Differences in the Spatiotemporal Parameters of Transtibial and Transfemoral Amputee Gait

M. Jason Highsmith, DPT, CP, FAAOP, Brian W. Schulz, PhD, Stephanie Hart-Hughes, PT, MSMS, NCS, Gail A. Latifief, DO, FAAPMR, Sam L. Phillips, PhD, CP, FAAOP

ABSTRACT

Lower limb amputees have less efficient gait patterns that may in part be due to spatiotemporal asymmetries. Transfemoral (TF) amputees are believed to have greater gait asymmetries than transtibial (TT) amputees, but this has not been clearly established. The purpose of this study was to determine the effects of amputation level on step length, width, and time for prosthetic and sound legs. Other spatiotemporal gait parameters of this subject cohort were also reported. Subjects traversed a GaitRite walkway 10 times at their habitual walking speed. Step length, width, and time were selected a priori to compare by amputation level and between sound and prosthetic sides. In addition, a degree of asymmetry (DoA) was calculated and tested for each of these three parameters. This is a cross-sectional/observational study with 15 community ambulating, unilateral lower limb amputees (seven with TT and eight with TF amputation). Prosthetic and sound sides averaged together, TF amputees utilized shorter (62.2 ± 7.0 cm vs. 72.1 ± 7.1 cm, p = 0.0007) and wider (20.7 ± 4.2 cm vs. 15.4 ± 3.1 cm, p = 0.0008) steps that were of longer duration (0.65 ± 0.8 seconds vs. 0.59 ± 0.04 seconds, p = 0.009) than those of TT amputees. The DoA analysis indicated that TF amputee step times were more asymmetrical than those of TT amputees (DoA = -0.08 ± 0.05 vs. 0.01 ± 0.04, p = 0.0008). TF amputees walk with greater temporal, but not spatial, asymmetry than TT amputees. (J Prosthet Orthot. 2010;22:26–30.)

Evaluation of amputee gait quality can be done observationally or through instrumented assessment. Observational assessment is often clinically useful because of the time efficiency and relative immediacy of feedback, but it generally lacks quantifiable data and documentation is not standardized. Instrumented gait assessment includes a spectrum of techniques ranging from very time-intensive optoelectronic motion analysis to stopwatch calculations of gait velocity over a known distance. In between these two extremes is the assessment of spatiotemporal gait parameters.

Tracking spatiotemporal gait quality is a useful compromise because it is possible to determine the present status of parameters compared with a normative nonamputee data set, that of persons affected by other conditions that cause gait impairment, and/or amputee data available in the literature. Tracking spatiotemporal gait quality also permits self-comparison longitudinally as prosthetic components are worn out, exchanged, and upgraded, because an individual suffers additional comorbidities or simply ages. Some sample parameters and associated considerations include:

1. Step length—which has roles in confidence and comfort with the prosthesis as well as the presence of joint contractures.2,3
2. Gait velocity—which has implications in determining one’s ability to ambulate safely in certain environmental conditions such as crossing the street or whether or not a person is at increased risk of falling due to low gait velocity.3,4
3. Cadence—the demonstration of variable cadence is a hallmark for being classified as either an unlimited household/limited community ambulator or an unlimited community ambulator. The latter of which permits access to higher functioning (microprocessor and energy storing) prosthetic components via reimbursement in the U.S. commercial insurance sector.4

Lower limb amputees are known to have less efficient gait patterns5,6 that may in part be due to spatiotemporal asym-
metrics. Transtibial (TF) amputees are believed to have greater gait asymmetries than transtibial (TT) amputees, but these effects have not been clearly established. Therefore, this study had two purposes: 1) to report spatiotemporal results of a cohort of TT and TF amputees via the GaitRite Portable Walkway System (CIR Systems, Inc., Havertown, PA) and 2) to determine the effects of amputation level specifically on step length, width, and time for prosthetic and sound legs.

**METHODS**

The study protocol was approved by both the Veterans’ Administration Research and Development Office and the Institutional Review Board of the University of South Florida. Subject inclusion criteria included the following:

1. Unilateral TT or TF amputation.
2. Community level of ambulation without personal assistance or assistive walking devices (e.g., cane and walker).
3. Must be ambulating with a prosthesis that has been unchanged (e.g., no change to socket, alignment, and component) for a minimum of 90 days.

