Data Article

Loading characteristics data applied on osseointegrated implant by transfemoral bone-anchored prostheses fitted with basic components during daily activities

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**Abstract**

The data in this paper are related to the research articles entitled “Kinetics of transfemoral amputees with osseointegrated fixation performing common activities of daily living” (Lee et al., Clinical Biomechanics, 2007.22(6). p. 665–673) and “Magnitude and variability of loading on the osseointegrated implant of transfemoral amputees during walking” (Lee et al., Med Eng Phys, 2008.30(7). p. 825 –833). This article contains the overall and individual loading characteristics applied on screw-type osseointegrated implant generated by transfemoral bone-anchored prostheses fitted with basic components during daily activities at self-selected comfortable pace. Overall and individual data was presented for the (A) spatio-temporal characteristics, (B) loading patterns, (C) loading boundaries and (D) the loading local extremum during level walking, ascending and descending ramp and stairs. Inter-participant variability of these new datasets with basic components is critical to improve the efficacy and safety of prosthetic components as well as the design of future automated algorithms and clinical trials. Online repository contains the files: https://data.mendeley.com/datasets/1h8rjjh73w/1.

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1. Data

The confounders of the loading characteristics data including selection criteria as well as the demographics, amputation, residuum and prosthesis, non-experimental setup and number of gait cycles analysed information are presented in Tables 1-6, respectively.

The mean and standard deviation as well as lower and upper limits of 95% confidence interval of the spatio-temporal gait characteristics, loading boundaries and loading extremum during walking, ascending and descending ramp and stairs are presented in Tables 7-11 respectively.

The box plots of the spatio-temporal gait characteristics during walking, ascending and descending ramp and stairs are presented in Figs. 1, 6, 10, 14 and 18, respectively.

The box plots of loading boundaries during walking, ascending and descending ramp and stairs are presented in Figs. 2, 7, 11, 15 and 19, respectively.

The mean and standard deviation of the pattern as well as dispersion and mean for up to three local extremum of forces and moments during walking, ascending and descending ramp and stairs are presented in Figs. 3, 8, 12, 16 and 20, respectively.

The box plots of onset of up to three local extremum of forces and moments during walking, ascending and descending ramp and stairs are presented in Figs. 4, 9, 13, 17 and 21, respectively.

The box plots of magnitude of up to three local extremum of forces and moments during walking, ascending and descending ramp and stairs are presented in Figs. 5, 10, 14, 18 and 22, respectively (see Figs. 23-25).
1.1. Confounders

1.2. Level walking

1.3. Ascending ramp

1.4. Descending ramp

1.5. Ascending stairs

1.6. Descending stairs

2. Experimental design, materials, and methods

2.1. Participants

Ten participants with unilateral transfemoral amputation fitted with screw-type fixation (OPRA, Integrum, AB) enabling direct skeletal attachment of bone-anchored prostheses participated in these studies (Table 1, Table 2, Table 3). [1,7] This cohort represented approximately 15% of the population of fitted with transfemoral bone-anchored prostheses worldwide at the time of the recording. [1,7]

2.2. Prostheses

Participants were fitted with instrumented bone-anchored prosthesis made of a transducer and their own usual components including hydraulic knees (i.e., single-axis GaitMaster (N = 1), polycentric Total Knee 1900 (N = 6)) or microprocessor-controlled knees (i.e., single-axis Adaptive (N = 1), C-Leg (N = 2)), foot prosthetic ankle-units (Multi-axial TruStep (N = 3), Total Concept (N = 1), energy-storing-and-returning: Carbon copy (N = 2), C-Walk (N = 2), Flex Foot (N = 1), unknown (N = 1)) and footwear (Table 4).

These components are referred to as “basic” as their mechanical design are no longer as advanced as commonly prescribed components according to current best-practice (e.g., microprocessor-controlled knees, energy-storing-and-returning feet). Indeed, only two participants used a C-Leg knee recommended for transfemoral bone-anchored prostheses fitted to screw-type fixation. [6,8]

The loads were directly measured with a purposely build apparatus including a multi-axis JR3 transducer set at 200 Hz with an accuracy better than 1 N and 1 Nm, that was fitted between the participant’s abutment and Rotosafe, when possible, or attached to the knee unit. [9–17]
2.3. Recording

Participants performed up to five trials of five standardized daily activities including straight-line level walking, ascending and descending ramp and stairs (Table 5, Table 6). [7,13] Participants were instructed to complete each activity at a self-selected comfortable pace as well as to use handrails and take sufficient rest between trials to avoid fatigue if needed. Some datasets relying on no more than three trials per activity were presented in Lee et al. (2007) and Lee et al. (2008). [1,7] Here, we purposely extracted and presented data for all five trials available to provide more thorough insights.

