# Leg Laterality in Bilateral Trans-Tibial Amputees, A Case Study using Prosthesis-Integrated Sensors

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## ABSTRACT

Bilateral leg amputation is obviously a severe detriment of physical integrity. However, at least in the case of bilateral trans-tibial amputation, rehabilitation efforts are often promising, and many patients succeed in learning to use prostheses. Due to the relatively small population size, literature on gait biomechanics for these patients is scarce, and prosthetic fitting practice is based on tradition and empiric rules of thumb. One question that is frequently encountered during fitting is whether there is a disparity in leg strength and controllability, and if so, which one of the legs is the favored one. This may have implications for the selection and adjustment of prosthetic parts, as well as for the prescription of physical therapy, and possibly recommended assistive devices. Prosthesis-integrated sensors suggest themselves as efficient assessment tools, as they can be installed in both legs, and thus allow continuous and un-obstructive data collection during various activities (Fiedler & Slavens, 2011). Simple pair-wise comparison of parameters between legs can then help answer the research question.

## INTRODUCTION

Among the many millions of people world-wide who live with limb loss, the fraction of bilateral trans-tibial amputees is considerable, and includes an estimated 11,400 individuals in the US alone (Su, Gard, Lipschutz, & Kuiken, 2007). Many of the main causes of amputation, such as cardiovascular disease, trauma, and congenital defects are usually not limited to a single limb or side. The rehabilitation of these patients can be challenging due to having to replace several limbs by prostheses. However, in many cases an efficient verticalization can be achieved, enabling the amputee to walk with little or even entirely without crutch support. The success rate in using prostheses for bilateral trans-tibial amputees has been reported to be as high as 60-90% (De Fretes, Boonstra, & Vos, 1994). Their gait has been found to be characterized by lower speeds, cadences, ankle moments and knee moments, compared to able bodied controls, which might be attributed to a deficit in available prosthetic componentry (Su, Gard, Lipschutz, & Kuiken, 2007).

One issue in the prosthetic fitting process is the decision about socket technology and functional part selection in cases where the residual limbs display different capabilities in terms of weight bearing, and prosthesis control. This is usually assumed when there is a large gap in limb length, and/or additional impairments such as large scars, muscular deficits or joint ailments affecting one side more than the other. Consequently, optimal selection and adjustment of the prosthetic foot components may be different for both legs. Prosthetic feet characteristics can generally be described as a continuum between stiffness and flexibility. While the former allows energy storage and return in the interest of a dynamic and efficient gait pattern, the latter secures stable ground contact, accommodation of uneven surfaces, and reduction of ankle moments, which is conducive to the stance stability and thus the (perceived) safety of the amputee (Su, Gard, Lipschutz, & Kuiken, 2010).

Knowledge on the preferred leg of bilateral trans-tibial amputees can inform the prescription of prosthetic feet and other functional parts such as torsion adapters or shock absorbers. Beyond that, it becomes possible to customize a physical therapy regimen that considers the respective different capabilities of both legs, so as to include strengthening and balance, and to practice individualized strategies for stair walking and other demanding tasks of everyday life.

## METHODS

IRB approval for this study was granted. Persons from 18 to 80 years of age with bilateral trans-tibial amputations who use prostheses built in modular technique, and were able to walk at least 30 minutes per day pain-free and without assistive devices were recruited for this study. Patients whose prostheses did not provide enough space between socket and foot module to fit the mobile measuring unit could not participate in this study. An initial screening was conducted to assure eligibility. Two male subjects (A: 61 years, 5'7", 185 lbs, and B: 32 years, 5'8", 178 lbs) participated in this study. Informed consent was obtained prior to the data collection.

In preparation of the data collection, the existing prostheses of the subject were modified by replacing the tube adapters above the foot modules with the iPecs integral sensor units (College Park Industries, Fraser, MI), and tube adapter in respectively shorter or longer lengths while maintaining the overall static alignment of the prostheses. In the gait lab, the subjects donned the modified prostheses in the usual fashion. In addition to measuring anthropometric data, such as limb dimensions, subject height and body mass, the Amputee Activity Score sheet was completed based on the subject's self report (Day, 1981).

Continuous iPecs measurements were conducted while subjects performed the following tasks in subsequent order:

- Walked in their preferred speed along the hallway (level surface, concrete floor),
- Walked down the stairs to the 1st floor (15 steps, concrete),
- Walked across a parking lot outside of the building (slightly uneven, asphalt and concrete sidewalk),
- Walked up a different set of stairs (13 steps), and
- While secured with a safety harness, walked through a 10 ft long sand box filled with gravel.

Gait analysis parameters such as step stance duration, knee-, and ankle moment, axial shin compression force, all delivered by the iPecs device were normalized to body weight and averaged over the trials of each task group (baseline gait inside the lab, stair gait, gait outdoors). A bilateral comparison was conducted by means of MANOVA, using the statistical package IBM SPSS 20. For every task, the mean difference of the parameters was calculated based on the available sample of steps.

