ANALYSE OF SOCKET-PROSTHESIS-BLUNT COMPLEX FOR LOWER LIMB AMPUTEE USING OBJECTIVE MEASURE OF PATIENT’S GAIT CYCLE

Mariana Rotariu¹, R. Filep², M. Turnea¹, M. Ilea¹, D. Arotăriței¹, Marilena Popescu³

University of Medicine and Pharmacy “Grigore T. Popa” - Iasi
Faculty of Medical Bioengineering
1. Department of Biomedical Sciences
2. OrtoProfil, Tg. Mureș, Romania
3. Secondary School of Balțăti, Iași

ANALYSE OF SOCKET-PROSTHESIS-BLUNT COMPLEX FOR LOWER LIMB AMPUTEE USING OBJECTIVE MEASURE OF PATIENT’S GAIT CYCLE (Abstract): The prosthetic application is a highly complex process. Modeling and simulation of biomechanics processes in orthopedics is a certainly field of interest in current medical research. Optimization of socket in order to improve the quality of patient’s life is a major objective in prosthetic rehabilitation. A variety of numerical methods for prosthetic application have been developed and studied. Material and methods: An objective method is proposed to evaluate the performance of a prosthetic patient according to surface pressure map over the residual limb. The friction coefficient due to various liners used in transtibial and transfemoral prosthesis is taken into account also. Results: Creation of a bio-based modeling and mathematical simulation allows the design, construction and optimization of contact between the prosthesis cup and lack of functionality of the patient amputated considering the data collected and processed in real time and non-invasively. The von Mises stress distribution in muscle flap tissue at the bone ends shows a larger region subjected to elevated von Mises stresses in the muscle tissue underlying longer truncated bones. Conclusions: Finite element method was used to conduct a stress analysis and show the force distribution along the device. The results contribute to a better understanding the design of an optimized prosthesis that increase the patient’s performance along with a god choice of liner, made by an appropriate material that fit better to a particular blunt. The study of prosthetic application is an exciting and important topic in research and will profit considerably from theoretical input. Interpret these results to be a permanent collaboration between math’s and medical orthopedics. Keywords: PROSTHETIC, SOCKET, BLUNT, SOLID WORKS, NUMERICAL MODELING.

Lower limbs prosthetic have many particular features that are taken into account in design and adjustment of prosthesis to make less discomfort as possible for patient. There are many papers related usage of finite-element method applied to transfemoral amputation but there are relatively less papers related to trans-tibial amputation.

The liner used as interface between skin and socket alleviates the satisfaction and patient’s comfort improving considerably the quality of life. The material of liner and consequently the coefficient of friction
between skin and liner has a major influence in performance of prosthetic amputee. The dynamic level of pressure between stump and prosthetic socket has a very high influence on patient’s comfort (1). Two new materials (Dermo and the Seal-In X5 liner) are tested in (1). The points of measurement for interface pressure were chosen according to information from literature were the most probable location of the pressure peaks: anterior, posterior, medial and lateral regions. The patient’s satisfaction was measured qualitatively using a questioner (Prosthetic Evaluation Questionnaire) and the conclusion was that Dermo liner provide more comfort that the other liner, Seal in (1).

An investigation related to interface stress between stump and trans-tibial prosthetic socket using 3D nonlinear finite element based on geometry of limb was done in (2). Automated surface-to-surface contact available in ABAQUS was used to model boundaries conditions (friction/slip)(2). The effect of load during gait cycle internal tissue of residual limb was studied in (3,4). The authors proved that the internal stress in are dependent on walking terrain, the more uneven or difficult is the terrain (e.g. stairs), the higher are the peaks of internal mechanical stress in the muscle flaps (4). Turning plays an important role in all the daily activities of patients with amputation of lower limb. In (5), compensatory strategy mechanisms developed by transtibial amputee were studied in comparison with non-amputee. The authors studied the evolution of main forces involved in turning: radial ground reaction and anterior–posterior forces (5). Modelling by finite element method (FEM) is often used in analysis of prosthetics for lower limb. FEM is used in (6) in donning procedure using patient-specific geometry given by CT and laser scan data. In distal-end socket type, the friction role is analyzed in (7).

Most of the studies in prosthetic application use the elastic, homogenous and isotropic models for bones soft tissues, flap muscles, fat, liner, and socket. Based on theory of large elastic deformation (8), other approaches more realistic studies that tackle with hyperelastic tissues are published by different authors (6,7,9). The models are more realistic ones, and in condition that constants for most common materials used in prosthetic models are available in publication we will use in this paper the hyperelastic Mooney-Rivlin model (7).