Seven TT and eight TF male amputees (Table 1) gave informed consent to participate in the study. Subjects traversed a GaitRite walkway 10 times at their self-selected walking speed. Although all the spatiotemporal gait parameters captured by the GaitRite walkway were collected, step length, width, and time were selected a priori to compare by amputation level and between sound and prosthetic sides. To simplify data analysis and interpretation, a degree of asymmetry (DoA) was calculated for each of the three a priori parameters using the following equation:

![Equation](image)

Using this calculation, a positive DoA would indicate greater sound side values and a negative DoA would represent greater prosthetic side values. Perfect symmetry would be a DoA value of zero, whereas a perfect asymmetry DoA is equal to ±1.0 indicating complete asymmetry. For gait, possibly the best example of complete asymmetry would be the case of complete hemiplegia where the parietic leg could not step (parietic side step length, width, and time all zero).

Intrasubject means for step length, width, and time for each subject were tested using analysis of variance with amputation level (TT or TF) and stepping leg (sound or prosthetic) as factors. Rather than test the interaction of these two factors, the effect of amputation level on DoA for each of these variables was tested using independent samples t-tests. Applying the Bonferroni correction for three a priori variables tested, p < 0.017 was considered to be

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Amputation level</th>
<th>Age (years)</th>
<th>No. of years since amputation</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Etiology</th>
<th>Amputated side</th>
<th>Suspension</th>
<th>Prosthetic knee</th>
<th>Prosthetic foot</th>
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<tr>
<td>1</td>
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<td>85.3</td>
<td>Trauma</td>
<td>Right</td>
<td>Shuttle lock</td>
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<td>Trustep</td>
</tr>
<tr>
<td>2</td>
<td>TT</td>
<td>70</td>
<td>2</td>
<td>188</td>
<td>85.0</td>
<td>Malignancy</td>
<td>Right</td>
<td>Shuttle lock</td>
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<tr>
<td>3</td>
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<td>60</td>
<td>12</td>
<td>188</td>
<td>93.0</td>
<td>PVD</td>
<td>Right</td>
<td>Shuttle lock</td>
<td>n/a</td>
<td>Perfect stride II</td>
</tr>
<tr>
<td>4</td>
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<td>9</td>
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<td>Trauma</td>
<td>Left</td>
<td>Shuttle lock</td>
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<td>Vari-flex</td>
</tr>
<tr>
<td>5</td>
<td>TT</td>
<td>32</td>
<td>15</td>
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<td>82.8</td>
<td>Trauma</td>
<td>Right</td>
<td>Shuttle lock</td>
<td>n/a</td>
<td>Renegade</td>
</tr>
<tr>
<td>6</td>
<td>TT</td>
<td>59</td>
<td>7</td>
<td>184</td>
<td>138.3</td>
<td>PVD</td>
<td>Right</td>
<td>Shuttle lock</td>
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<tr>
<td>7</td>
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<td>1</td>
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<td>10</td>
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<td>93.4</td>
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<td>Right</td>
<td>Suction</td>
<td>C-Leg</td>
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<td>Trauma</td>
<td>Right</td>
<td>Suction</td>
<td>C-Leg</td>
<td>Energy storing*</td>
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<tr>
<td>15</td>
<td>TF</td>
<td>60</td>
<td>41</td>
<td>173</td>
<td>77.1</td>
<td>Trauma</td>
<td>Left</td>
<td>Suction</td>
<td>C-Leg</td>
<td>Luxon Max</td>
</tr>
</tbody>
</table>

All subjects were male.

*Patient record indicated energy storing foot. Brand not indicated. Cosmetic cover prevented identification.

TT, transtibial; TF, transfemoral; PVD, peripheral vascular disease.
Table 2. Mean (SD) spatiotemporal gait data

<table>
<thead>
<tr>
<th>Steps</th>
<th>Transtibial</th>
<th>Transfemoral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sound side</td>
<td>Prosthetic side</td>
</tr>
<tr>
<td>Step length (cm)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>73.8 (5.7)</td>
<td>70.5 (8.5)</td>
</tr>
<tr>
<td>Step width (cm)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.6 (3.0)</td>
<td>15.3 (3.3)</td>
</tr>
<tr>
<td>Step time (seconds)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.60 (0.05)</td>
<td>0.58 (0.03)</td>
</tr>
<tr>
<td>Cadence (steps/sec)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.70 (0.82)</td>
<td></td>
</tr>
<tr>
<td>Velocity (m/sec)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.21 (0.19)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Degree of asymmetry (DoA) = (sound side value - prosthetic side value)/(sound side value + prosthetic side value).
<sup>b</sup>Significant ($p < 0.01$) effect of amputation level.
<sup>c</sup>Significant ($p = 0.0008$) degree of asymmetry effect.
<sup>d</sup>Values reported for reference and not statistically tested.

