Modelling and research of durability of the Ankle-Foot Orthosis

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Introduction

Pathological motion of the ankle-foot complex presents a major problem in the rehabilitation of stroke and head injury patients. For example, stroke patients often develop "drop foot", a problem involving excessive and uncontrolled plantar flexion. Ankle-foot orthoses (AFOs) are prescribed and used to restore normal motion or to constrain and inhibit abnormal motion. Research projects need to be conducted that include new methods of studies and experimental testing in which a better design could be achieved and appropriate prescription could be applied [1]. Historically, orthotic devices have been used for the treatment of musculoskeletal injuries or dysfunctions and have provided support, protection, immobilization, and correction [1]. The most popular materials for orthoses are polypropylene (PP) and polyethylene (PE) due to their high fatigue resistance, high strength, light weight, and excellent molding characteristics. PP is heat sensitive and can be molded into every thin-walled orthosis when it is warm; more grinding, fixing, and modifications are needed after the device becomes cold [1, 2]. Taking into account that the process of treatment of arthronosos is usually long-lasting and often the patient is forced to use an orthosis for all his/her life, durability of the orthosis is of a particular importance. The issue of foot orthoses' durability has not been thoroughly discussed upon in scientific and technical literature as well as medical publications, and an orthosis for a patient was usually chosen upon taking into account the mechanical properties of its material [2, 3] and ignoring the difference between durability of the orthosis and durability of its material.

The aim of the work is research of durability of Ankle-Foot Orthosis AFO upon taking into account the properties of its material and development of methods for detailed assessing a fitness of an orthosis upon taking into account its durability and other properties in any specific case.

Methods

The simplified structure of the system under discussion, its kinematics and distribution of static forces are presented in Fig. 1. The Fig. 1 shows static loads that affect a standing human (in the sagittal plane). Here q_1 – the distributed load, caused by the contact of the shin with the orthosis. The load q_2 appears because of pressure of the foot onto the surface of the orthosis. It should be noted that while the human is standing of the both feet, the load is equal to a half of his/her weight. In respect of durability, the most dangerous load is the bending moment M that appears when the body gravity line is some centimeters in front of the transverse axis of the ankle joint.

On the base of anthropometric norms and the principles of somatography, a three-dimensional model of Ankle-Foot Orthosis was developed in digital *SolidWorks* environment.

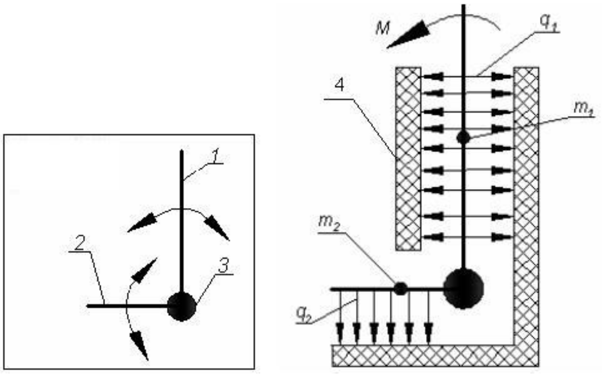

Fig. 1. The model of the ankle joint: 1 – the shin; 2 – the foot; 3 – the joint; 4 – the orthosis

The orthosis is loaded with forces equal to 70, 850 and 1000 N; the chosen thickness of the orthosis is 3, 4 and 5 mm, respectively; the materials of the orthosis are polyethylene (PE) and polypropylene (PP). The mechanical and material properties for the soft tissue, the PP and PE AFO were all assumed to be linear, elastic, and isotropic.

Results

In solution of contact-related tasks, the maximum stresses and shifts of AFO model take place upon the effect of the horizontal component of body gravity force. It was found that abrupt transitions are absent in points of maximum concentration of stresses, so supplemental stress concentrators that may turn into foci of micro cracks do not appear. However, because of the contact between AFO and the foot, a complicated deformation of the orthosis as well as additional compression and stretching of the material take place in adjacent zones and may cause a negative impact upon the durability of the orthosis. In addition, it should be noted that distribution of stresses is asymmetric because of a complicated shape of the orthosis. The typical breaking points of the orthosis models and the numbers of cycles corresponding to them were established. The models produced from high density polyethylene were rather endurant ($3 \cdot 10^7$ cycles of load) compared to those made of polypropylene ($1{,}6 \cdot 10^7$ cycles of load). Thus, the use of polyethylene splints should be extended at bigger loads.

Conclusions

The developed 3D computer model of Ankle-Foot Arthosis enables to forecast the operational life of the Ankle-Foot Orthosis and to choose an orthosis properly upon taking into account the patient's weight, height and degree of mobility as well as the durability of the material of the orthosis. In respect of durability, polyethylene is considerably superior to polypropylene. So, polyethylene is a desirable structural material for foot orthoses. Polypropylene may be used in certain cases for orthoses where the thickness of the material is no less than 5 mm that are usable for patients with a lower degree of mobility.

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