2.4. Loading characteristics

The raw forces and moments recorded directly by tri-axial transducer connected to a laptop nearby were imported and processed into a specifically designed Matlab program.

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Table 1
Selection criteria including inclusion and exclusion criteria applied for the recruitment and selection of participants using unilateral transfemoral bone-anchored prosthesis fitted with basic components.

| Inclusion criteria |
|--------------------|
| 1. To be fitted with OPRA osseointegrated fixation more than 6 months prior testing |
| 2. To be fully rehabilitated |
| 3. To have at least 6 cm clearance between abutment and prosthetic knee to fit the transducer |
| 4. To be able to be fitted with one of the nominated basic components |
| 5. To be willing to participate to this project of research |
| 6. To be willing to comply with protocol |
| 7. To be able to walk 200 m independently with prosthesis |
| 8. To be between 18 and 80 years of age |
| 9. To be free of infection on the day of the recording session |

| Exclusion criteria |
|--------------------|
| 1. To have bilateral amputation |
| 2. To have self-reported pain level greater than 4 out of 10 at study outset |
| 3. To have experienced a fall within the last 8 weeks before assessment |
| 4. To have mental illness or intellectual impairment |
| 5. To not be able to give informed consent |
| 6. To have injuries involving contralateral (intact) limb |
| 7. To present signs of infection 2 weeks prior testing session |
| 8. To have major uncorrected visual deficit |
| 9. To have history of epilepsy or recurrent dizziness |

Table 2
Overall and individual demographics information for cohorts of ten participants fitted with basic components. M: Male, F: Female, BMI: Body mass Index.

| Participant | Demographics |
|-------------|--------------|
| Gender (M/F) | Age (Yrs) | Height (m) | Mass (kg) | BMI (kg/m2) |
| 1 | F | 57 | 1.63 | 61.10 | 21.679 |
| 2 | M | 50 | 1.81 | 74.24 | 21.547 |
| 3 | M | 59 | 1.85 | 87.12 | 24.316 |
| 4 | M | 62 | 1.80 | 105.00 | 31.003 |
| 5 | F | 49 | 1.58 | 53.30 | 20.029 |
| 6 | M | 73 | 1.77 | 96.55 | 29.589 |
| 7 | M | 26 | 1.78 | 90.00 | 27.048 |
| 8 | M | 46 | 1.89 | 99.50 | 26.735 |
| 9 | M | 48 | 1.82 | 99.80 | 28.967 |
| 10 | M | 45 | 1.72 | 80.40 | 25.994 |
| Mean | M | 52 | 1.77 | 84.70 | 25.691 |
| SD | M | 13 | 0.10 | 17.33 | 3.718 |
Table 3
Overall and individual amputations and residuum information for cohorts of ten participants fitted with basic components. TR: Trauma, TU: Tumor, IN: Infection, OT: Other, L: Left, R: Right, AMP: amputation, BAP: Bone-anchored prosthesis, %SND: Percentage of sound limb, -: missing data due to inaccessible medical record.

| Participant | Amputation Cause | Side (L/R) | Time since AMP (Yrs) | Time since BAP (Yrs) | Length (cm) | Length (%SND) |
|-------------|------------------|------------|----------------------|----------------------|-------------|---------------|
| 1           | TR               | R          | —                    | —                    | 17.50       | 45.81         |
| 2           | TR               | L          | 15.4                 | 6.71                 | 22.30       | 54.13         |
| 3           | TR               | R          | 41.8                 | 6.89                 | 16.00       | 39.02         |
| 4           | TR               | L          | 16.0                 | 3.42                 | 35.00       | 71.43         |
| 5           | TU               | R          | 48.9                 | 1.20                 | 18.00       | 48.65         |
| 6           | TR               | R          | 14.3                 | —                    | 17.40       | 41.23         |
| 7           | TR               | R          | 7.1                  | —                    | 17.20       | 41.75         |
| 8           | TR               | L          | 21.3                 | 5.20                 | —           | —             |
| 9           | TU               | R          | 6.3                  | 14.28                | 24.80       | 59.05         |
| 10          | OT               | R          | 11.8                 | 4.62                 | 28.00       | 59.57         |
| Mean        |                  |            | 20.3                 | 6.05                 | 21.80       | 51.18         |
| SD          |                  |            | 15.0                 | 4.12                 | 6.41        | 10.74         |

