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Development of 3D Printed Insoles

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Abstract

The main objective of the study was to print a pair of customized insoles based on foot scanning. At first plantar pressure distribution while walking in an average group of 51 young adults (21 males and 30 females, age 22 ± 2 years, height 1.72 ± 0.1 m, weight: 70 ± 16 kg) was measured. One of these participants who had an European foot type was selected for future feet scanning and modeling. For plantar scanning a scanner type ATOS III TripleScan was used and then a 3D model of the feet was made. These models were used for the subsequent 3D printing of the insoles. Developed insoles were printed with an OBJET Connex 500 printer (technology PolyJet Matrix) and the blend of Agilus30 and VeroBlack material was used. Initial plantar pressure measurement results with the insole prototype indicated a positive effect to the gait cycle when a subject´s foot contact area was changed. Our experience and knowledge may be used in the future to influence gait cycle through adjustment of the customized insoles in a patients with a different foot deformities.

Introduction

In designing of footwear and the components of the shoe, it is very useful to perform a comprehensive study of the foot. As human feet vary widely from person to person, it is beneficial to understand and recognize trends which will then lead to the creation of shoe and sole designs that will be optimized for the average foot in terms of comfort and style. As such, the advancement of 3D scanning to analyze and measure the human foot accelerates the process, becoming a very useful tool for research on this design.

As one of the primary considerations of selecting the proper footwear, comfort is a complex parameter in the design of footwear. The proper fit may be dictated by several factors such as shape, size, weight, materials among others and it is also necessary to take into consideration measurements such as heel width, heel to ball width, heel to ball length, toe box space among others. And as such, the three-dimensional shape of the foot is critical in understanding and designing for the proper fit of the shoe [1].

Foot scanning methodology

Prior to the more robust and accurate methods of measuring the foot using 3D scanning, many techniques have also been used for analyzing the structure of the foot, including manual measurements of the lengths using calipers or Brannock devices [2,3,8,9], as well as other conventional methods such as determination from digital footprints or the Harris mat also known as the force foot imprinter kit [8]. However, 3D scanning equipment prove to provide accurate and precise results as compared to these other methods in collecting anthropometric data, where consistency in the measurement is important while measuring across different foot types [8]. Usually, subjects are asked to stand up and loaded foot is scanned. The output is a 3-dimensional cloud of data points which represents the surface of the foot.

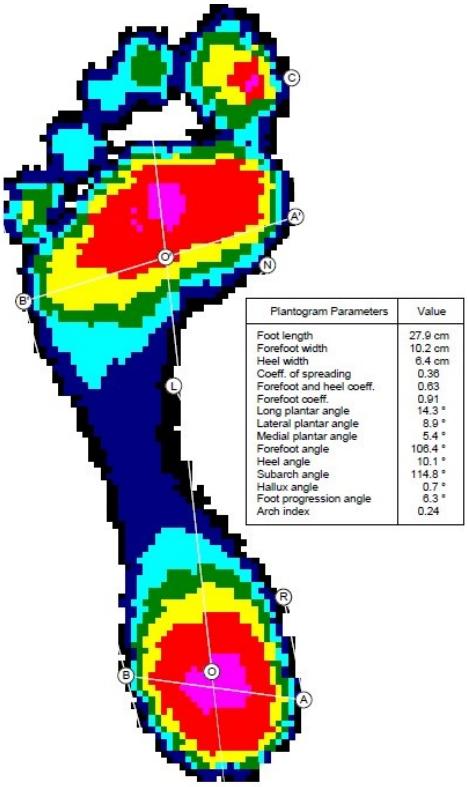
Model of the foot

As the foot is a flexible structure, there are several measurements taken of the foot as the parameters for differentiating foot types and determining the structure of the foot. Measurement of foot length, foot width, horizontal foot breadth, instep length, instep height, ball angle, medial ball length, lateral ball length, anatomical heel width, hallux and toe height are used as parameters to classify the foot shape or for customization of the shoe as needed. According to these measurements three major clusters of European foot types are identified [4,5]. The most common is foot characterized by low instep length, average anatomical ball width, low heel width, long medial ball length and large ball angle. The aim of our study was to develop a 3D printed customized insoles for this type of foot.

