FROM 3D SCAN TO BODY PRESSURE OF COMPRESSION GARMENTS

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ABSTRACT

Human bodies come under loads in sports. For safety or other purposes, athletes wear compression garments to help avoid wrong postures or movement. We assessed anthropometrics of elite rowers, and found significant differences with the general population, indicating compression garments would behave differently for the athletes. By combining 3D scanning technique and FEM modelling software, we were able to predict compression garment performance on part of the athlete bodies . Abaqus Explicit solver was applied to simulate movement of athletes actually putting on a compression garment, and to track stress distribution during the process.

Key Words: simulation, 3D modelling, compression garment

1. INTRODUCTION

Human bodies come under loads in sports, while wrong postures or movement will cause injuries or poor performances. Therefore sportswear are developed to be comfortable, fitted and functional wear for athletes, which often take the form of compression garments [1-3]. It is crucial that the garment not only provides the proper compression for different body shapes, but also that it does not hinder body movements.

To obtain appropriate designs before production, this has led to an increased interest in predicting pressure functional performances. In order to measure the compression magnitudes and distributions on the skin, two methods have been commonly undertaken. Directly, pressure sensors are used to test objective pressure at some points, such as the Kikume and the PicoPress [4]. Indirectly, it can be estimated from physical characteristics of compression materials, or calculated based on Laplace’s Law [5-7].

However, limitations exist as human bodies are irregular objects so no sensor can measure satisfactory over the entire surface. Even with material properties of the garment determined, during the process of wearing a compression garment, the interactions between the human body and the garment are dynamic and change the observed compression. The stretchy garment material exerts pressure on skin, which is seen as soft tissues and approximately elastic, hence it redistributes the forces leading to new relative displacement. Kinematical constraints in both normal and tangent direction of the contact surface need to be considered as well because the friction between the garment and skin prevents a totally even distribution of forces in the stretched garment [8].

In this study we attempted to simulate the whole process of putting on clothes, and track the stress distribution during this movement. Abaqus Explicit solver was introduced to analyse a dynamic mechanical behaviour. Combined with 3D scanning techniques we can better understand the mechanism and predict performance of compression garments more precisely.

2. METHODS

2.1 Scanning Protocol and Measuring Campaigns

Previous work was done to conduct measuring campaigns of elite Belgian rowers and cyclists, and to assess their body measurements [9]. Two types of techniques/principles were employed: structured light 3D Body scanning by a state of the art 3D body scanner and photographing/photometry (i.e. based on 2D pictures). The following infrastructure was used during the measurement campaign to assess body measurements in static and dynamic rowing/cycling postures and skin-garment interface pressure respectively:

- Anthropometer KERN MSF 200
- Measuring tape, 3D body scanners Symcad/TC2, QuantaCorp mobile scanner
- PicoPress portable compression measurement system max. 189mmHG (~25 kPa)
- Ergometer Concept 2 and bike+ fastening system Tacx Cycleforce Flow
- Outfit identical design (white color/material, 6 garment sizes) worn by athletes during scanning.)

