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Combined experimental and numerical approach for the assessment of pressure generated by elastic compression bandage

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1. Introduction

Elastic compression bandage is a common treatment for venous or lymphatic disorders. Even though the efficacy of this treatment is admitted, its mechanism remains poorly understood. The success of the treatment depends on the applied pressure, which depends on the bandage tension and the curvature of the limb (Laplace's Law), the number of layers of the bandage, its components (padding layer, crepe ...) and elastic properties, and the interactions between bandages and leg. To better understand the action of compression bandage, many interface pressure measurements have been done, but those measurements only give local information and for now, the whole pressure distribution on the leg is not known. Also, due to complex leg curvature and to bandage-leg and bandage-bandage interactions, the Laplace's law is not sufficient to give a fine description of the pressure fields. Some simulations of the leg compression exist. Most of them are modeling the action of a compression sock on a leg [1][2], whose mechanical properties are more or less complex [3]. As far as we know, the simulation of bandage application on the leg has never been done yet.

The aim of this communication is to present a first numerical model of the action mechanisms of bandages onto the skin developed through an experimental-numerical approach. A subject-specific FE model of bandage application is developed and compared with experimental measurements on two subjects.

2. Methods

Pressure measurements

The elastic bandages used in this work were the Biflex® 16 (B16) and Biflex® 17 (B17), manufactured by THUASNE. The Biflex® 17 is stiffer ('stronger') than Biflex® 16. The interface pressure is measured for 3 subjects in order to be compared with the model data. The sensors (PicoPress®) were located at two reference heights at which 3 sensors were located around the leg (medial, lateral and posterior locations). Both bandages, B16 and B17, were applied on the leg in the supine position, in a spiral technique with 2 and 3 layers. The interface pressure was measured in the supine position and the foot was slightly raised in order to prevent any contact between the examination

bed and the calf. Another measurement was carried out in standing position, after 30s at rest in this position.

Leg geometry and mechanical properties

In order to have a subject-specific model, the leg was scanned with a structured light 3D scanner (Artec 3D® scanner), to obtain the external geometry. In the area of interest, from the ankle to the tibial plateau, horizontal sections were defined every 5 to 10 mm. The leg geometry was obtained by a sweeping operation along these sections. The bone geometries were extracted from anatomical slices of the 'Visible Human Server' (EPFL) and were scaled to fit the leg geometry. The complete geometry was meshed in Abaqus® with 4-node linear tetrahedron elements. The leg tissue was considered as a single homogeneous material consisting in equal proportion of adipose tissue and muscle tissue, modelled with a neo-Hookean material whose parameters were taken from the literature [3].

Bandage geometry and mechanical properties

The only known parameter of the bandage model was its longitudinal stretch which is equal to 1.3 once the bandage has been applied on the leg (calibration marker printed on the bandage). For this reason, the bandage geometry was modelled from the external leg geometry, whose horizontal sections were approximated by Fourier polynomials. From these sections, it was possible, with a custom meshing programme in Matlab®, to build any bandage model knowing its width (in this case 100 mm) and the number of layers (2 or 3). The bandage was meshed with 4-node shell elements with reduced integration. Bandage material was considered as orthotropic linear elastic. For both bandage types, the mechanical properties have been measured experimentally (planar tension, uniaxial tension, shear, bending tests). $\nu_{12} = 0.053$

Biflex® 16	$E_1 = 0.192 \text{ N.mm}^{-1}$	$\nu_{12} = 0.053$
	$E_2 = 0.297 \text{ N.mm}^{-1}$	$G = 0.09 \text{ N.mm}^{-1}$
Tension for a stretch equal to 1.3 : 57.6 cN/cm		
Biflex® 17	$E_1 = 0.379 \text{ N.mm}^{-1}$	$\nu_{12} = 0.066$
	$E_2 = 0.604 \text{ N.mm}^{-1}$	$G = 0.24 \text{ N.mm}^{-1}$
Tension for a stretch equal to 1.3 : 113.6 cN/cm		

Table 1: Bandage mechanical properties

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Simulation strategy

The simulation was done in 2 steps:

- bandage dilation (displacement along the radial direction)
- bandage relaxation and activated contact

The contact between the bandage and the leg allows no penetration and had a friction coefficient equal to 0.3. There was no contact between the different bandage layers.

3. Results and Discussion

Experimental results

The main results and trends observed experimentally are as follows:

- the pressure was higher with 3 layers than with 2 layers (for the large circumference : pressure with 2 layers 35.9 ± 7.6 mmHg and with 3 layers 64.9 ± 9.6 mmHg)
- the pressure in the supine position was the same as the one in the standing position
- the pressure exerted by the bandage B17 was about 1.55 times higher than the one exerted by bandage B16 (for the large circumference : pressure with B16 43.5 ± 14.6 mmHg and with B17 57.33 ± 17.0 mmHg)

Note that, according to the elastic properties of the different bandages, the pressure exerted by the B17 was expected to be twice as high as the one exerted by the B16.

Numerical results

Two cases are presented here: a small and a large leg circumference. For the sake of verification, the bandage stretch was checked at the end of the simulation. It was about 1.29. The small difference with the expected stretch is mainly due to the decrease of the leg circumference (its cross section becomes rounder) resulting from the compression of the leg. The pressure was extracted at the same measurement points as for the experimental measurements. The pressure with the bandage B17 was twice as high as with the bandage B16, which could have been expected because of the two bandage mechanical properties, and the pressure with 3 layers was about 73% higher than with 2 layers.

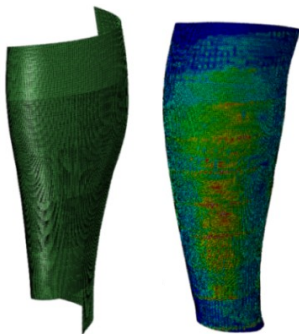


Figure 1: bandage and pressure map

The range of pressure obtained with the model was in agreement with the pressure distribution levels predicted with the Laplace's law for both legs.

Discussion

The pressure values from the simulation were compared with the experimental data. Simulation values were lower than experimental data by 27% for the B17 to 54% for the B16.

The study of the experimental and numerical results has led to the following remarks:

- the difference between the numerical and the experimental results is higher for the B16 than the B17
- experimentally, the ratio between the pressure exerted by a B17 and the one exerted by a B16 is much lower than expected (1.55 instead of 2)
- the model was used to assess the influence of bandage strain variation and it was shown that 1 to 2% pressure increase is induced per % strain increase whereas a 10% strain increase leads to a barely distinguishable shape change of the calibration marker.
- an uncertainty exists regarding the bandage mechanical properties (complex mechanical behavior and important hysteresis).

Hence, it is necessary to improve a few points:

- a better control of the bandage stretch for the bandage application is required
- the interaction between the different layers of the bandage have to be taken into account for the simulation.

4. Conclusions

This study consists in an experimental and numerical approach of a non-trivial problem, such as the assessment of pressure distribution exerted by elastic compression bandage and questions the supposed action mechanism of bandage.

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