A FINITE ELEMENT MODEL FOR SIMULATING THE RESIDUAL LIMB SKIN TEMPERATURE DISTRIBUTION IN TRANSTIBIAL SOCKETS

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INTRODUCTION

In a recent survey, amputees ranked “avoidance of blisters or sores on the residual limb” as one of their top three prosthesis related concerns (Legro, 1999). Prostheses for amputated limbs are not well designed to accommodate the thermal loads that may cause discomfort to amputees during routine activities.

The purpose of this study was to develop a finite element (FE) model of a transtibial residual limb and prosthesis to predict the skin temperature distribution within suction and nonsuction socket systems. This model may help prosthetists and prosthesis manufacturers to better understand the thermal environment and lead to the development of improved prosthetic systems for amputees.

METHODS

Transverse CT images of a residual limb were used to obtain the FE model geometry (Camacho, 2002). The subject was scanned supine and approximately 300 transaxial slices were taken at 1 mm intervals between the tibial crest and the distal end of the residual limb. The tetrahedral mesh for the fat, skin, bone, muscle tissue and prosthesis was generated using 111,672 nodes and 33,146 elements (Cosmos 2003, SolidWorks Corp., Concord, MA).

To validate the FE model, the solution was compared to experimental results previously reported by our group. Skin temperatures were measured at the anterior, lateral, posterior and medial locations on five residual limbs within the suction socket and nonsuction socket prosthetic systems (Peery, 2004). Model predictions were obtained at locations comparable to the human subjects experimental results.

RESULTS AND DISCUSSION

In the model, muscle tissue generated a relatively large amount of thermal energy, due to its high rate of metabolism and

Table 1: Skin Temperatures (mean ± SD) for numerical and experimental data (Peery, 2004)

<table>
<thead>
<tr>
<th>Section</th>
<th>Numerical Nonsuction Socket Temperature (°C)</th>
<th>Numerical Suction Socket Temperature (°C)</th>
<th>Experimental Nonsuction Socket Temperature (°C)</th>
<th>Experimental Suction Socket Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>32.1 ± 0.6</td>
<td>30.6 ± 0.7</td>
<td>32.6 ± 0.4</td>
<td>30.8 ± 0.3</td>
</tr>
<tr>
<td>Lateral</td>
<td>33.5 ± 0.4</td>
<td>32.3 ± 0.5</td>
<td>33.5 ± 0.4</td>
<td>31.9 ± 0.3</td>
</tr>
<tr>
<td>Posterior</td>
<td>33.3 ± 0.5</td>
<td>32.1 ± 0.6</td>
<td>34.2 ± 0.5</td>
<td>31.4 ± 0.3</td>
</tr>
<tr>
<td>Medial</td>
<td>33.1 ± 0.4</td>
<td>31.8 ± 0.5</td>
<td>33.5 ± 1.0</td>
<td>30.7 ± 0.1</td>
</tr>
<tr>
<td>Overall</td>
<td>33.0 ± 0.6</td>
<td>31.7 ± 0.7</td>
<td>33.5 ± 0.4</td>
<td>31.4 ± 0.4</td>
</tr>
</tbody>
</table>
perfusion, resulting in elevated skin temperatures near muscle tissue. Lower temperatures were located anterior to the tibia and at the distal end where fat and bone provided increased thermal resistance between the muscle and the skin (Fig. 1). The suction and nonsuction models resulted in similarly shaped temperature contours. However, due to the lower conductivity of the liner used in the nonsuction socket which effectively insulated the limb, the mean skin temperature of the nonsuction socket was approximately 1.3 °C greater than that of the suction socket (Table 1).

Both numerical and experimental results demonstrated greater mean skin temperatures at lateral and posterior locations and lower mean skin temperatures at anterior and medial locations. Additionally, both numerical and experimental data generated warmer skin temperatures with the nonsuction socket.

SUMMARY

A thermal model of a transtibial residual limb was developed and used to predict the steady state skin temperature distribution inside suction and nonsuction socket systems. Model results, verified by experimental data, indicate that the type of prosthetic socket worn affects the temperature at the skin-prosthesis interface. High skin temperatures were predicted near muscle tissue and low temperatures were predicted anterior to the tibia and at the distal end of the residual limb. These results provide researchers with a better understanding of the thermal conditions at the skin-prosthesis interface that may relate to locality and severity of blister and sore occurrences.

REFERENCES


ACKNOWLEDGEMENTS

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**Figure 1:** Frontal and sagittal slices illustrating the location of the tissues and medial, lateral, anterior and posterior views illustrating skin temperature contours (nonsuction socket shown).