Table 4
Individual prosthesis information for cohorts of ten participants fitted with basic components.

| Participant | Prosthesis Knee | Prosthesis Ankle | Footwear |
|-------------|-----------------|------------------|----------|
| 1           | Total Knee      | Total Concept    | Sandals  |
| 2           | Total Knee      | TruStep          | Sandals  |
| 3           | Total Knee      | TruStep          | Leather shoes |
| 4           | Adaptive        | Unknown          | Running shoes |
| 5           | Total Knee      | C-Walk           | Sandals  |
| 6           | C-Leg           | Carbon copy      | Sandals  |
| 7           | C-Leg           | Carbon copy      | Leather shoes |
| 8           | Total Knee      | C-Walk           | Sandals  |
| 9           | GaitMaster      | Flex Foot        | Leather shoes |
| 10          | Total Knee      | TruStep          | Running shoes |

Table 5
Description of non-experimental setup used for ecological direct measurements of loading applied on osseointegrated fixation by transfemoral bone-anchored prosthesis fitted with basic components during activities of daily living.

| Straight level walking |
|------------------------|
| Location               | Indoor |
| Length (m)             | 30     |

| Ascending and descending ramp |
|------------------------------|
| Location                    | Outdoor |
| Length (m)                  | 12      |
| Incline (deg)               | 6.5     |
| Height of handrail (cm)     | 70      |

| Ascending and descending stairs |
|-------------------------------|
| Location                      | Indoor  |
| Number of steps               | 11      |
| Height of step (cm)           | 30      |
| Depth of step (cm)            | 34      |
| Width of step (cm)            | 180     |
| Height of handrail (cm)       | 80      |
Table 6
Breakdown of cumulated number of gait cycles analysed for the cohorts of ten participants fitted basic components performed over up to five trials during five activities of daily living.

| Activity                | Number of steps analysed |
|-------------------------|--------------------------|
| Level walking           | 555                      |
| Ascending ramp          | 469                      |
| Descending ramp         | 566                      |
| Ascending stairs        | 284                      |
| Descending stairs       | 253                      |
| Total                   | 2,127                    |

Table 7
Mean and standard deviation (SD) as well as lower and upper limits of 95% confidence interval (CI) of the spatio-temporal gait characteristics, loading boundaries and loading extremum (PT1, PT2, PT3) when fitted with basic components during walking (GC: Gait cycle, F: Force, M: Moment, AP: Antero-posterior, ML: Medio-lateral, LG: Long, BW: Bodyweight, SUP: Support).

| Spatio-temporal gait characteristics | Mean  | SD    | 95%CI-Lower | 95%CI-Upper |
|--------------------------------------|-------|-------|-------------|-------------|
| Cadence (Strides/min)                | 47    | 4     | 44          | 49          |
| Gait cycle (s)                       | 1.29  | 0.11  | 1.28        | 1.30        |
| Swing (s)                            | 0.74  | 0.07  | 0.73        | 0.74        |
| Support (%GC)                        | 57    | 3     | 57          | 57          |
| Swing (s)                            | 0.55  | 0.07  | 0.55        | 0.56        |
| Support (%GC)                        | 43    | 3     | 43          | 43          |

| Loading boundaries                  |       |       |             |             |
|-------------------------------------|-------|-------|-------------|-------------|
| Minimum                             |       |       |             |             |
| FAP (%BW)                           | -7.26 | 3.43  | -7.54       | -6.97       |
| FML (%BW)                           | -0.51 | 1.02  | -0.60       | -0.43       |
| FLG (%BW)                           | -4.72 | 3.22  | -4.99       | -4.45       |
| MAP (%BWm)                          | -2.791| 0.946 | -2.869      | -2.712      |
| MML (%BWm)                          | -2.266| 1.000 | -2.349      | -2.182      |
| MLG (%BWm)                          | -0.367| 0.221 | -0.385      | -0.349      |
| Maximum                             |       |       |             |             |
| FAP (%BW)                           | 13.00 | 4.52  | 12.62       | 13.38       |
| FML (%BW)                           | 12.92 | 5.04  | 12.50       | 13.34       |
| FLG (%BW)                           | 84.73 | 6.93  | 84.16       | 85.31       |
| MAP (%BWm)                          | 0.424 | 0.881 | 0.351       | 0.498       |
| MML (%BWm)                          | 1.623 | 1.195 | 1.524       | 1.723       |
| MLG (%BWm)                          | 0.458 | 0.304 | 0.432       | 0.483       |

