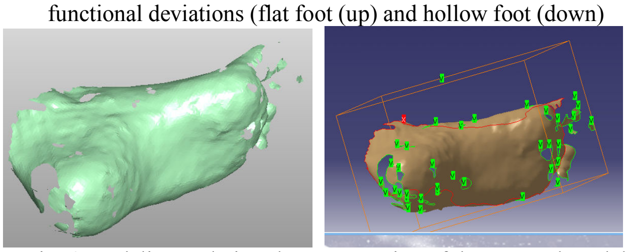


Fig. 4 Modeling and virtual recontsruction of the scanned model

For the two analyzed variants, a set of 3D models resulted, having the surfaces shown in fig.5.

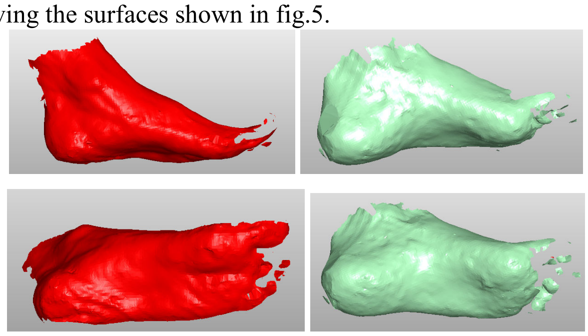
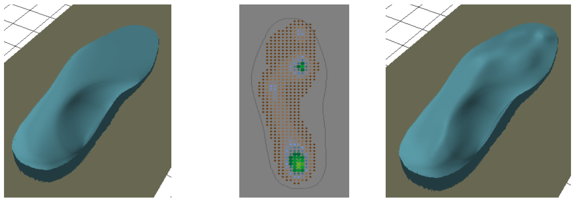
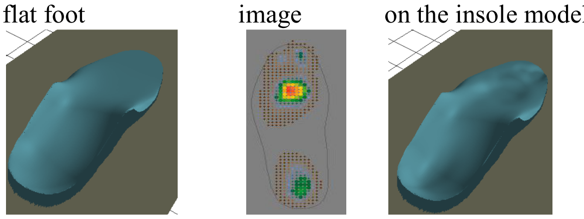


Fig. 5 Representation of virtual models for the two variants flat foot-left and hollow foot-right

Further on, in order to create the insoles for each subject by using *EasyCad* software, it was necessary to import the static images of the pressures recorded on Footscan plate upon their surfaces. These „prints" left upon each insoles helps each subject to set the sole in the most comfortable way, so that the pressure will uniformly distribute on the entire sole surface.



Insole model for flat foot | Footscan image | Importing static image on the insole model



Insole model for hollow foot | Footscan image | Importing static image on the insole model

Fig. 6 Importing the plantar pressure image on the corrective insoles

Before the corrective insoles manufacturing, the correspondence between the digital shape of the 3D models for the scanned feet and the insoles virtual models were checked. In fig.7 we are able to assess the virtual compatibility between the foot 3D model and the insole.

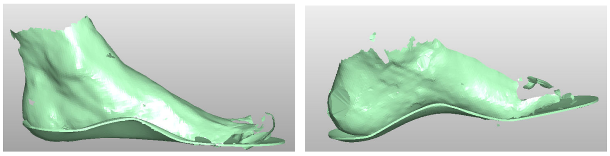


Fig. 7 Performing virtual compatibility between the foot 3D model and the insole (flat foot-left, hollow foot-right)

Having compatible virtual models, the prototyping machine was used to manufacture the corrective insoles. Processing time for each insole was approximately 6 hours and the processing resolution was set to 0,254 mm.

Fig. 8 Manufacturing corrective insoles using rapid prototyping method (flat foot-left, hollow foot-right)

Last stage of this project was checking the corrective insoles prototypes upon the plantar surfaces of the subjects with respective abnormalities. Each subject was required to position its plantar surface on the prototype, in bipedal state, normally used to assess their compatibility (fig.9.)

Fig. 9. Study of real compatibility between the plantar surfaces and the corrective insoles manufactured by rapid prototyping (flat foot-left, hollow foot-right)

From the previous observations, both insoles prototypes were dimensionally suitable and shape compatible for each subject with malfunctions.

The concept at the fundament of the presented research has the main goal of establishing a *direct correspondence* between the recordings on the *Footscan* pressure plate and the corrective insoles prototype, created by 3D printing. The intermediate steps between the data obtained from the recordings on the pressure plate and the final shape of insoles has the purpose of validating the proposed concept and also obtaining a fast, correct and practical procedure for this type of testing. This complex procedure for analyzing and processing corrective models can be simplified and automated by using a system that includes a pressure plate type equipment and a specific software dedicated to modeling and technological manufacturing of corrective insoles.

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