Socket/Liner Interface Volume and Vacuum Pressure Decay in Persons with Transfemoral Amputations

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INTRODUCTION
Vacuum-assisted suspension is becoming a popular system for use in lower-limb prostheses. However, we know very little about socket/liner interface volume in persons with transfemoral amputations (TFA) or the rate at which vacuum pressure decays during regular activity. What research has been performed in this area pertains to persons with transtibial amputations.¹ Understanding these two characteristics of vacuum-assisted suspension could lead to improvements in vacuum pump designs and assist in provision of improved lower-limb prostheses with vacuum-assisted suspension. In this study, an empirical approach was used to obtain evacuation curves on human subjects by measuring change in vacuum pump pressure, and therefore to gain insight into socket/liner interface volume and pressure decay.

METHOD
Subjects: Persons with unilateral TFA who regularly used vacuum-assisted suspension with sub-ischial sockets and silicone liners were recruited to participate in this study. The Northwestern University Institutional Review Board approved this study and informed consent was obtained from subjects prior to participation.

Apparatus: The pumps used in this study were the Otto Bock Harmony® e-pulse and the Ohio WillowWood LimbLogic® VS. Data were captured using a DigiVac digital vacuum pressure gauge. Subjects walked on a Cosmed Sport Treadmill.

Procedures: Each subject was asked to don their prosthesis and stand quietly while the space between socket and liner was evacuated to a vacuum pressure of ~17 inHg (5 evacuation trials with each pump). Between evacuation trials air was allowed to return into the system by disconnecting the tubing attaching pump to socket. Vacuum pressure data and time were recorded during evacuation using National Instruments LabVIEW. Additionally, subjects were asked to walk for 10 minutes with each pump at a comfortable pace on the treadmill while the vacuum pressure in their socket was monitored.

Data Analysis: Vacuum pressure versus time were plotted using Microsoft® Excel and times to evacuation were calculated graphically. Interface volume was then calculated from the relationship between time to evacuation in the human subjects and time to evacuate sealed canisters of known volume which were assessed for the same pumps in a related study performed by the same authors.²

RESULTS
Twelve subjects were involved in the study (age = 56±14 years; height = 174±7cm; and mass = 82±25kg). Table 1 shows the calculated interface volumes for both pumps.

Only 5 of the 12 subjects participated in treadmill testing. From 4 of these subjects (one outlier) we determined that the average (± standard deviation) rate of vacuum decay was 0.0061 ± 0.0047 and 0.0045 ± 0.0021 inHg/sec for the LimbLogic® and e-pulse, respectively.

<table>
<thead>
<tr>
<th>Interface Volume (cm³)</th>
<th>e-pulse</th>
<th>LimbLogic®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>97.8</td>
<td>103.4</td>
</tr>
<tr>
<td>SD</td>
<td>47.4</td>
<td>49.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>176.0</td>
<td>189.9</td>
</tr>
<tr>
<td>Minimum</td>
<td>21.1</td>
<td>24.3</td>
</tr>
</tbody>
</table>

Table 1. Calculated average interface volumes for the e-pulse and LimbLogic® reported in cubic centimeters.

DISCUSSION & CONCLUSIONS
Estimated average volume for the transfemoral sockets tested was about 100 cm³. The “S” shaped curves observed in 5 of the 12 subjects may represent a change in the initial volume for those people who are pulled into the socket with “soft” tissue (i.e. having a small distal gap between liner and socket before vacuum is generated). Testing on a greater number of subjects is needed to better understand the rate of vacuum depletion in these systems.

REFERENCES

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