| Loading extremum                    |       |       |             |             |
|-------------------------------------|-------|-------|-------------|-------------|
| Onset                               |       |       |             |             |
| FAP-PT1 (%SUP)                      | 16.43 | 4.56  | 16.05       | 16.81       |
| FAP-PT2 (%SUP)                      | 81.41 | 5.43  | 80.96       | 81.86       |
| FML-PT1 (%SUP)                      | 63.80 | 17.88 | 62.32       | 65.29       |
| FLG-PT1 (%SUP)                      | 53.75 | 17.67 | 52.28       | 55.22       |
| MAP-PT1 (%SUP)                      | 50.82 | 27.66 | 48.52       | 53.12       |
| MML-PT1 (%SUP)                      | 17.56 | 11.46 | 16.60       | 18.51       |
| MML-PT2 (%SUP)                      | 67.46 | 8.46  | 66.76       | 68.16       |
| MML-PT3 (%SUP)                      | 94.01 | 3.88  | 93.68       | 94.33       |
| MLG-PT1 (%SUP)                      | 17.59 | 12.07 | 16.58       | 18.59       |
| MLG-PT2 (%SUP)                      | 73.47 | 11.17 | 72.54       | 74.40       |

| Magnitude                           |       |       |             |             |
|-------------------------------------|-------|-------|-------------|-------------|
| FAP-PT1 (%BW)                       | -7.26 | 3.43  | -7.54       | -6.97       |
| FAP-PT2 (%BW)                       | 13.00 | 4.52  | 12.62       | 13.38       |
| FML-PT1 (%BW)                       | 12.92 | 5.04  | 12.50       | 13.34       |
| FLG-PT1 (%BW)                       | 84.73 | 6.93  | 84.16       | 85.31       |
| MRT-PT1 (%BWm)                      | 3.516 | 0.850 | 3.445       | 3.587       |
| MAP-PT1 (%BWm)                      | -2.787| 0.946 | -2.866      | -2.709      |
| MML-PT1 (%BWm)                      | -1.313| 0.780 | -1.378      | -1.248      |
| MML-PT2 (%BWm)                      | 1.485 | 1.348 | 1.373       | 1.598       |
| MML-PT3 (%BWm)                      | 2.197 | 1.047 | 2.284       | 2.110       |
| MLG-PT1 (%BWm)                      | -0.364| 0.223 | -0.383      | -0.345      |
| MLG-PT2 (%BWm)                      | 0.445 | 0.320 | 0.418       | 0.472       |
Table 8
Mean and standard deviation (SD) as well as lower and upper limits of 95% confidence interval (CI) of the spatio-temporal gait characteristics, loading boundaries and loading extremum (PT1, PT2, PT3) when fitted with basic components during ascending ramp (GC: Gait cycle, F: Force, M: Moment, AP: Antero-posterior, ML: Medio-lateral, LG: Long, BW: Bodyweight, SUP: Support).

| Spatio-temporal gait characteristics | Mean | SD  | 95%CI-Lower | 95%CI-Upper |
|--------------------------------------|------|-----|-------------|-------------|
| Cadence (Strides/min)                | 46   | 4   | 43          | 48          |
| Gait cycle (s)                       | 1.29 | 0.11| 1.28        | 1.30        |
| Swing (s)                            | 0.78 | 0.05| 0.78        | 0.79        |
| Support (%GC)                        | 61   | 4   | 61          | 61          |
| Swing (s)                            | 0.51 | 0.08| 0.50        | 0.52        |
| Support (%GC)                        | 39   | 4   | 39          | 39          |