Results

Table 2 contains the group averaged (±SD) for a priori parameters and DoA values involved in hypothesis testing in addition to other selected spatiotemporal parameters of interest. Prosthetic and sound sides averaged together, TF amputees utilized shorter (62.2 ± 7.0 cm vs. 72.1 ± 7.1 cm, $p = 0.0007$) and wider (20.7 ± 4.2 cm vs. 15.4 ± 3.1 cm, $p = 0.0008$) steps that were of longer duration (0.65 ± 0.8 seconds vs. 0.59 ± 0.4 seconds, $p = 0.009$) than those of TT amputees. All subjects tended to utilize prosthetic side steps of longer duration (0.64 ± 0.08 seconds vs. 0.60 ± 0.05 seconds, $p < 0.05$), but this effect did not reach the established level of significance. The DoA analysis indicated that TF step times were more asymmetrical than TT (DoA = -0.08 ± 0.05 vs. 0.01 ± 0.04, $p = 0.0008$).

Discussion

This study reinforces data from other studies reporting similar walking velocities for TF amputees. In a sample of 29 unilateral TF amputee subjects, an average walking velocity of 1.04 m/sec was reported. Hafner et al. similarly reported walking velocities of 0.97–1.04 m/sec, depending on the type of prosthetic knee used in a sample of 17 community ambulating TF amputees. The sample in the current study walked with an average velocity of 0.96 m/sec. These values are notably higher than another recent clinical trial of the C-Leg where the mean group velocity while using the C-Leg was 0.87 m/sec. In this latter sample, Kahle et al. studied a mixed functional sample of 19 unilateral TF amputees that included a number of individuals with dysvascular etiology (7 of 19) and advanced age ([51 ± 19 years (range 22–83 years)] that appeared to considerably reduce their average group velocity. Nonetheless, a velocity range is emerging across the varied level of function that comprises the community ambulating TF amputee.

Studies reporting walking velocity in the unilateral TT amputee population indicate greater habitual speeds than those of TF amputees. A number of studies have produced a range of habitual TT walking velocities from as low as 0.75 m/sec to upper limits of 1.22 m/sec. This study is in close agreement with the upper limits of this range and particularly findings of Lenaire et al. at 1.20 m/sec and Doane and Holt at 1.22 m/sec. Although TT amputees walk at faster velocities than TF amputees, both groups walk slower than nonamputees. Young nonamputees tend to walk at a velocity of 1.45 m/sec where the elderly tend to walk at a velocity of 1.36 m/sec. Because velocity is the result of relationships between both spatiotemporal parameters and event frequencies, cadence is worth mentioning. Similar to the closer velocity between TT amputees and nonamputees as opposed to that of TF amputees is a relationship with cadence. That is, the typical cadence for nonamputee males is approximately 1.83 steps/sec. TT amputees walked with a similar cadence (1.70 steps/sec), whereas TF amputees were considerably different from both reported values for nonamputees and TT amputees with a much lower cadence (1.36 steps/sec). Cadence is of particular importance in the lower limb amputee population. This is because of its direct connection to functional classification and potential access to advanced components (e.g., microprocessor and energy storing) when an amputee can demonstrate “variable” cadence.

To recapitulate, step length, width, and duration were hypothesized to differ between TT and TF amputees and significant differences were found in these measures. A few studies have reported step length for lower limb amputees. Some have reported step length when assessing the validity and reliability of step activity monitoring equipment, some when assessing the outcomes of an experimental prosthesis, and others while simply reporting objective, observational gait quality measures similar to one purpose of this study.