**MATERIALS AND METHODS**

We propose to use a fused adapted gait deviation index (faGDI) as objective measure of performance for lower limb amputee for pairs liner-socket materials. Gait deviation index (GDI) is proposed to be used as index of gait pathology for non-amputee persons in very recent papers (10,11). About our best knowledge, only one paper that tackle with lower limb amputee using GDI is published until now. There are few proposals for gait deviation index: Gillette Gait Index (GGI), Gillette Functional Assessment Questionnaire Walking Scale (GFAQW), and topographic classifications (diagnosis of Cerebral Palsy -CP). GDI include a balanced analysis of univariate parameters, SVD (Singular Value Decompositions) and singular values for each parameter are identified (10). The moments and joint power in different location are correlates with the body mass of subject.

Instead to use the GDI for pathology identification, we propose to use infor-
Analyse of socket-prosthesis-blunt complex for lower limb amputee using objective measure of patient’s gait cycle

mation given by pressure sensors in order to evaluate the faGDI as objective measure for quality of prosthesis. The moment $M_{\text{sensor}}$ is used for rotation (turning gait).

$$G_f = \begin{bmatrix} F_{\text{sensor}1} & F_{\text{sensor}2} & F_{\text{sensor}3} \\ F_{\text{sensor}4} & F_{\text{sensor}5} & F_{\text{sensor}6} \\ M_{\text{sensor}} \end{bmatrix}$$

Data were collected from two amputee (fig. 1) with set of 32 repetition of cycle (8 cycles for normal walking, 8 cycles for up the stairs, 8 cycles for down the stairs and 8 cycles normal walking with two rotation on each cycle. The vectors collected from each subject were concatenated in a faGDI matrix:

$$G_f = \begin{bmatrix} g_1^1 & g_2^2 & \ldots & g_m^m \\ g_1^2 & g_2^2 & \ldots & g_m^m \\ \vdots & \vdots & \ddots & \vdots \\ g_1^{32} & g_2^{32} & \ldots & g_m^{32} \end{bmatrix}$$

Practically, faGDI is a scaled measure of distance between a patient’s gait ant the other from the same group.

**RESULTS AND DISCUSSION**

In the first stage we considered the materials homogenous. The material properties are taken from literature (13) and are summarized in tab. 1. The materials used in the analysis, with the characteristic parameters, are listed in a library of materials, from where are accessed.

**TABLE I**

<table>
<thead>
<tr>
<th>Material Properties for homogeneous FE model</th>
<th>Young’s Modulus</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>15 GPa</td>
<td>0.3</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>200 KPa</td>
<td>0.45</td>
</tr>
<tr>
<td>Socket</td>
<td>15 GPa</td>
<td>0.3</td>
</tr>
<tr>
<td>Liner</td>
<td>0.38 MPa</td>
<td>0.49</td>
</tr>
</tbody>
</table>

All soft tissues were assumed to be hyperelastic, homogeneous, and isotropic, and were modeled using the Generalized Mooney-Rivlin Solid strain energy function (7):

$$E = C_{10}(I_1 - 3) + C_{11}(I_1 - 3)(I_2 - 3) + D_1(J - 1)^2$$

The constants which depend on material are taken from literature (7). It is clear that on wearing trans-femoral prosthesis higher strain occurs at the brim of socket. Equivalent Von-Mises stresses acting on different parts of above knee prosthesis is as shown in fig. 2-4. The von Mises stress distribution in muscle flap tissue at the bone ends shows a larger region subjected to elevated von Mises stresses in the muscle tissue underlying longer truncated bones.
Fig. 2. SolidWorks approximation for assembly femur-stump-liner-socket.

Fig. 3. Force applied to assembly femur-stump-liner-socket during gait cycle.

Fig. 4. Von Misses force in internal tissues for assembly femur-stump-liner-socket during gait cycle. The von Mises strain was found maximum at the bottom line of the socket.
CONCLUSIONS

The use of Solid Works in this article illustrates the important role of informatics in research in biomechanical modeling. An objective method is proposed to evaluate the performance of a prosthetic patient according to surface pressure map over the residual limb is proposed in this paper. Two liners are investigated during simulations using FEM. The distal end boundary conditions are marked by using large deformations permitted by SolidWorks Premium 2012 and kinetic records. The experimental results showed an average of faGDI ≈ 121.47 for Dermo liner and faGDI ≈ 105.62 for Sean-in. Based on this results, we can conclude that the combination polyurethane socket-Dermo liner is more performant that polyurethane socket- Sean-in liner. The design solution obtained from the results can be used as a reference to choose material for fabrication of socket in developing countries like Romania, depending on the cost and availability.
REFERENCES