| Loading boundaries                   | Minimum | Maximum | Loading extremum |
|--------------------------------------|---------|---------|------------------|
| FAP (%BW)                            | −5.88   | 14.63   | FAP-PT1 (%SUP)   |
| FML (%BW)                            | −0.27   | 12.07   | FAP-PT2 (%SUP)   |
| FLG (%BW)                            | −1.88   | 91.08   | MML-PT1 (%SUP)   |
| MAP (%BWm)                           | −2.528  | 0.228   | MML-PT2 (%SUP)   |
| MML (%BWm)                           | −2.453  | 2.199   | MML-PT3 (%SUP)   |
| MLG (%BWm)                           | −0.358  | 0.671   | MLG-PT1 (%SUP)   |

| Magnitude                            | FAP-PT1 (%BW) | FAP-PT2 (%BW) | FML-PT1 (%BW) | FLG-PT1 (%BW) | MAP-PT1 (%BWm) | MML-PT1 (%BWm) | MML-PT2 (%BWm) | MML-PT3 (%BWm) | MLG-PT1 (%BWm) | MLG-PT2 (%BWm) |
|--------------------------------------|---------------|---------------|---------------|---------------|----------------|----------------|----------------|----------------|---------------|---------------|
| Onset                                | 14.53         | 14.63         | 62.23         | 59.73         | 35.96          | 10.59          | 55.68          | 94.09          | 12.63         | 55.32         |
| Magnitude                            | −5.88         | 14.63         | −2.502        | 12.07         | 91.01          | 3.559          | −2.452         | 0.665          | −0.333        | −0.358        |

The load data for a given activity was extracted following a step-by-step basic processing including: calibration (e.g., Offset of raw data according to the magnitude of the load recorded during calibration), detection of relevant segment (e.g., elimination of the first and the last strides recorded for each trial to analyze only steps taken at a steady pace free of gait initiation and termination), detection of gait events (e.g., manual detection of individual heel contact and toe-off events using loading profile applied on the long axis), time normalization (e.g., time-normalization from 0 to 100 throughout the gait cycle or support phases) and bodyweight normalization (e.g., express forces and moments data as percentage of bodyweight).
The characterization of loading profile for each activity was achieved through more advanced processing to extract spatio-temporal gait characteristics (e.g., cadence, duration of gait cycle as well as support and swing phases), loading patterns, loading boundaries (e.g., minimum and maximum of forces and moments expressed in %BW and %BWm for all gait cycles considered regardless of the onset), up to three loading local extremum (e.g., semi-automatic detection of onsets (%SUP) and magnitudes (%BW or %BWm) of points of inflection between loading slopes occurring consistently over successive gait cycles across all participants). [1,3,7,10–13,18]

The continuous data (e.g., loading pattern) was represented by mean and one standard deviation. For all discrete datasets (e.g., spatio-temporal gait characteristics, loading boundaries, local extremum), the confidence intervals were calculated using the CONFIDENCE function in Microsoft Excel 2010 and

### Table 9

Mean and standard deviation (SD) as well as lower and upper limits of 95% confidence interval (CI) of the spatio-temporal gait characteristics, loading boundaries and loading extremum (PT1, PT2, PT3) when fitted with basic components during descending ramp (GC: Gait cycle, F: Force, M: Moment, AP: Antero-posterior, ML: Medio-lateral, LG: Long, BW: Bodyweight, SUP: Support).

