Using a texture analyser to objectively quantify foot orthoses

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Abstract—Background and aim: Foot orthoses alter the kinematics and kinetics in gait. With the increasing importance of evidence based practice and with the permanent development of subtractive manufacturing and introduction of additive manufacturing, there is a growing need for quantification of orthoses parameters. We describe a measurement method and protocol to quantify different parameters of a foot orthosis.

Technique: A texture analyser is used to impose a displacement of the surface of the orthosis, while the applied force is measured. The measured points are determined based on the location of anatomical landmarks on the foot. Out of the measured data, parameters are calculated representing the stiffness, compression set and shape.

Discussion: To illustrate the proposed technique, five different parameters are extracted from three example orthoses. Results show the added value of the proposed technique as the parameters are not only defined by the material but also by the shape.

I. INTRODUCTION

Foot orthoses (often referred to as insoles) are orthoses that encompass the whole or part of the foot [10]. Depending on their patient-specific purpose, they need to reduce or alter plantar pressure, or change the position of the bones to alter kinematics and kinetics in gait.

The purpose of the orthosis should be determined by the clinician after assessing the (biomechanical) requirements of the patient. To translate this purpose into a patient-specific orthosis, the clinician needs to have a thorough comprehension of the parameters that influence the clinical effect of the insole. In literature the shore A value is often used when describing the properties of an insole [11], [12]. The shore A value however only gives an indication of the hardness of the material. Since insoles often consist of multiple layers of different materials that are glued together, the shore A value of such a multi material sample will only give an indication of the hardness of the top layer directly located underneath the Shore A durometer.

The complete set of insole parameters is however not only determined by a combination of the different materials, but also by production process and shape of the orthosis. The latter is defined by wedges and/or local elevations [4]. The material properties influence the functioning of the orthosis: softer materials can be used to provide comfort and

protection of the skin, while rigid materials can provide more structural stability [4].

To increase the evidence based practice in the manufacturing of foot orthoses, their parameters need to be quantified [5], [6] and they should be reproducible. Therefore, quantitative measurements should be available.

Some studies test the materials that are used to produce orthoses, but this is mostly done on material samples instead of the finished orthoses. For example Paton et al. [7], derive different material properties from materials used to produce orthoses for diabetic patients. However, some production techniques can alter the material properties after the orthosis is fabricated. Brodsky et al. show that heating of material used for making orthoses change their properties [1]. Hence, the materials can behave differently compared to what is expected. Also, material properties can change after a certain time of usage, resulting in a possible decrease of the desired alterations of the gait kinematics, kinetics and pressure distribution. Hence, a quantification of the orthosis parameters is necessary to a better understanding of the change in the functional outcome.

Fig. 1. measurement setup using texture analyser.

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Fig. 2. applied measurement protocol, displaying the distance of the probe to the surface in time.

New production techniques such as additive manufacturing (or so-called 3D-printing) are more and more investigated to be used in the orthopedic workplace [3], [9]. Nowadays, 3D-printed foot orthoses are already available on the market. While in traditional foot orthoses, shock absorption is determined by the materials used, in 3D-printed designs it is determined by not only the material but rather by a combination of the material and the (cell) structure.

In this study, we propose a test method to map the properties of the foot orthosis in one measurement system, capable of measuring the parameters of a foot orthosis, determined by structure, shape and the material properties (which can be altered by the production process and usage).

II. METHOD

A. Measurement setup

The TA-XTplus Texture Analyser (Stable Micro Systems) is used to measure the orthosis parameters. It measures force and displacement simultaneously. A spherical probe with a diameter of 0.5 inch is used. The orthosis is attached to the surface using a clamping system (Figure 1) that fixates two or three specific points of the orthosis, depending on the point that is measured, according to a predefined protocol.

B. Measurement protocol

The parameters of the orthosis are measured at different locations on the surface. At each location, the probe applies a displacement sequence. The maximum displacement is based on an initial slow compression to 4.905 N (500g), for the following compressions the same displacement is used. It includes different displacements at different speeds (1 mm/s to 40 mm/s), as well as a stress relaxation test (Figure 2).

The value of 4.905 N is determined based on the maximum plantar pressure observed in a set of measurements, recalculated to the contact area of the spherical probe. Out of the measured force and imposed displacement, different orthosis parameters are derived that represent stiffness, compression set and the shape [7], [8], [13].

In this study, we use a specific protocol to determine the locations to measure, to be able to compare them between three orthoses. We measure three foot orthoses designed by the same CPO (Certified Prosthetist/Orthotist) for the same patient with a leg length discrepancy and a mild form of scoliosis [2]. The orthoses all have a similar shape and are produced in three different densities of ethylene-vinyl acetate (EVA): shore A values of 25, 50 and 70.

A reference coordinate system is fixed to every orthosis, by letting the subject stand comfortably on the orthosis. The locations of the calcaneus, first and fifth metatarsal and the most proximal point between the hallux and second toe are used to construct the reference coordinate system. A grid of points is then projected onto the orthosis. The same coordinates on all tested orthoses are used in the comparison in the following zones: medial arch (3 points), heel (5 points), metatarsal heads (9 points) and forefoot (6 points). These points are shown in Figure 3 (b-d).

C. Extracted parameters

As an example, the following parameters are extracted from the measured data:

- Shape: represented by the height at applying a force of 0.049 N (5g)
- Stiffness [7], [8], [13]: represented by the ratio between the measured force and the imposed displacement. The

Fig. 3. Illustration of measured parameters of three different orthoses. Height measured on full grid of the medium density EVA (50) (a), the measured force after compressing the orthosis height with 1% on the zones of interest of low density EVA (25) (b), medium density EVA (50) (c), high density EVA (70) (d).

point on the orthosis is compressed until a force of 4.905 N (500g) is measured. Displacements are calculated for force intervals of 0.981 N (100g). The force needed for a certain compression (e.g. 1%) of the original insole thickness at a point is also measured.

