Inter-participant variability data in characterization of anthropomorphy of prosthetic feet fitted to bone-anchored transtibial prosthesis

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Abstract
The data in this paper are related to the research article entitled “Automated characterization of anthropomorphy of prosthetic feet fitted to bone-anchored transtibial prosthesis” (Frossard et al, 2019: DOI: 10.1109/TBME.2019.2904713). This article contains the individual angles of dorsiflexion and bending moments generated while walking with transtibial bone-anchored prostheses including prosthetic feet with different index of anthropomorphy. Inter-participant variability were presented for the (A) position of the load cell measuring directly to the bending moments, (B) patterns of angles of dorsiflexion and bending moment as well as moment-angle curves and (C) variations of magnitude of angles of dorsiflexion as well as the raw and bodyweight-normalized bending moments between toe contact and heel off. These initial inter-participant variability benchmark datasets are critical to design future automated algorithms and clinical trials. Online repository contains the files: https://eprints.qut.edu.au/127745/1/127745.pdf.

Keywords
Amputation; Artificial limb; Bone-anchored prosthesis; Direct skeletal attachment; Osseointegrated implants; Osseointegration; Prosthesis; Loading; Kinetics; Feet; Stiffness

Specifications Table
- **Subject area**
  - Biomechanics
- **More specific subject area**
  - Gait analysis of individuals using lower limb prosthesis
- **Type of data**
  - Graph, figure, table
- **How data was acquired**
  - Three participants walked consecutively with two instrumented bone-anchored prostheses including their own prosthetic feet and Free-Flow foot (Ohio Willow Wood, US). Angle of dorsiflexion was extracted from video footage. Bending moment was recorded using multi-axis transducer attached to osseointegrated fixation.
- **Data format**
  - Analyzed
- **Experimental factors**
  - Angle of dorsiflexion and bending moment were time-normalized from 0 to 100% during the support phase
- **Experimental features**
  - Participants fitted with transtibial bone-anchored prostheses, including a connector, a transducer attached with pyramidal adaptors, a pylon, either their own or Free-Flow prosthetic foot, were asked to perform five trials of level walking in straight-line on a
Value of the Data

- The individual data includes the angles of dorsiflexion and bending moments generated while walking with transtibial bone-anchored prostheses including prosthetic feet with different index of anthropomorphism. This information provides valuable insight into inter-participants variability in variables characterizing feet stiffness.
- The individual data presented here that were collected for the first time on individuals fitted with transtibial bone-anchored prostheses consist of an initial benchmark of angles of dorsiflexion and bending moments. This baseline information could be used in future meta-analyses and/or comparative studies involving other cohorts of individuals fitted with transtibial bone-anchored or socket-suspended prostheses, respectively.
- The inter-participant variability of angles of dorsiflexion and bending moments is critical to assist the design of algorithms capable to quantify automatically the anthropomorphopcity of prosthetic feet. This will greatly facilitate processing large datasets relying on on-board inertial motion sensors to determine angle of dorsiflexion and embedded load cell to measure directly bending moments.
- The inter-participant variability of angles of dorsiflexion and bending moments provided here can educate the design of subsequent clinical trials testing different types of prosthetic feet. For instance, the ranges of differences between the usual and Free-Flow feet can informed the calculation of sample size required to achieve sufficient statistical power during analytical planning stage.

Data

Figure 1 illustrates inter-participant variability in position of the tri-axial transducer (iPecLab, RTC, US) measuring directly the bending moment in relation the ankle joint that was embedded in the instrumented transtibial bone-anchored prosthesis fitted with Free-Flow Foot.

Figure 2 provides the inter-participant variability of the mean and standard deviation patterns over time of angle of dorsiflexion and bending moment as well as moment-angle curves of bespoke usual (i.e., RUSH, Trias, Triton) and Free-Flow feet fitted to transtibial bone-anchored prostheses.

Table 1 shows inter-participant variability and difference of mean and standard deviation of magnitude of angle of dorsiflexion as well as variation in raw and bodyweight-normalized bending moment between toe contact and heel off of bespoke usual and Free-Flow feet fitted to transtibial bone-anchored prostheses.