|                      | Mean     | SD      | 95%CI-Lower | 95%CI-Upper |
|----------------------|----------|---------|-------------|-------------|
| **Spatio-temporal gait characteristics** |          |         |             |             |
| Cadence (Strides/min) | 48       | 6       | 45          | 52          |
| Gait cycle (s)       | 1.23     | 0.14    | 1.22        | 1.25        |
| Swing (s)            | 0.72     | 0.08    | 0.71        | 0.73        |
| Support (%GC)        | 58       | 2       | 58          | 59          |
| Swing (s)            | 0.51     | 0.07    | 0.51        | 0.52        |
| Support (%GC)        | 42       | 2       | 41          | 42          |
| **Loading boundaries** |         |         |             |             |
| Minimum              |          |         |             |             |
| FAP (%BW)            | –11.81   | 4.68    | –12.19      | –11.42      |
| FML (%BW)            | –0.14    | 0.63    | –0.20       | –0.09       |
| FLG (%BW)            | –0.90    | 1.64    | –1.03       | –0.76       |
| MAP (%BWm)           | –2.958   | 1.611   | –3.054      | –2.863      |
| MML (%BWm)           | –3.706   | 1.663   | –3.843      | –3.569      |
| MLG (%BWm)           | –0.022   | 0.331   | –0.069      | –0.039      |
| Maximum              |          |         |             |             |
| FAP (%BW)            | 8.72     | 4.14    | 8.37        | 9.06        |
| FML (%BW)            | 10.39    | 3.66    | 10.09       | 10.70       |
| FLG (%BW)            | 87.69    | 6.95    | 87.12       | 88.27       |
| MAP (%BWm)           | 0.284    | 0.486   | 0.244       | 0.324       |
| MML (%BWm)           | 0.780    | 0.779   | 0.716       | 0.844       |
| MLG (%BWm)           | 0.283    | 0.260   | 0.262       | 0.305       |
| **Loading extremum** |          |         |             |             |
| Onset                |          |         |             |             |
| FAP-PT1 (%SUP)       | 36.83    | 27.95   | 34.52       | 39.13       |
| FAP-PT2 (%SUP)       | 88.12    | 8.55    | 87.42       | 88.82       |
| FML-PT1 (%SUP)       | 59.26    | 17.00   | 57.86       | 60.66       |
| FLG-PT1 (%SUP)       | 38.51    | 12.82   | 37.45       | 39.56       |
| MAP-PT1 (%SUP)       | 52.07    | 23.83   | 50.11       | 54.04       |
| MML-PT1 (%SUP)       | 14.63    | 24.71   | 12.59       | 16.66       |
| MML-PT2 (%SUP)       | 65.01    | 27.07   | 62.78       | 67.24       |
| MLG-PT1 (%SUP)       | 43.49    | 26.03   | 41.34       | 45.63       |
| MLG-PT2 (%SUP)       | 47.76    | 38.16   | 44.62       | 50.91       |
| Magnitude            |          |         |             |             |
| FAP-PT1 (%BW)        | –11.81   | 4.68    | –12.19      | –11.42      |
| FAP-PT2 (%BW)        | 8.15     | 4.80    | 7.76        | 8.55        |
| FML-PT1 (%BW)        | 10.39    | 3.66    | 10.09       | 10.70       |
| FLG-PT1 (%BW)        | 87.69    | 6.95    | 87.12       | 88.27       |
| MRT-PT1 (%BWm)       | 4.681    | 1.386   | 4.567       | 4.795       |
| MAP-PT1 (%BWm)       | –2.958   | 1.161   | –3.054      | –2.863      |
| MML-PT1 (%BWm)       | 0.780    | 0.779   | 0.716       | 0.844       |
| MML-PT2 (%BWm)       | –3.706   | 1.663   | –3.843      | –3.569      |
| MLG-PT1 (%BWm)       | –0.622   | 0.331   | –0.650      | –0.595      |
| MLG-PT2 (%BWm)       | 0.283    | 0.260   | 0.262       | 0.305       |
Table 10
Mean and standard deviation (SD) as well as lower and upper limits of 95% confidence interval (CI) of the spatio-temporal gait characteristics, loading boundaries and loading extremum (PT1, PT2, PT3) when fitted with basic components during ascending stairs (GC: Gait cycle, F: Force, M: Moment, AP: Antero-posterior, ML: Medio-lateral, LG: Long, BW: Bodyweight, SUP: Support).

| Spatio-temporal gait characteristics | Mean | SD  | 95%CI-Lower | 95%CI-Upper |
|--------------------------------------|------|-----|-------------|-------------|
| Cadence (Strides/min)                | 45   | 5   | 42          | 48          |
| Gait cycle (s)                       | 1.33 | 0.17| 1.31        | 1.34        |
| Swing (s)                            | 0.70 | 0.09| 0.69        | 0.71        |
| Support (%GC)                        | 53   | 4   | 52          | 53          |
| Swing (s)                            | 0.63 | 0.12| 0.61        | 0.64        |
| Support (%GC)                        | 47   | 4   | 47          | 48          |