## RESULTS

Both participants were comparably active prosthesis users with several years of experience. Subject A has been a bilateral amputee for 17 years and scored 15 on the Amputee Activity Score. Both of his residual limbs had about the same dimensions with a length of 16.5 cm. Subject B lost his legs 4 years prior, and had an Amputee Activity Score of 21. His residual limbs measured 16.5 cm (right) and 15 cm (left) in length. Both participants were fitted with patellar tendon bearing sockets with silicon liners and energy storing carbon feet.

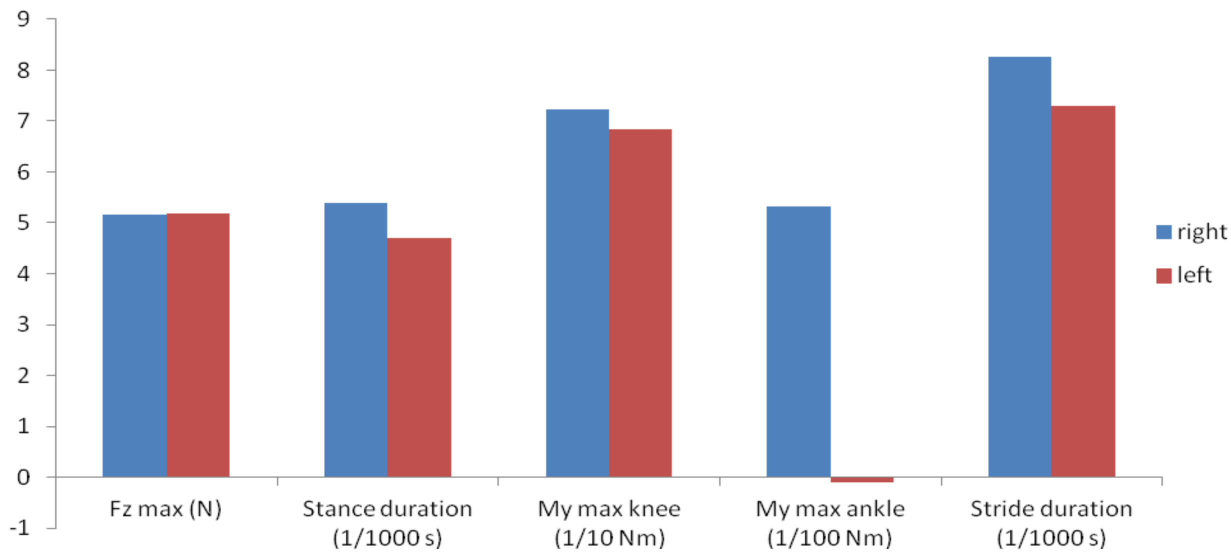


Figure 1: Average values in peak vertical force (Fz), stance phase duration, Ankle flexion moment, Knee flexion moment, and stride duration for 17 steps of walking on level ground for Subject A. All values are normalized to lbs body weight.

Participant A preferred a slower walking speed, and used a cane with his right hand. His time on the 210 m long circuit path (including the stairs) was 5:55 minutes, equaling an average velocity of about 0.59 m/s. Participant B walked without assistive devices and averaged a lap time of 3:53 minutes (0.90 m/s). Both participants climbed up stairs employing an alternating pattern and using handrails. For the task of walking down stairs, Subject A preferred to step forward always with his right foot before placing the left foot on the respective same stair step, whereas Subject B displayed an alternating foot placement.

Table 1: Bilateral comparison of step parameters during different walking activities. Listed are the absolute values for Subject A. * marks significant bilateral differences at the .05 level.

| Subject A | level walk | | | | down stairs | | | |
|---|---|---|---|---|---|---|---|---|
| | **left** | **right** | **difference** | **p-value** | **left** | **right** | **difference** | **p-value** |
| $F_z$ (N) | 956.925 | 956.848 | 0.077 | 0.991 | 822.622 | 922.951 | 100.329 | <0.001* |
| Stp durat. (s) | 0.868 | 0.996 | 0.128 | <0.001* | 1.217 | 1.174 | 0.043 | 0.266 |
| $M_y$ knee (Nm) | 126.676 | 133.938 | 7.262 | 0.004* | 111.284 | 65.505 | 45.779 | <0.001* |
| $M_y$ ankle (Nm) | -0.173 | 9.853 | 10.026 | <0.001* | 0.209 | 2.331 | 2.123 | 0.003* |
| Stride dur. (s) | 1.351 | 1.528 | 0.177 | <0.001* | 1.771 | 1.887 | .116 | 0.019* |
| | outdoors | | | | upstairs | | | |
| $F_z$ (N) | 980.777 | 936.442 | 44.336 | <0.001* | 817.541 | 890.423 | 72.882 | 0.168 |
| Stp durat. (s) | 0.928 | 0.968 | 0.039 | 0.118 | 1.787 | 2.219 | 0.432 | 0.122 |
| $M_y$ knee (Nm) | 122.74 | 127.276 | 4.536 | 0.181 | 74.761 | 56.045 | 18.717 | 0.082 |
| $M_y$ ankle (Nm) | -0.489 | 6.595 | 7.085 | <0.001* | 2.342 | 10.479 | 8.138 | 0.011* |
| Stride dur. (s) | 1.46 | 1.476 | 0.016 | 0.605 | 2.851 | 3.55 | .699 | 0.039* |