Experimental Design, Materials, and Methods Gait

Participants were fitted with transtibial bone-anchored prostheses including with their own or Free-Flow prosthetic foot and performed five trials of level walking in straight-line on a 5-meter walkway at self-selected comfortable pace.[2]

Detection of gait events

Heel contact, toe contact, heel off and toe off events were detected manually using displacements of heel and toe of prosthetic foot as well as loading profile on the long axis. Angle of dorsiflexion and bending moment were time-normalized from 0 to 100% over the support phase of each gait cycle.[3]

Angle of dorsiflexion

Raw video footage obtained with a digital camera (25 Hz) were imported into a motion analysis software package (Kinovea) allowing manual selection of the angle of dorsiflexion corresponding to the projected angle in sagittal plane between the long axes of leg and foot intersecting at the ankle joint for each frame of the support phase with accuracy of approximately 2 Deg.[4-7]

Bending moment

The raw bending moment was recorded directly using a portable kinetic system (iPecLab, RTC, US) including a tri-axial transducer sending wirelessly moment (200 Hz) applied on the fixation to a receiver connected to a laptop nearby with an
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accuracy better than 1 Nm. [2, 3, 8-14] The raw bending moments were imported into a Matlab program and offset according to load yielded during calibration before being expressed in Nm and percentage of bodyweight (%BWm).

**Variability**

Individual or intra-variability of angles of dorsiflexion and bending moments was determined using the percentage of variation (PV= absolute [standard deviation / mean] x100)). We considered than a PV inferior or superior to 20% indicated a low (L) or high (H) variability, respectively.[2]

**Minimum Clinically Important Difference**

The differences in angles of dorsiflexion and bending moments between feet were determined so that a positive difference indicated that Free-Flow foot was algebraically larger than usual foot. We considered that a difference inferior or superior to 10% was below (B) or above (A) a minimum clinically important difference (MCID), respectively.[15]

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**Transparency document. Supporting information**

Transparency data associated with this article can be found in the online version at https://eprints.qut.edu.au/127745/1/127745.pdf

To know more

**References**

[1] L. Frossard, B. Leech, and M. Pitkin, “Automated characterization of anthropomorphy of prosthetic feet fitted to bone-anchored transtibial prosthesis,” IEEE Trans Biomed Eng, vol. IEEEExplore (DOI: 10.1109/TBME.2019.2904713), pp. 1-9, Mar 13, 2019.

[2] W. Lee, L. Frossard, K. Hagberg et al., “Magnitude and variability of loading on the osseointegrated implant of transfemoral amputees during walking,” Med Eng Phys, vol. 30, no. 7, pp. 825-833, Sep, 2008.

[3] L. Frossard, K. Hagberg, E. Hägström et al., “Functional Outcome of Transfemoral Amputees Fitted With an Osseointegrated Fixation: Temporal Gait Characteristics,” Journal of Prosthetics and Orthotics, vol. 22, no. 1, pp. 11-20, 2010.

[4] X. Drevelle, C. Villa, X. Bonnet et al., “Analysis of ankle stiffness for asymptomatic subjects and transfemoral amputees in daily living situations,” Comput Methods Biomech Biomed Engin, vol. 17 Suppl 1, no. sup1, pp. 80-1, 2014/08/06, 2014.

[5] H. Pillet, X. Drevelle, X. Bonnet et al., “APSIC: Training and fitting amputees during situations of daily living,” Irbm, vol. 35, no. 2, pp. 60-65, 2014.

[6] M. Pitkin, "Ballistic synergy in Normal Gait, in:," Biomechanics of lower limb prosthetics, pp. 39-52, Heidelberg, Dordrecht, London, New York: Springer, 2010.

[7] M. R. Pitkin, “Synthesis of a cycloidal mechanism of the prosthetic ankle,” Prosthet Orthot Int, vol. 20, no. 3, pp. 159-71, Dec, 1996.