| Loading boundaries                   |      |     |             |             |
|--------------------------------------|------|-----|-------------|-------------|
| Minimum                              |      |     |             |             |
| FAP (%BW)                            | −2.95| 2.68| −3.26       | −2.63       |
| FML (%BW)                            | −0.46| 0.61| −0.53       | −0.39       |
| FLG (%BW)                            | −2.26| 2.23| −2.52       | −2.00       |
| MAP (%BWm)                           | −1.964| 0.919| −2.070     | −1.857      |
| MML (%BWm)                           | −0.753| 0.388| −0.798     | −0.708      |
| Maximum                              |      |     |             |             |
| FAP (%BW)                            | 6.79 | 3.48| 6.39        | 7.20        |
| FML (%BW)                            | 10.23| 3.78| 9.79        | 10.67       |
| FLG (%BW)                            | 100.43| 9.28| 99.35       | 101.51      |
| MAP (%BWm)                           | 0.625| 0.550| 0.561     | 0.689       |
| MML (%BWm)                           | 1.298| 1.042| 1.177     | 1.419       |
| MLG (%BWm)                           | 0.320| 0.242| 0.292     | 0.348       |

| Loading extremum                     |      |     |             |             |
|--------------------------------------|------|-----|-------------|-------------|
| Onset                                |      |     |             |             |
| FAP-PT1 (%SUP)                       | 13.38| 14.51| 11.70      | 15.07       |
| FAP-PT2 (%SUP)                       | 86.71| 5.99 | 86.01      | 87.40       |
| FML-PT1 (%SUP)                       | 58.94| 23.07| 56.26      | 61.63       |
| FLG-PT1 (%SUP)                       | 42.01| 18.97| 39.80      | 44.22       |
| MAP-PT1 (%SUP)                       | 47.01| 24.82| 44.13      | 49.90       |
| MML-PT1 (%SUP)                       | 60.54| 28.20| 57.26      | 63.82       |
| MLG-PT1 (%SUP)                       | 32.88| 29.35| 29.46      | 36.29       |
| MLG-PT2 (%SUP)                       | 66.89| 30.53| 63.34      | 70.44       |
| Magnitude                            |      |     |             |             |
| FAP-PT1 (%BW)                        | −2.89| 2.74 | −3.21      | −2.57       |
| FAP-PT2 (%BW)                        | 6.76 | 3.54 | 6.35       | 7.17        |
| FML-PT1 (%BW)                        | 10.23| 3.78 | 9.79       | 10.67       |
| FLG-PT1 (%BW)                        | 100.43| 9.28| 99.35      | 101.51      |
| MRT-PT1 (%BWm)                       | 2.513| 0.996| 2.397      | 2.628       |
| MAP-PT1 (%BWm)                       | −1.943| 0.964| −2.055     | −1.831      |
| MML-PT1 (%BWm)                       | 1.227| 1.111| 1.098      | 1.356       |
| MLG-PT1 (%BWm)                       | −0.257| 0.203| −0.281     | −0.233      |
| MLG-PT2 (%BWm)                       | 0.308| 0.255| 0.278      | 0.338       |
Table 11
Mean and standard deviation (SD) as well as lower and upper limits of 95% confidence interval (CI) of the spatio-temporal gait characteristics, loading boundaries and loading extremum (PT1, PT2, PT3) when fitted with basic components during descending stairs (GC: Gait cycle, F: Force, M: Moment, AP: Antero-posterior, ML: Medio-lateral, LG: Long, BW: Bodyweight, SUP: Support).