- Compression set [7], [8]: represented by measuring the force after a stress relaxation test after 60 seconds.

III. RESULTS

With the proposed technique we can identify mechanical and geometrical parameters of a finished orthosis. In a first comparison, we measure three foot orthoses designed by the same CPO (Certified Prosthetist/Orthotist) for the same patient that are produced in three different densities of ethylene-vinyl acetate (EVA): shore A values of 25, 50 and 70. Figure 3 shows the results of the measurements of the EVA 25 (b), EVA 50 (a, c) and EVA 70 (d) orthoses, more specific the height (a) and the measured force when compressing the orthosis height with 1% (b, c, d).

Table I shows the extracted parameters for the four zones of the three orthoses. The mean value of the measured locations of one zone is given, together with the standard deviation. We observe that the parameter values at different locations on one orthosis have different values, even though it is made from one material. From these objective measurements, we observe that the parameters are not only defined by the material but also depend on the shape. E.g. a higher displacement is applied at the arch region when measuring a force of 4.856 N (495g) compared to other regions, due to the larger volume of material and the specific arch geometry. Also the influence of the heel height, with a rather high difference between EVA 50 and EVA 70, is present in other characteristics. Furthermore, the production process can have an influence on the orthosis parameters by altering the material properties.

IV. DISCUSSION

Our proposed method is able to capture the influences not only from the material properties but is also more suited compared to conventional techniques such as Shore measurements, to capture influences from the shape of the orthosis, the production process or changes due to wear. Even more complex (cell) structures that are used in additive manufacturing can be measured. This enables a better comparison between conventionally made and additive/subtractive manufactured orthoses.

Although the proposed method is able to measure the properties of insoles in a better way, a limitation of this method is the time needed to do the measurements according to the proposed protocol. Especially when measuring a large number of different locations to cover the complete surface of an insole, the method becomes cumbersome. This was partially caused by the fact that the position of the clamps of the clamping system needed to be changed for each of the measured zones on the three insoles. Furthermore once the insole is clamped properly, the insole and clamping system needs to be precisely positioned to measure in the locations defined according to the coordinate system. An automated system to position the insole underneath the texture analyser could significantly speed up the measurement. A possible way to automate this process is to use a motorized X-Y table on which the clamping system is mounted. Such a system would allow for a quicker repositioning of the insole in between subsequent measurement locations and in a more accurate way. Also, it should be noted that in the current setup, only one point at a time is investigated. When all the loads would be applied simultaneously, this would affect the extracted parameters.

The parameters that can be extracted out of the measurements are not limited to the ones proposed in this study. For

TABLE I

THIS TABLE GIVES AN OVERVIEW OF DIFFERENT PARAMETERS THAT WERE EXTRACTED FROM THE ORTHOSES IN DIFFERENT MATERIALS. MEAN VALUES AND STANDARD DEVIATIONS (BETWEEN BRACKETS) ARE GIVEN.

	Height (mm)			Displacement 0.049 N - 0.981 N (mm)			Displacement 3.924 N - 4.856 N (mm)		
	EVA 25	EVA 50	EVA 75	EVA 25	EVA 50	EVA 75	EVA 25	EVA 50	EVA 75
Heel	3.59 (0.99)	5.11 (1.57)	2.38 (0.88)	0.29 (0.08)	0.16 (0.08)	0.16 (0.05)	0.14 (0.02)	0.05 (0.01)	0.09 (0.07)
Foot arch	20.05 (0.84)	19.47 (0.70)	21.06 (0.58)	0.59 (0.06)	0.19 (0.02)	0.12 (0.02)	0.39 (0.03)	0.13 (0.02)	0.09 (0.02)
Metatarsals	7.76 (1.06)	7.31 (1.46)	7.87 (1.69)	0.2 (0.03)	0.09 (0.02)	0.05 (0.01)	0.14 (0.02)	0.05 (0.01)	0.03 (0.00)
Forefoot	4.51 (0.68)	4.25 (0.61)	4.36 (0.89)	0.28 (0.06)	0.24 (0.23)	0.30 (0.44)	0.15 (0.01)	0.08 (0.03)	0.07 (0.03)

	Load (N) 1% compression			Endpoint stress relaxation (N)		
	EVA 25	EVA 50	EVA 75	EVA 25	EVA 50	EVA 75
Heel	0.139 (0.021)	0.306 (0.109)	0.182 (0.046)	4.157 (0.057)	4.150 (0.086)	4.106 (0.208)
Arch	0.345 (0.029)	0.995 (0.123)	1.931 (0.463)	4.212 (0.040)	4.015 (0.029)	3.993 (0.068)
Meta	0.304 (0.049)	0.804 (0.223)	1.649 (0.439)	4.148 (0.033)	4.130 (0.086)	4.238 (0.046)
Fore	0.172 (0.025)	0.327 (0.206)	0.422 (0.329)	4.094 (0.024)	4.113 (0.164)	4.033 (0.126)

example, by applying displacements at different speeds, it is also possible to determine the visco-elastic behavior of the orthosis under dynamic conditions such as walking and running.

Having the measured parameters of an orthosis instead of having just material properties, will help objectifying and comparing guidelines from different clinical studies, and thus bringing scientific research into practice.

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