Methods

The first objective was to measure plantar pressure distribution while walking in an average group of 51 young adults (21 males and 30 females, age 22 ± 2 years, height 1.72 ± 0.1 m, weight: 70 ± 16 kg). Dynamographic records of all participants´ gait at a normal speed (v = 5 $km.h^{-1}$) using force plates (Emed®-c50, Novel, Munich, Germany) were performed. During their walk, every third step in the sequence was measured. In each participant, a total of 10 steps (5 left, 5 right) were analysed, from which the average values of the foot length, forefoot width, heel width, plantar angles and Arch index were analysed (Fig. 1). Based on these results, participant with the typical European foot type without any deformities like flatfoot or highfoot was selected for future scanning and foot model developing.

All experiments were performed with the approval granted by the institutional Review Board. The experimental work conforms to the highest standards of safety and ethics, with respect to the Declaration of Helsinki and to the national laws. The informed consent of all people participating in the research has been obtained.



Plantogram Parameters	Value
Foot length	27.9 cm
Forefoot width	10.2 cm
Heel width	6.4 cm
Coeff. of spreading	0.36
Forefoot and heel coeff.	0.63
Forefoot coeff.	0.91
Long plantar angle	14.3 °
Lateral plantar angle	8.9 °
Medial plantar angle	5.4 °
Forefoot angle	106.4 °
Heel angle	10.1 °
Subarch angle	114.8 °
Hallux angle	0.7 °
Foot progression angle	6.3 °
Arch index	0.24

Fig. 1: Plantar pressure distribution in a subject with European foot type

The next step was to scan the foot with the scanner type *ATOS III TripleScan* (Fig. 2).

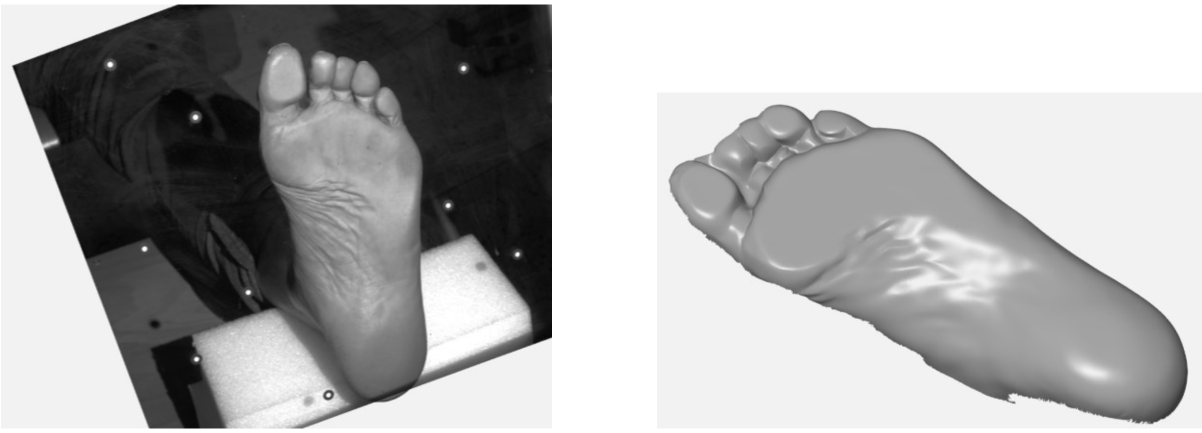


Fig. 2: Scanner view and model of the foot

Based on the plantar scanning (scanner type *ATOS III TripleScan*) a 3D model of the feet was made. These models were used for the subsequent 3D printing of the insoles. Developed insoles were printed with a *OBJET Connex 500* printer (technology PolyJet Matrix) and the blend of *Agilus30 and VeroBlack* material was used (Fig. 3).

Fig. 3: Development of printed insoles

Resulting printed insoles were tested by a subject while walking. Plantar pressure analysis carried out while walking barefoot and using these insoles showed a plantar pressure (PP) differences that can cause a positive effect of the use of insoles in terms of balance and posture stabilization during stance phase. Relative peak pressure ($PP_{rel.}$) normalized to 1 kg of body weight (PP_{max}/kg, where *kg* is the body weight) decreased with the use of customized printed insoles from 4.46 (without customized insoles) to 3.94. In absolute values it was 45 ± 8 kPa.

Conclusions

The objective of the study was to print a pair of customized insoles for one of the three main foot types based on foot scanning. As a suitable material for 3D printed insoles was chosen the blend of *Agilus30* and *VeroBlack* material. Initial plantar pressure measurement results with the insole prototype indicated a positive effect to the gait cycle when a subject´s foot contact area was changed. Our experience and knowledge may be used in the future to influence gait cycle through adjustment of the customized insoles in a patients with a different foot deformities.

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