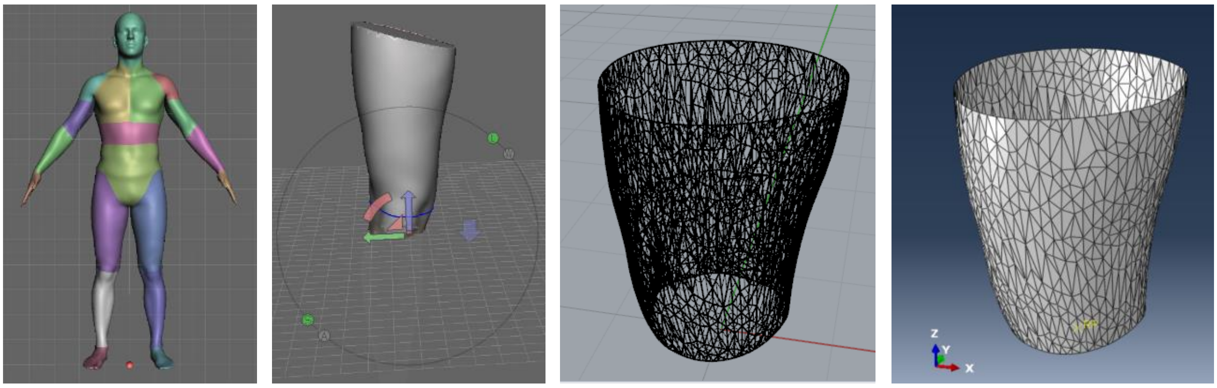
Figure 1. Measuring infrastructure

Among others, the result of this study was that out of 22 body measurements (taken by 3D body scanner) of heavy weight male rowers (maximum weight 90 kg), 13 were found to have statistically significant differences when compared with the normal population [9]. This indicates specific body size charts are required for different sports, and that the effect of compression garments will change if not adapted for use within the sport. We further investigated how best to evaluate the compression garment effect on the wearer.

2.2 Model Modification

The geometry of a body model was obtained from a single healthy male rower subject. 3D point clouds were collected and processed to form fully closed avatars before being imported in CAD software. As whole 3D body simulation causes massive amount of calculation and time, it is important to modify and simply the whole body avatar into an acceptable model so as to balance calculation accuracy and simulation duration. Simulation software has specific requirements on the 3D files that can be used, so the avatars obtained as .stl or .obj files needs to be converted for use in a FEM simulation package. We selected as software for the computation Abaqus which is well-known for strong calculation capability in not only modelling and analysis of mechanical components and assemblies (pre-processing), but also visualizing the finite element analysis result.

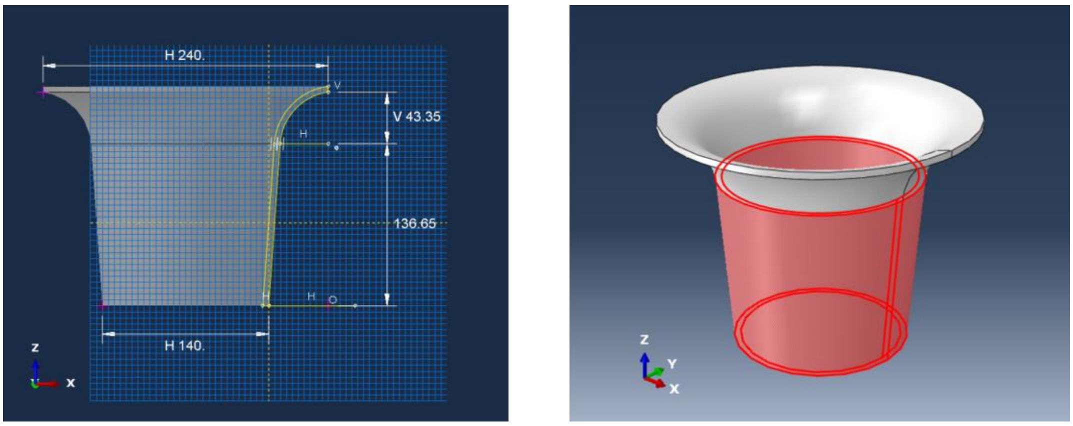
To extract a feasible part (e.g. the right leg) from the avatar (Figure 1(a)), the FreeCAD open source software was introduced to plane-cut out a proper area (Figure 1(b)). The bottom cutting line was set above the knee to have a more smooth bottom edge of the model yet still leave enough thigh area to put on the garment. Next, using software package Rhinoceros (Figure 1(c)), the right thigh part was converted from a mesh surface into an open polysurface so as to be able to import this into Abaqus as an ACIS geometry (Figure 1(d)) for follow-up analysis. Note that such geometries can however only be considered as a rigid body by Abaqus. In this stage of the research, we do not consider this a large drawback, due to the large difference in hardness between the muscle and the fabric, and also because this workflow starts from scans which already can represent a body part in a dynamic posture typical for the sport.



