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Numerical simulation of pressure therapy glove by using Finite Element Method

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ABSTRACT

Pressure therapy garments apply pressure to suppress the growth and flatten hypertrophic scars caused by serious burns. The amount of pressure given by the pressure garments is critical to the treatment adherence and outcomes. In the present study, a biomechanical model for simulating the pressure magnitudes and distribution over hand dorsum given by a pressure glove was developed by using finite element method. In this model, the shape geometry of the hand, the mechanical properties of the glove and human body tissues were incorporated in the numerical stress analyses. The geometry of the hand was obtained by a 3D laser scanner. The material properties of two warp knitted fabrics were considered in the glove fabric model that developed from the glove production pattern with 10% size reduction in circumferential dimensions. The glove was regarded an isotropic elastic shell and the hand was assumed to be a homogeneous, isotropic and linearly elastic body. A glove wearing process was carried in the finite element analysis and the surface-to-surface contact pressure between hand and glove fabric was hence obtained. Through validation, the simulated contact pressure showed a good agreement with the experimental interface pressure measurement. The simulation model can be used to predict and visualise the pressure distribution exerted by a pressure therapy glove onto hand dorsum. It can provide information for optimising the material mechanical properties in pressure garment design and development, give a clue to understand the mechanisms of pressure action on hypertrophic scars and ultimately improve the medical functions of pressure garment.

1. Introduction

Pressure therapy garment is the mainstay of treatment for hypertrophic scars caused by burn injury. Sufficient garment pressure is crucial to suppress the formation of extracellular matrix and thus the growth of hypertrophic scars. In order to achieve certain amount of pressure delivery, the pressure garment production pattern is developed with a 10–20% reduction factor (RF) which indicates the amount of reduction in circumferential dimensions of the actual body parts. The extent of dimension reduction not only directly affects the treatment outcomes but also affect comfort perception and hence treatment adherence. The geometry of scars, the curvatures of anatomy locations, the choice of fabric used and their tensile properties are also regarded as the main variables that influence the garment-skin interface pressure [1,2]. Many different types of pressure sensor, including

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pneumatic pressure sensor [3–6], hydrostatic pressure sensor [7,8] and electrical pressure transducers [9–11] are available to determine the amount of pressure given by a pressure garment to human body. However, due to the lack of measuring devices, time and/or other difficulties in clinical practice, there is an absence of actual measurements for garment-skin interface pressure to objectively monitor the efficiency of the pressure garment from time to time [12,13].

Some of the previous work has simulated pressures exerted onto the limbs of the body by constructing pressure sleeves in a tubular form [14–16]. Based on Laplace's equation and the tensile properties of elastic fabric, Hui and Ng [17] created a pressure model with elastic fabric for the development of pressure garments for the limbs and/or trunks of the body. Macintyre and Ferguson [18] also developed a pressure garment design tool to calculate the amount of pressure induced onto the limbs with Laplace's equation. However, the pressure prediction based on the Laplace's equation is limited to the cylindrical shape body parts for instance limbs. The non-circular shape and special contours of the hand increase the difficulty to measure or predict the pressure given by a pressure therapy glove which hence increases the difficulty in controlling and obtaining the optimum pressure over hypertrophic scars on the hand.

Recently, with advances in three dimensional (3D) modelling technologies, 3D biomechanical models can be developed to numerically simulate garment-skin interface pressure by means of computation modelling. The finite element method (FEM) is one of the most common computer simulation methods adopted in garment pressure prediction studies. FEM has been introduced early to handle mechanical problems. With the advancement of computer technology, many researchers then adopted FEM to handle more complicated biomechanical problems. This method solves problems by using differential equations. The simulation model is created based on certain assumptions and boundary conditions which determine the degree of complexity and accuracy of the model. The geometric and mechanical properties of the garment and human tissue are the fundamental components to building the simulation model. With the use of FEM, the garment and human body structures are approximated into a mesh of smaller finite number of 'elements' where the interacting points of each element are called 'nodes'. FEM connects many simple equations over the finite elements to approximate a more complex equation over a larger domain. In addition to consideration of the contact and interaction between the garment and the skin, the interface pressure can be estimated through FEM. A completed simulation also provides various calculated variables such as stress, displacement, contact pressure, etc. which help to understand the impact of the garment on the human body. Finally, the simulation model has to be validated by comparing the predicted values with the experimental values to ensure accuracy. With the use of FEM, the impact of the different mechanical properties of garments on the interface pressure can be observed simply by changing the input parameters of the simulation model instead of setting up complicated experiments.

Several studies have developed numerical models for simulating the pressure between the garment and body parts by using FEM. Many of the studies focused on predicting garment pressure on the legs. Lin et al. [19] investigated the effect of the compression properties of sportswear fabrics on the contact pressure distribution on a leg with FEM. Dan et al. [20] simulated displacement and pressure distribution on the human leg caused by men's socks by using FEM to look for a functional relationship between pressure and displacement. Liu et al. [21] used a computation model based on FEM to simulate the dynamic pressure functional performance exerted by graduated compression stockings from ankle to thigh. There are also studies simulated the garment pressure on top part of body. Liu et al. [22] studied the garment pressure induced by sports vests on the female body bust. Zhang et al. [23] developed a model to predict the dynamic mechanical behaviour of perfectly fitting garments on a rigid trunk body during wear. Ishimaru et al. [24] predicted the garment pressure given by a half-length sleeve underwear made of knitted fabric on a female body. With the simulation model development via FEM, an understanding on the interface pressure distribution over certain body part can be provided.

The purpose of this study is therefore to develop a 3D biomechanical model to numerically simulate the glove-skin interface pressure by using FEM. The surface of the hand image was obtained by using a 3D laser scanning method and the 3D model of hand was then built for the finite element analysis. On the basis of the simulation model, the pressure distribution given by the pressure therapy glove in relation to the hand geometry, prescribed RF in pattern development process, fabric choice, scar conditions and skin pliability can be accurately predicted and controlled during the course of treatment. The simulation model therefore allows instant evaluation of glove-skin interface pressure in response to different material choice and RFs. This will enable practitioners to choose the most desirable materials to be used for making pressure therapy gloves for optimal fit and comfort. The outcome of the pressure distribution can also give useful reference for the adjustment, and thus enhancing the quality and effectiveness of the treatment.

2. Method – finite element model building

A commercial FEM software, ABAQUS/CAE 6.10-1 (Dassault Systémes SA, France), was used to carry out the simulation. The interface pressure simulation model mainly consists of two materials: a hand and glove fabric. First, geometrical models of the hand and glove fabric were created. Secondly, the appropriate element type and material properties were defined. After meshing, the numerical processing of the wearing of the glove fabric on a hand was carried out by defining the initial and boundary conditions and displacement loading of the glove fabric to obtain the numerical solution. The corresponding pressure magnitudes and distribution over the hand dorsum can thus be simulated. Then, the results were post-processed and validated.

2.1. *Geometric model of hand and glove fabric*

2.1.1. *Construction of hand contour model*

In order to study the pressure distribution on the hand dorsum, it is essential to develop a 3D hand geometric model.