Table 2: Bilateral comparison of step parameters during different walking activities. Listed are the absolute values for Subject B. * marks significant bilateral differences at the .05 level.

| Subject B | level walk | | | | down stairs | | | |
|---|---|---|---|---|---|---|---|---|
| | **left** | **right** | **difference** | **p-value** | **left** | **right** | **difference** | **p-value** |
| $F_z$ (N) | 1186.65 | 933.629 | 253.022 | <0.001* | 1381.38 | 1293.76 | 87.62 | 0.511 |
| Stp durat. (s) | 0.838 | 0.721 | 0.116 | <0.001* | 0.891 | 0.829 | 0.062 | 0.135 |
| $M_y$ knee (Nm) | 135.300 | 164.681 | 29.381 | <0.001* | 163.565 | 192.233 | 28.669 | 0.003* |
| $M_y$ ankle (Nm) | 4.477 | 2.308 | 2.170 | 0.002* | 6.45 | 4.111 | 2.338 | 0.258 |
| Stride dur. (s) | 1.145 | 1.109 | 0.035 | 0.080 | 1.423 | 1.465 | 0.043 | 0.589 |
| | outdoors | | | | upstairs | | | |
| $F_z$ (N) | 1164.585 | 918.434 | 246.151 | <0.001* | 1176.017 | 914.486 | 261.532 | <0.001* |
| Stp durat. (s) | 0.859 | 0.725 | .135 | <0.001* | 0.916 | 0.925 | 0.009 | 0.940 |
| $M_y$ knee (Nm) | 127.691 | 159.29 | 31.598 | <0.001* | 142.968 | 186.247 | 43.280 | 0.021* |
| $M_y$ ankle (Nm) | 4.887 | 3.372 | 1.515 | 0.015* | 3.942 | 5.23 | 1.288 | 0.276 |
| Stride dur. (s) | 1.224 | 1.097 | .127 | 0.001* | 1.621 | 1.398 | 0.222 | 0.181 |

As a result, 13 steps of down stair walking have been recorded for both legs of Subject A (not counting the respective first and last steps), and seven, respectively six steps for the two legs of Subject B. Walking up the stairs both subjects had five or six valid steps of each leg. Level ground walking involved 17 steps (A) and 15 steps (B), while outdoor walking was evaluated over 27 steps (A) and 31 steps (B) respectively. No useable data could be collected for Subject A walking on the gravel path, and only four steps were evaluated for Subject B performing this task.

Figure 1 illustrates the bilateral differences between legs during level ground walking in Subject A. All comparisons are summarized in tables 1 and 2.

## DISCUSSION

The bilateral differences of walking parameters can be interpreted as an indicator of gait symmetry. According to the data we collected, bilateral amputee walking seems to be characterized by a considerable asymmetry in gait parameters. The parameters that display those asymmetries appear to be individually different. Subject A had very symmetrical weight distribution (judged by the peak vertical forces) during level walking, but significant bilateral differences in stance phase duration, knee moment and ankle moment. When walking on less smooth ground outdoors, the vertical forces became less balanced, but differences in knee moment and stance phase duration diminished. The only consistent pattern over all four walking tasks was that the ankle moment in the right foot was greater than in the left foot. The bilateral differences in Subject B were overall more consistent. Most notably was the knee moment that in all situations was higher in the right leg than in the left. The subject reported that he often depends more on his left leg, which seems to be confirmed by the peak forces that are mostly higher for this side. The fact that greater moments were measured in the right knee might be related to this residual limb being longer than the left one.

Our chosen data evaluation method based on discrete variables has been used in previous studies (Chow, Holmes, Lee, & Sin, 2006), but has its limitations in that it cannot entirely describe the kinetics parameters of the step cycle. Judged by the data plots, the measured differences may appear even greater when assessed more elaborately. In this context, however, it could be discussed what level of difference is indeed of clinical significance. Does the discrepancy of 10 Nm in ankle moment warrant a change of the used prosthetic foot component, or is such a small aberration an individual peculiarity that does not call for an intervention? A more extensive study, both in sample size, and assessment period, may be required to answer this question.

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