(a) (b) (c) (d)

Figure 2. Model modification process (in FreeCAD, Rhinoceros, and Abaqus)

The next part to consider in the simulation is the compression garment. This garment is constructed according to the actual size and shape of the garment. The 3D model of the thigh compression garment part was constructed using the *Sweep* option in ABAQUS/CAE (Figure 3(a)), which results in a cylindrical thigh legging part. This part was considered as deformable solid with given thickness. Note that a trumpet-shaped part is present at the top (Figure 3(b)). This was added to allow to simulate a pulling behaviour on the edge as people do when putting on trousers. This part also contributes to smoothen the first contact between the thigh body part and the compression garment.



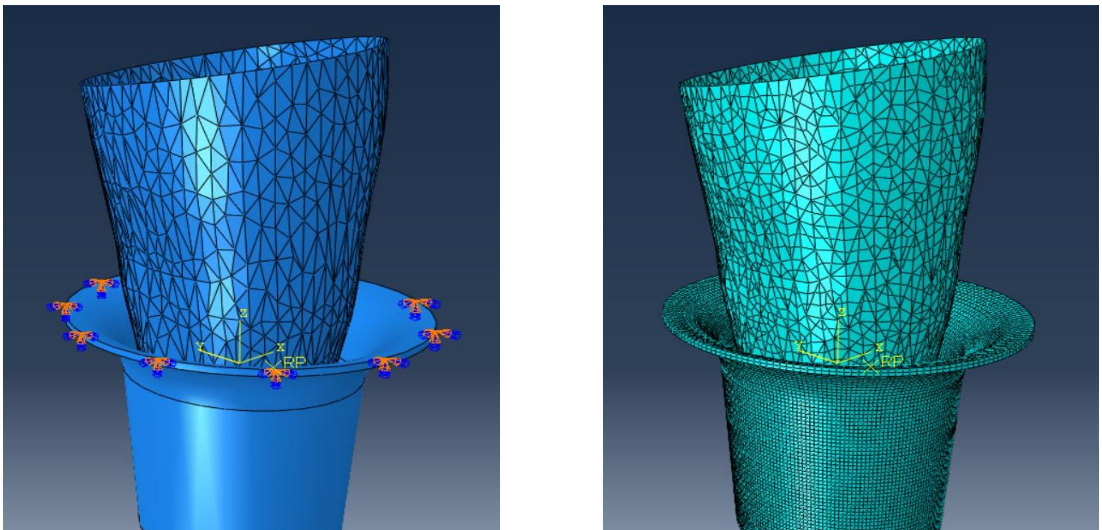
(a) (b)

Figure 3. 3D Model of the compression garment (thigh part) in Abaqus/CAE

2.3 The Finite Element Analysis (FEA)

In Abaqus/Explicit solver, the surface-to-surface contact was applied to simulate the interface interactions between the thigh and garment. Friction was also considered as contact interaction property by setting the friction coefficient in tangential behaviour to 0.05. Two surfaces underwent mechanical finite-sliding and were allowed to arbitrarily move relative to each other forming the contact pair. The penalty contact algorithm was employed to enforce contact constraints between the slave surface nodes (inner surface of the garment) and the master surface (thigh surface) [8].

The modelling process was realized by defining boundary conditions where the top edge was completely fixed as it is assumed to be initially held in human hands (Figure 4(a)). Then in the next step, with restriction of moving only in the Z direction, the thigh went straight down for a pre-set displacement (160 mm), and this within a limited time (20 second). The exact thigh part was able to deform freely by stretching and the alterations due to the rigid thigh volume. Both parts were meshed as C3D8R elements and it was crucial to plant at least 4 seeds in the direction of the garment thickness as 4 layers is a requirement from applying the C3D8R elements. This results in a fine mesh for the garment part (see Figure 4(b)) but is a condition to be able to obtain more accurate calculations. Computational time of the simulation will be impacted by this selection.