Significant. All statistical analyses were performed using SAS v9.1.1 (SAS Institute Inc., Carey, NC).
Problems in comparing spatiotemporal data between studies may emerge if data was collected from use of an experimental prostheses and/or walking in a confined laboratory setting. Situations such as these are likely to cause reported data to differ from established values from more ecologically valid, representative values. In addition, some authors report stride length so side to side contributions from step length are not available. Moreover, some authors report a single average step (or stride) length value so again, the side to side difference or contribution remains unknown. Lee et al. reported step lengths of 68.8 cm (prosthetic) and 63.7 cm (sound) with a subsequent 0.04 DoA for TT amputees. These values were similar to values found in our TT group. Lemaire et al. only reported stride, as opposed to step length in their study. Using a crude estimation of half of their reported stride length (1.41 m), an approximate step length of 75 cm is again a reasonable comparative value for our TF sample’s step length (73.8 and 70.5 cm sound and prosthetic sides, respectively). Houdijk et al. reported a single step length value in a widely heterogeneous group of amputees including a bilateral case, rotationplasty case as well as TT and TF amputees. Their group reported a single average group step length, which is low compared with both of our groups’ mean values at 59 cm. Again, this is expected as the small sample, heterogeneity and outliers in their group could have easily brought the average step length down below a more representative, homogeneous sample’s value. Nonetheless, these studies indicate that the current step lengths reported here are both reasonable and representative. We observed that TF amputees utilized shorter step lengths for both prosthetic and sound legs.

Step width is not as commonly reported in the literature as other measures. Su et al. compared step width in a bilaterally involved group of TT amputees with varied etiology to a group of non-amputees. Authors reported that the average step width of non-amputees was 1.6 cm. Their bilaterally involved TT amputees of traumatic etiology had a step width of 16.8 and 20.7 cm for those of dysvascular etiology. Subjects’ step widths in the current study were within the range provided by these extremely functionally differing groups, again suggesting that these values are representative and reasonable. Interestingly, TF amputees in this study had a significantly wider step width than did the TT amputees. There are three plausible contributing explanations. The first is concerned with prosthetic fabrication and alignment. To create a narrow base of support consistent with maximal efficiency, abductor pre-stretch and an adductor moment at the hip, the prosthetic foot is inset at bench alignment.12,23 Through the fitting process and dynamic alignment, this changes until the patient is comfortable and functional and it is possible that the foot-inset position for optimal efficiency is altered to improve patient comfort. The second reason for the wider step width in TF amputees is that step width is known to increase when an individual requires increased side to side stability such as in toddlers, the elderly, and dysvascular bilateral TT amputees.21,24 The third and probably most speculative reason for increased step width in this population is the possibility that amputees may be concerned with lateral stability and preventing fall risk to the point that they are willing to sacrifice ambulatory energy efficiency.

No significant differences in spatial gait parameters were observed between sound and prosthetic sides for either TT or TF while TF amputees demonstrated substantial temporal asymmetry. Temporal asymmetry was previously observed by Cheung et al.7 to be present at both levels of amputation and in their study it was similarly reported to be greater in TT amputees. TT amputees had a negligible difference between sound and prosthetic legs for step time (DoA = 0.01 ± 0.04) whereas TF had significantly greater prosthetic step duration (DoA = −0.08 ± 0.05, p = 0.0008). Said differently, TF sound side steps were of similar distance but shorter in duration, suggesting that TF amputees were effecting a spatially symmetric gait pattern while attempting to restore weightbearing onto the sound foot as soon as possible via swing phase temporal asymmetry. As step time includes the double-support portion of stance phase, the DoA of the percent of gait cycle comprising swing phase (%swing) was examined to evaluate this post hoc hypothesis that asymmetry was more directly related to swing phase. Asymmetry was found to be greater for %swing than for step time (%swing DoA for TT = −0.02 ± 0.05, DoA for TF = −0.13 ± 0.06, p = 0.0006), which supports our post hoc hypothesis that %swing is the variable underlying the observed temporal asymmetry. It is possible that the amputee is motivated to hasten the sound step for feeling unstable when weightbearing on the prosthesis and/or for some level of discomfort when weightbearing in the socket during prosthetic stance.22

STUDY LIMITATIONS

GaitRite assessment does not permit the calculation of joint kinematics or kinetics—joint angles, moments and powers cannot be determined. The GaitRite system also defines some gait parameters using local instead of global coordinate systems and various pressure centers rather than surface markers to define displacements, both of which may result in some discrepancies in data from those of other studies. However, these discrepancies have been shown to be negligible in practice.25,26

Specific to this study, a possible limitation is in the heterogeneity of our sample. In this study, a wide age range (21–72 years) of varied amputation etiology, history of prosthetic use, and componentry were studied. We believe that this increases the data’s generalizability but should be considered when comparing these data to that of less heterogeneous samples.

CONCLUSIONS

TF amputees walk with significantly greater temporal, but not spatial, asymmetry than TT amputees due to their prosthetic leg spending a greater percentage of its gait cycle in swing phase and a smaller percentage in stance phase.
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REFERENCES