[8] L. Frossard, J. Beck, M. Dillon et al., “Development and preliminary testing of a device for the direct measurement of forces and moments in the prosthetic limb of transfemoral amputees during activities of daily living,” Journal of Prosthetics and Orthotics, vol. 15, no. 4, pp. 135-142, 2003.

[9] L. Frossard, K. Hagberg, E. Haggstrom et al., “Load-relief of walking aids on osseointegrated fixation: instrument for evidence-based practice,” IEEE Trans Neural Syst Rehabil Eng, vol. 17, no. 1, pp. 9-14, Feb, 2009.

[10] L. Frossard, E. Haggstrom, K. Hagberg et al., “Load applied on a bone-anchored transfemoral prosthesis: characterisation of prosthetic components – A case study ” Journal of Rehabilitation Research & Development, vol. 50, no. 5, pp. 619–634,
Inter-participant variability data in characterization of anthropomorphicity of prosthetic feet fitted to bone-anchored transtibial prosthesis

2013.

[11] W. C. Lee, L. A. Frossard, K. Hagberg et al., “Kinetics of transfemoral amputees with osseointegrated fixation performing common activities of daily living,” Clin Biomech (Bristol, Avon), vol. 22, no. 6, pp. 665-73, Jul, 2007.

[12] E. S. Neumann, J. Brink, K. Yalamanchili et al., “Use of a Load Cell and Force-Moment Analysis to Examine Transtibial Prosthesis Foot Rollover Kinetics for Anterior-Posterior Alignment Perturbations,” JPO Journal of Prosthetics and Orthotics, vol. 24, no. 4, pp. 160-174, 2012.

[13] E. S. Neumann, J. Brink, K. Yalamanchili et al., “Use of a load cell and force-moment curves to compare transverse plane moment loads on transtibial residual limbs: a preliminary investigation,” Prosthet Orthot Int, vol. 38, no. 3, pp. 253-262, Aug 6, 2013.

[14] E. S. Neumann, K. Yalamanchili, J. Brink et al., “Transducer-based comparisons of the prosthetic feet used by transtibial amputees for different walking activities: a pilot study,” Prosthet Orthot Int, vol. 36, no. 2, pp. 203-16, Jun, 2012.

[15] A. G. Copay, B. R. Subach, S. D. Glassman et al., “Understanding the minimum clinically important difference: a review of concepts and methods,” Spine J, vol. 7, no. 5, pp. 541-6, Sep-Oct, 2007.

Figure 1. Inter-participant variability in position of the tri-axial transducer (iPecLab, RTC, US) in relation to the ankle joint embedded in the instrumented transtibial bone-anchored prosthesis fitted with Free-Flow Foot (Ohio Willow Wood).

| Participant 1 | Participant 2 | Participant 3 |
|---------------|---------------|---------------|
| ![Participant 1](image1) | ![Participant 2](image2) | ![Participant 3](image3) |
| 11.20 cm | 8.96 cm | 12.87 cm |
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Figure 2. Inter-participant variability of the mean and standard deviation patterns of angle of dorsiflexion and bending moment as well as moment-angle curves of bespoke usual (i.e., RUSH, Trias, Triton) and Free-Flow feet fitted to transtibial bone-anchored prostheses.

| Participant 1 | Participant 2 | Participant 3 |
|---------------|---------------|---------------|
| **Support phase (%)** | **Support phase (%)** | **Support phase (%)** |
| 0 20 40 60 80 100 | 0 10 20 30 40 50 60 70 80 | 0 20 40 60 80 100 |
| **Bending moment (Nm)** | **Bending moment (Nm)** | **Bending moment (Nm)** |
| -40 0 40 80 120 | -40 0 40 80 120 | -40 0 40 80 120 |
| **Angle of dorsiflexion (Deg)** | **Angle of dorsiflexion (Deg)** | **Angle of dorsiflexion (Deg)** |
| -30 -20 -10 0 10 | -30 -20 -10 0 10 | -20 -15 -10 -5 0 |
| **RUSH foot** | **Trias foot** | **Triton foot** |
| **Free-Flex foot** | **Free-Flex foot** | **Free-Flex foot** |

