Step-to-step transition work during level and inclined walking using passive and powered ankle-foot prostheses


**Products**

BiOM (Bionic powered ankle-foot prosthesis)

**Major Findings**

With BiOM compared to energy return and storage foot (ESR) and to able-bodied control subjects (Control):

- **Greater trailing limb step-to-step transition work on level with BiOM**
  - By 63% when compared to ESR

- **Lower metabolic rate with BiOM on level ground with BiOM**
  - By 16% when compared to ESR

- **Improved ankle angle and ankle power**
  - with BiOM compared to ESR.
  - Ankle angle improved by 14° (Level ground) and 13.1% (5° incline)
  - Ankle power improved by 110% (Level ground) and 63% (5° incline)

![Improved ankle angle with BiOM on level ground and incline](image)

**Population**

| Subjects | 6 unilateral, transtibial amputees (5 male, 1 female) |
| Previous prosthetic foot | Flex-Foot, Ossur (3); Renegade, Freedom Innovations (2); Pathfinder, Ohio Willow Wood (1) |
| Mean age | Amputees: 29 ± 6 yrs | Control: 23 ± 5 yrs |
| Mean height | Amputees: 1.81 ± 0.1 m | Control: 1.79 ± 0.1 m |
| Mean body mass | Amputees: 92.7 ± 6.3 kg | Control: 91.4 ± 12.1 kg |
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**Study Design**

Interventional, pre-to post design:

- 12 TT amputees
- Previous foot
- Data collection
- 12 TT amputees
- BiOM
- Fitting of BiOM
- Data collection
- Exclusion of 6 subjects

Subjects walked at a standardized velocity (±5%) over level ground and up the inclined walkway (5°). Three successful trials in which the prosthetic limb and then the intact limb contacted consecutive force platforms were recorded. Metabolic demand was assessed as the steady state rate of oxygen consumption (VO₂). As subjects breathed into a plastic mask that sealed around the nose and mouth, a portable metabolic unit recorded VO₂ using indirect calorimetry and 30-s averaging. Six subjects were excluded, because they had step lengths that were either too long or too short to fully contact each of the force platforms on the inclined walkway without adjustments.

### Results

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<th>Category</th>
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**Level Walking**

- **Step –to-step trailing leg transition work [J/kg]**
  - BiOM vs ESR: ++ (+63%)
  - BiOM vs Control: + (+28%)
  - ESR vs Control: − (−22%)

- **Peak plantarflexion Angle [°]**
  - BiOM vs ESR: ++ (-286%)
  - BiOM vs Control: 0
  - ESR vs Control: −− (+139%)  

- **Ankle Moment [Nm/kg]**
  - BiOM vs ESR: 0
  - BiOM vs Control: − (−11%)
  - ESR vs Control: − (−13%)  

**Ramps, Hills**

- **Step –to-step trailing leg transition work [J/kg]**
  - BiOM vs ESR: ++ (+53%)
  - BiOM vs Control: 0
  - ESR vs Control: 0

- **Peak plantarflexion Angle [°]**
  - BiOM vs ESR: ++ (-234%)
  - BiOM vs Control: + (−45%)
  - ESR vs Control: −− (+141%)  

- **Ankle Moment [Nm/kg]**
  - BiOM vs ESR: 0
  - BiOM vs Control: − (−11%)
  - ESR vs Control: − (−13%)  

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<td>Ankle Power [W/kg]</td>
<td>BiOM vs ESR</td>
<td>BiOM vs Control</td>
</tr>
<tr>
<td></td>
<td>++ (+63%)</td>
<td>+ (+19%)</td>
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<tr>
<td></td>
<td>BiOM vs Control</td>
<td>ESR vs Control</td>
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<td>++ (+63%)</td>
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<td>Metabolic Energy Consumption</td>
<td>Metabolic rate (Level walking) [Steady state VO2]</td>
<td>BiOM vs ESR</td>
</tr>
<tr>
<td></td>
<td>++ (-16%)</td>
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<td></td>
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<td>0</td>
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<tr>
<td></td>
<td>-- (-27%)</td>
<td>+ (+9%)</td>
</tr>
<tr>
<td></td>
<td>Metabolic rate (5° Incline) [Steady state VO2]</td>
<td>BiOM vs ESR</td>
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</tbody>
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* no difference (0), positive trend (+), negative trend (−), significant (++/−−), not applicable (n.a.)

**Author’s Conclusion**

“In conclusion, the powered BiOM prosthesis increased ankle power and trailing limb push-off work during step-to-step transitions on both level ground and inclines. The improvement in trailing limb push-off may partly account for the reduction in metabolic rate over level ground, but it had little effect on reducing the energy lost during step-to-step transitions. On inclines, the ESR trailing limb did not display deficiencies in push-off work relative to able-bodied individuals; the slightly lower values still resulted in leading limb compensations and net energy dissipation. Although leading and trailing limb mechanical work during step-to-step transitions do not account for total metabolic demand, they do contribute substantially to a portion of it. The powered BiOM ankle-foot prosthesis reduced metabolic rate on level ground but not on inclines, but resulting values were equivalent to able-bodied individuals. Overall, there were limited negative biomechanical or metabolic consequences to wearing a powered ankle-foot prosthesis. The results of this study may be used to guide the development and use of actively powered prosthetic devices in high-functioning individuals. Future work may examine how different inclines and velocities affect VO2 and individual limb work in individuals with amputations who are using new prosthetic technology.” (Russell Esposito et al., 2016)