Ankle foot orthosis with exchangeable elastic elements

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Abstract

Abnormal motion of the ankle-foot complex presents a major problem in the rehabilitation of stroke patients. These patients often develop drop foot, a problem involving excessive and uncontrolled plantar flexion. An ankle-foot orthosis (AFO) is prescribed to constrain and inhibit this abnormal motion. The purpose of this investigation is to simulate the drop foot problem determining the stress distribution in the orthosis. Computer modelling is a method for optimal design of medical devices (prosthesis and orthoses). The study is oriented to develop ankle foot orthosis with exchangeable elastic elements, in order to assist the very frequently observed gait abnormalities of the human ankle-foot complex. CAD modelling is used for that purpose. Methods of reconstructing 3D models of the ankle-foot based on Reverse Engineering are fully investigated, and new personalized AFOs are proposed on their basis. The main goal is to assist the ankle-foot flexors and extensors during the gait cycle (stance and swing) using elastic elements.

Keywords: 3D computer modelling, ankle foot orthosis (AFO), biomechanics

1. Introduction

Drop Foot (DF) is a term that describes an abnormal neuromuscular disorder affecting patients’ ability to raise their foot at the ankle. Ankle-Foot Orthoses (AFOs) are devices intended to assist or restore the motions of the ankle-foot complex. In this paper, personalised AFO development based on 3D models of the patient’s ankle-foot complex is introduced. Methods of reconstructing 3D models of the ankle-foot based on Reverse Engineering (RE) are investigated and used for the new personalized AFO design. This new generation AFOs are designed to effectively assist the ankle flexion-extension for DF patients.

Different orthoses are used to enhance the ankle-foot initial position and mobility during gait. The most common types are “hingeless orthoses” and “hinge orthoses”. Using torsion springs, the “hinge orthoses” can assist ankle flexion/extension during gait, and i.e. they are “pseudo-active” orthotic devices. The standard commercialized AFO is a rigid polypropylene structure which prevents any ankle motion. There are several possible treatments for foot-drop –medicinal, orthotic or surgical. Note that orthotic treatment is the most common one. Its key goal is to assist the patient achieving normal gait patterns.

It is to note that the leading O&Ps companies Otto Bock Health Care, Becker Orthopaedic, Maramed Orthopaedics Systems etc. do not propose multifunctional personalized ankle-foot dynamic orthoses on the market.
The European population is moving and getting older with more persons (absolutely and relatively) having some kind of disability due to chronic illness or age.

More or less all countries in Europe implement new legislation considering the rights of persons with disabilities and based on equality, non-exclusion and non-discrimination. The proposed study is in relation with the modern European goals - independence and participation in society.

The study proposes new AFO based on 3D design being oriented to one of the most effective micro-layered technologies - Reverse Engineering.

2. Methods

In our case, RE was used to collect geometrical patient data in order to develop 3D CAD model of the ankle-foot complex.

There are four main steps to design personalized AFO: (a) Data acquisition; (b) Data registration and processing; (c) 3D CAD model of the patient ankle-foot (NURBS model); (d) AFO design on the basis of the model. In this study, laser scanning was used for data acquisition. CopyCAD, PowerShape (Delcam Inc.), Pro Engineer (PTC) were used for points and triangle mesh data manipulations as well as for geometrical modelling processes. We used two methods for capturing the external surface of the ankle-foot complex: direct and indirect scanning. In the direct scanning, RE data acquisition was done by direct scanning of the ankle-foot complex. In the indirect scanning, first of all, a wax print model of the ankle-foot complex was obtained; laser scanning was performed after that.

The output of laser scanning is “cloud of points”. After optimization, pre-processing and reconstruction, the final 3D CAD model of the ankle-foot is ready to be used for design of the personalized AFO.

The main idea was to design two personalized AFO parts - lower (foot) and upper (calf), using two different RE procedures: (d) ankle-foot direct laser scanning; (b) laser scanning of ankle-foot wax print model.

Fig.1. Direct laser scanning of the ankle-foot complex
Mituyoto CMM machine and Hymarc Laser Scanning system were used for scanning data acquisition (Fig. 1). Different scanning angles were used to cover all the scanning points representing the ankle-foot complex. The point cloud data were obtained. Preprocessing was used in order to remove the redundant point data and noises and to reconstruct the point cloud data into “optimal” data for CAD modeling. CopyCAD™ software was used to pre-process the scanning data and to fit contours and surfaces. Based on the contours presenting ankle-foot geometry, surface and solid models were constructed in CAD/CAM modeling packages ProEngineer™ and UniGraphics™. Error analysis was used to estimate the differences between the CAD models and the original point cloud data. ProEngineer™ was used for CAD of the new orthotic devices.

The final AFO model is in STL format – ready for Rapid Prototyping (RP). RP is a Selective Laser Sintering (SLS) technology used in our study to fabricate the AFO prototypes.
3. Results

Based on the 3D NURBS model of the patient ankle-foot complex, different models of personalized AFOs were developed. Fig. 3 shows one version of the new personalized AFO, ready to be produce with SLS technology (Rapid Prototyping). The new AFO was designed with two main components: lower part (foot) and upper part (calf) are shown in Fig.4 and Fig.5. Different types of elastic elements, connecting the two main components, were developed. A new AFO has two wave-shaped elastic elements (lateral and medial) and one flat-shaped spring support element (posterior) and lock-connecting mechanisms (elastic wave-shaped elements to lower and upper parts and one posterior elastic element).

Fig.3. A version of the Personalized Ankle-Foot Orthosis with exchangeable elastic elements with different mechanical parameters.

The new AFO was designed with two main components: lower part (foot) and upper part (calf) – Fig. 4 and Fig. 5.

Fig.4. Lower part ankle-foot orthosis
Different types of elastic elements, connecting the two main components, were developed. A new AFO has two wave-shaped elastic elements (lateral and medial) and one flat-shaped spring support element (posterior). Lock-connecting mechanisms (elastic wave-shaped elements to lower and upper parts and one posterior elastic element) are shown in Fig.6. and Fig.7.

The personalised AFO is with lower and upper components, which are connected by two elastic wave-shaped elements (lateral and medial).
4. Discussion

Method of constructing 3D model of patient’s ankle-foot complex for personalized AFO development is presented. Reverse Engineering approach using direct and indirect scanning were used. After optimization, pre-processing and reconstruction, the final 3D CAD model of the ankle-foot was obtained - ready to be used for design of the personalized AFO and finally to be produced by Rapid Prototyping. The exchangeable elastic elements with different mechanical parameters allow: (a) precise fitting “patient – orthosis”; (b) effective rehabilitation due to the possibility to use elastic elements with different mechanical parameters.

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References