2019. Data In Brief
Table 1. Inter-participant variability and difference of mean and standard deviation of magnitude of angle of dorsiflexion and raw and bodyweight-normalized bending moment at and between toe contact (TC) and heel off (HO) of bespoke usual and Free-Flow feet fitted to transtibial bone-anchored prostheses (N: Number of gait cycles, H: High PV, L: Low PV, A: Above MCID, B: Below MCID).

|                     | Participant 1 (N=5) | Participant 2 (N=5) | Participant 3 (N=4) |
|---------------------|---------------------|---------------------|---------------------|
| **Usual foot**      |                     |                     |                     |
| **Angle of dorsiflexion (Deg)** |                     |                     |                     |
| At TC               | -15.84±2.49         | L -17.32±3.24       | L -19.62±1.28       |
| At HO               | 10.01±2.91          | H -0.08±3.58        | H -3.02±3.07        |
| Between TC and HO   | 25.85±3.89          | L 17.24±4.55        | H 16.60±2.30        |
| **Bending moment (Nm)** |                     |                     |                     |
| At TC               | -12.55±4.47         | H -7.45±8.38        | H -5.97±1.24        |
| At HO               | 90.61±10.81         | L 66.86±1.35        | L 28.65±3.08        |
| Between TC and HO   | 103.16±12.57        | L 74.31±8.60        | L 34.62±3.24        |
| **Bending moment (%BWm)** |                     |                     |                     |
| At TC               | -1.17±0.42          | H -0.93±1.04        | H -1.02±0.21        |
| At HO               | 8.46±1.01           | L 8.34±0.17         | L 4.91±0.53         |
| Between TC and HO   | 9.64±1.17           | L 9.27±1.07         | L 5.93±0.56         |
| **Free-Flow foot**  | (N=5)               | (N=4)               | (N=5)               |
| **Angle of dorsiflexion (Deg)** |                     |                     |                     |
| At TC               | -16.90±1.76         | L -17.84±4.57       | H -22.71±2.45       |
| At HO               | 16.46±4.57          | H 2.60±4.53         | H -2.57±3.40        |
| Between TC and HO   | 33.36±3.43          | L 20.44±2.43        | L 20.14±5.18        |
| **Bending moment (Nm)** |                     |                     |                     |
| At TC               | -13.49±0.38         | L -6.29±0.21        | L -4.14±4.58        |
| At HO               | 52.59±12.10         | H 50.05±9.24        | L 38.69±2.07        |
| Between TC and HO   | 66.07±11.73         | L 56.33±9.26        | L 42.83±6.22        |
| **Bending moment (%BWm)** |                     |                     |                     |
| At TC               | -1.26±0.04          | L -0.78±0.03        | L -0.71±0.78        |
| At HO               | 4.91±1.13           | H 6.24±1.15         | L 6.63±0.35         |
| Between TC and HO   | 6.17±1.10           | L 7.03±1.15         | L 7.34±1.07         |
| **Difference (Free-Flow foot-Usual foot)** |                     |                     |                     |
| **Angle of dorsiflexion (Deg)** |                     |                     |                     |
| At TC               | -1.05               | B -0.52             | B -3.09             |
| At HO               | 6.45                | A 2.67              | A 0.45              |
| Between TC and HO   | 7.51                | A 3.20              | A 3.54              |
| **Bending moment (Nm)** |                     |                     |                     |
| At TC               | -0.93               | B 1.17              | A 1.83              |
| At HO               | -38.02              | A -16.81            | A 10.04             |
| Between TC and HO   | -37.09              | A -17.97            | A 8.21              |
| **Bending moment (%BWm)** |                     |                     |                     |
| At TC               | -1.05               | B -0.52             | A -3.09             |
| At HO               | 6.45                | A 2.67              | A 0.45              |
| Between TC and HO   | 7.51                | A 3.20              | A 3.54              |