Energetic cost of gait and functional mobility: a comparison of vacuum, suction, and sleeve suspensions

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INTRODUCTION
Daily fluctuation in residual limb volume can affect prosthetic fit and comfort. Vacuum assisted suspension systems (VASS) anchor the prosthetic socket on the residual limb, minimizing fluctuations, reducing pistoning and peak socket pressures (Beil 2002), thereby improving comfort. Still, the extent to which VASS improves function and mobility is unclear. The purpose of this study is to quantify VASS-induced improvements in performance-based and self-reported outcome measures. Here we present preliminary data from an ongoing study to test the hypotheses that VASS will 1) reduce the energetic costs of gait and 2) improve outcomes measures related to function, mobility and quality of life.

METHOD
To date, 10 subjects (8 males; 7 transtibial, 1 transfemoral, 2 knee disarticulation; 5 traumatic, 5 non-vascular; 45.1±12.0 years; 179.9±7.5 cm; 88.3±10.8 kg) completed the study. Inclusion criteria include: current use of VASS for ≥6 months, ≥1 year since amputation and ability to walk without assistance for six minutes. Subjects performed three tasks using each of three, randomly assigned, suspension setups: 1) VASS, 2) suction with inactive vacuum, and 3) suspension sleeve without one-way valve. For Task 1 subjects traversed an 8m walkway while motion capture tracked 22 passive reflective markers. From these motions, as per Board (2000) we calculated a symmetry index (SI) for stance time and step length (SL) as 100*[(prosthetic-sound)/(prosthetic+sound)]. Task 2 was the 10 meter walk (10 mW) test to assess maximum speed. For Task 3, subjects walked a carpeted, indoor track for six minutes at a self-selected pace while the rate of O2 consumption (ml/min) was measured using a portable device. Energetic cost was calculated as the mean rate of consumption over the final two minutes normalized by mass (kg) and mean speed during that time (m/min). Total distance and socket comfort score (0-10) after six minutes were noted. For Tasks 2 and 3 data is presented for 9 and 8 subjects, respectively. Variables were compared across suspension using an ANOVA and LSD correction with significance at p<0.05.

RESULTS
Stance time was significantly more asymmetric for sleeve compared to VASS and suction, but similar between VASS and suction (Table 1). There was no effect of suspension on SI for SL. Times for the 10 mW test were significantly less for VASS compared to sleeve. There were no differences in energetic costs or total distance walked over six minutes, but comfort systematically decreased across all conditions.

<table>
<thead>
<tr>
<th></th>
<th>VASS</th>
<th>suction</th>
<th>sleeve</th>
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</thead>
<tbody>
<tr>
<td>10 mW (s)</td>
<td>3.6±0.7*</td>
<td>3.7±0.7</td>
<td>3.9±0.7*</td>
</tr>
<tr>
<td>6 min walk (m)</td>
<td>486±95</td>
<td>474±86</td>
<td>473±81</td>
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<tr>
<td>cost (ml/kg-m)</td>
<td>0.17±0.03</td>
<td>0.17±0.04</td>
<td>0.17±0.04</td>
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<tr>
<td>SL - SI (%)</td>
<td>1.8±7.3</td>
<td>2.5±7.9</td>
<td>1.6±7.6</td>
</tr>
<tr>
<td>SL - stance (%)</td>
<td>-3.5±5.5*</td>
<td>-3.8±6.4*</td>
<td>-21.3±9.8*</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSION
Despite greater stance time symmetry with VASS (which is consistent with Board et al. (2001)), energetic costs across conditions were similar. Thus temporal asymmetry alone may not necessarily be associated with the economy of amputee gait. While a study by Mattes et al. (2000) demonstrated an association between the two, in that study asymmetry was induced by adding mass on the prothesis, making it difficult to isolate the effects of asymmetry. Still, an association is logical, and given similar SL symmetry between conditions, similar energetic costs may not be unexpected. Although VASS has been shown to improve SL symmetry (Board 2000), this was measured over 30 minutes to allow residual limb volume loss similar to that seen over a day. If volume loss increases asymmetry (and inefficiency), then benefits of VASS may go unnoticed unless sufficient time (i.e., >6 minutes) is provided to allow significant volume loss after vacuum removal. Similarly, any benefits of improved comfort on gait should also become more apparent with walking duration and seemingly with increasing speed as well. The more “intimate” fit offered by VASS may provide increased control of the prosthetic limb, which may be necessary to achieve greater speed. Indeed, 10mW time was 10% faster with VASS. While energetic costs of amputee gait do increase with speed (Genin 2008), if VASS facilitates faster speeds this may also allow less energy to be utilized to increase speed beyond preferred. In conclusion, VASS provides improved comfort, maximum speed, and stance symmetry. Future work will consider if VASS improves energetic costs when walking longer than six minutes and/or above preferred walking speeds.

CLINICAL APPLICATIONS
VASS may prevent speed- and comfort-related limitations in activity for high functioning amputees.

REFERENCES
Beil et al. JRRD. 39, 693-700, 2002