Comparing Prosthetic Feet Using Stiffness Profiles
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This research was supported by the Dept. of Veterans Affairs, Rehabilitation R & D Service (A9243C, RX01840, & A9248-S)

INTRODUCTION
The stiffness of a prosthetic foot can significantly influence the gait mechanics of lower-limb amputees (e.g., Fey et al., 2012). Currently, prosthetists rely heavily on experience and patient feedback when prescribing specific stiffness levels for an individual. Previous studies quantifying prosthetic foot stiffness (e.g., Major et al., 2012) have often focused on quantifying stiffness during isolated conditions (e.g., at heel strike or toe-off) in a single plane of motion. Understanding how prosthetic foot stiffness varies over the gait cycle in both the sagittal and coronal planes would allow prosthetists to more accurately compare specific feet and improve prescription outcomes for individuals who walk on a variety of terrains. The purpose of this study was to identify the sagittal and coronal plane stiffness profiles for a number of commercially available prosthetic feet during walking conditions and assess how these profiles vary across feet.

METHOD
Twenty-eight feet with a range of stiffness categories across 9 different foot styles were evaluated using quasi-static linear compression tests over a range of forces and displacements experimentally measured during gait. The force and displacement data applied to each foot were measured with a 9281CA Kistler force plate affixed to an R-2000 Rotopod robot.

The stiffness was calculated at each orientation by applying a linear regression to the force-displacement data over a force range of ±1 standard deviation from the expected load at each sagittal (-15, -10, -7.5, -5, -2, 1, 0, 1, 2, 5, 10, 15, 20, 25, 30°) and coronal (-10, -5, 0, 5, 10°) orientation. Several stiffness ratios were then calculated to compare relative changes in the stiffness profiles across feet (Table 1).

RESULTS
The maximum stiffness of the category (cat) 6 feet ranged greatly from 208 N/mm for the Sierra foot to 474 N/mm for the Catalyst. However, the range of stiffness measured at midstance was much less, ranging from 72 N/mm to 87 N/mm (Table 1).

<table>
<thead>
<tr>
<th>Stiffness @ 30% GC (N/mm)</th>
<th>Catalyst</th>
<th>EVO</th>
<th>Sierra with Heel Wedge</th>
<th>Sierra</th>
<th>Seattle Lightfoot</th>
<th>SureFlex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness (N/mm)</td>
<td>77</td>
<td>87</td>
<td>81</td>
<td>77</td>
<td>72</td>
<td>73</td>
</tr>
<tr>
<td>Inversion (10° / 0°)</td>
<td>0.86</td>
<td>0.94</td>
<td>0.89</td>
<td>0.91</td>
<td>1.04</td>
<td>0.83</td>
</tr>
<tr>
<td>Eversion (-10° / 0°)</td>
<td>0.84</td>
<td>0.87</td>
<td>0.92</td>
<td>0.93</td>
<td>0.97</td>
<td>0.86</td>
</tr>
<tr>
<td>Heel (5% GC/30% GC)</td>
<td>1.69</td>
<td>0.85</td>
<td>1.06</td>
<td>1.06</td>
<td>1.62</td>
<td>1.40</td>
</tr>
<tr>
<td>Toe (50% GC/30% GC)</td>
<td>0.43</td>
<td>0.34</td>
<td>0.50</td>
<td>0.52</td>
<td>0.51</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Table 1. Stiffness metrics for the category 6 feet tested. The stiffness value reported is for a 0° coronal orientation at midstance (30% of the gait cycle (GC)). The inversion and eversion ratios are normalized metrics comparing the stiffness value at 0° coronal angle with ±10° coronal stiffness values, respectively. The heel and toe ratios are normalized metrics comparing the stiffness value at 30% GC with the stiffness values at 5% GC (loading) and 50% GC (late stance), respectively.

DISCUSSION
Most feet showed decreasing stiffness as the inversion or eversion angle increased. Most feet also displayed increasing stiffness through heel strike and the transition to midstance, followed by decreasing stiffness in terminal stance and toe off. Despite having similar profile shapes, the feet differed in how stiff specific orientations were relative to the overall profile. The relative stiffness ratios highlight how the coronal and sagittal stiffness characteristics can vary widely across feet.

CONCLUSION
While the general shape of the stiffness profiles were similar across feet, the magnitude of the stiffness varied despite being considered in the same category.

CLINICAL APPLICATIONS
Quantifying the stiffness profiles of prosthetic feet will allow for more informed prescription decisions.

REFERENCES

American Academy of Orthotists & Prosthetists
43rd Academy Annual Meeting &
Scientific Symposium
March 1-4, 2017

FPTh14