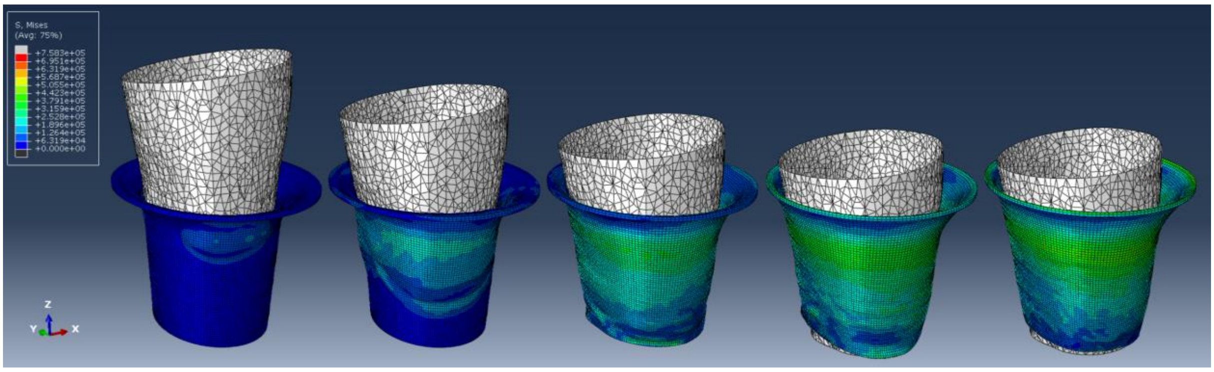
(a) (b)

Figure 4. 3D Model of the compression garment (thigh part) in Abaqus/CAE

3. EXPERIMENTAL RESULTS

With the parts, physics, and boundary conditions defined, a simulation is run. The step procedure was set to be *Dynamic, Explicit* and in total 1560 increments were successfully calculated. Figure 4(a)-(e) illustrates the simulated magnitude and distribution of pressure in the compression garment during the wearing process at 8s, 11s, 14s, 17s, and 20s respectively.

It can be seen that, as the thigh models moved downward, or relatively, the garment upward, compression occurred dynamically in the garment after contact with the thigh model. Though the thigh was seen as a rigid body where no deformation existed, stress distribution showed continuous variations during the process. During the first seconds the garment was stretched accordingly to cover the thigh. Because the thigh is not a regular cylinder, stress concentration would lead to partial stress redistribution, which was however also influenced by the friction between the parts which works against redistribution of the garment over the thigh.



(a) (b) (c) (d) (e)

Figure 4. Garment pressure at (a) 8s, (b) 11s, (c) 14s, (d) 17s, and (e) 20s

The greatest stress was found at the bottom edge around 16 second into the simulation (Figure 5(d)). Again this showed that when the garment fabric did not achieve uniform contact everywhere, this produces uneven pressure over different parts of the thigh. After a few seconds however, the stress was distributed again more evenly in a balanced way. The results can next be used to compare with PicoPress measurements done for different postures and materials.

4. DISCUSSION

In this study, through 3D body scanning, material physical testing and numerical simulation, a numerical model has been developed for modelling the compression garment deformations, the surface pressure magnitude and distribution in longitudinal directions, and dynamic mechanical interactions between fabric and skin during wear. The simulated result has shown a good agreement with expected pressure ranges, and will be used to compare with in-vivo pressure measurements. Through this way we find the optimal approach to improve the prediction of functional pressure performances for compression garment designs.

Future research should include more realistic human body models as human bodies include bones and soft tissues. The mechanism is more complex when the deformation of the muscle is also considered. Additionally, different types of fabric models are to be studied other than the basic 3D deformable object used in the current model.

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