|                  | Mean  | SD   | 95%CI-Lower | 95%CI-Upper |
|------------------|-------|------|-------------|-------------|
| **Spatio-temporal gait characteristics** |       |      |             |             |
| Cadence (Strides/min) | 47    | 7    | 43          | 52          |
| Gait cycle (s)      | 1.27  | 0.22 | 1.24        | 1.30        |
| Swing (s)           | 0.61  | 0.10 | 0.60        | 0.62        |
| Support (%GC)       | 48    | 5    | 47          | 49          |
| Swing (s)           | 0.66  | 0.16 | 0.64        | 0.68        |
| Support (%GC)       | 52    | 5    | 51          | 53          |
| **Loading boundaries** |       |      |             |             |
| Minimum             |       |      |             |             |
| FAP (%BW)           | −10.50| 8.59 | −11.56      | −9.44       |
| FML (%BW)           | −0.73 | 1.14 | −0.87       | −0.59       |
| FLG (%BW)           | −0.66 | 1.03 | −0.79       | −0.54       |
| MAP (%BWm)          | −2.179| 0.920| −2.292      | −2.066      |
| MML (%BWm)          | −1.924| 1.899| −2.158      | −1.690      |
| MLG (%BWm)          | −0.398| 0.330| −0.439      | −0.357      |
| Maximum             |       |      |             |             |
| FAP (%BW)           | 2.92  | 3.32 | 2.52        | 3.33        |
| FML (%BW)           | 7.05  | 2.08 | 6.79        | 7.30        |
| FLG (%BW)           | 85.09 | 12.37| 83.56       | 86.61       |
| MAP (%BWm)          | 0.483 | 0.359| 0.439       | 0.527       |
| MML (%BWm)          | 1.511 | 1.177| 1.373       | 1.649       |
| MLG (%BWm)          | 0.383 | 0.240| 0.353       | 0.412       |
| **Loading extremum** |       |      |             |             |
| Onset               |       |      |             |             |
| FAP-PT1 (%SUP)      | 33.78 | 28.24| 30.30       | 37.26       |
| FML-PT1 (%SUP)      | 55.47 | 18.75| 53.16       | 57.78       |
| FLG-PT1 (%SUP)      | 51.78 | 16.95| 49.69       | 53.87       |
| MAP-PT1 (%SUP)      | 46.87 | 25.12| 43.78       | 49.97       |
| MML-PT1 (%SUP)      | 58.01 | 35.00| 53.70       | 62.32       |
| MLG-PT1 (%SUP)      | 56.28 | 33.20| 52.19       | 60.37       |
| Magnitude           |       |      |             |             |
| Onset               |       |      |             |             |
| FAP-PT1 (%BW)       | −10.50| 8.59 | −11.56      | −9.44       |
| FML-PT1 (%BW)       | 6.97  | 2.13 | 6.71        | 7.23        |
| FLG-PT1 (%BW)       | 85.09 | 12.37| 83.56       | 86.61       |
| MRT-PT1 (%BWm)      | 3.439 | 1.459| 3.259       | 3.619       |
| MAP-PT1 (%BWm)      | −2.157| 0.930| −2.271      | −2.042      |
| MML-PT1 (%BWm)      | −1.832| 1.978| −2.076      | −1.588      |
| MLG-PT1 (%BWm)      | −0.398| 0.330| −0.439      | −0.357      |
Fig. 1. Box plots showing low and high 95% confidence interval, mean and outliers of the spatio-temporal gait characteristics including cadence, duration of gait cycle (GC) as well as support and swing phases when fitted with basic components during walking.
Fig. 2. Box plots showing low and high 95% confidence interval, mean and outliers of the loading boundaries including minimum (Min) and maximum (Max) of forces and moments applied when fitted with basic components during walking.
Fig. 3. Mean and standard deviation of the pattern as well as dispersion (cross) and mean (circle) for first (red), second (blue) and third (green) local extremum of forces and moments for cohort of participants fitted with basic components during walking (N = 555 gait cycles).
Fig. 4. Box plots showing low and high 95% confidence interval, mean and outliers of the onset expressed in percentage of support phase (%SUP) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during walking.
Fig. 5. Box plots showing low and high 95% confidence interval, mean and outliers of the magnitude expressed in percentage of bodyweight (%BW, %BWm) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during walking.
Fig. 6. Box plots showing low and high 95% confidence interval, mean and outliers of the spatio-temporal gait characteristics including cadence, duration of gait cycle (GC) as well as support and swing phases when fitted with basic components during ascending ramp.
Fig. 7. Box plots showing low and high 95% confidence interval, mean and outliers of the loading boundaries including minimum (Min) and maximum (Max) of forces and moments applied when fitted with basic components during ascending ramp.
Fig. 8. Mean and standard deviation of the pattern as well as dispersion (cross) and mean (circle) for first (red), second (bleu) and third (green) local extremum of forces and moments for cohort of participants fitted with basic components (469 gait cycles) during ascending ramp.
Fig. 9. Box plots showing low and high 95% confidence interval, mean and outliers of the onset expressed in percentage of support phase (%SUP) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during ascending ramp.
Fig. 10. Box plots showing low and high 95% confidence interval, mean and outliers of the magnitude expressed in percentage of bodyweight (%BW, %BWm) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during ascending ramp.
Fig. 11. Box plots showing low and high 95% confidence interval, mean and outliers of the spatio-temporal gait characteristics including cadence, duration of gait cycle (GC) as well as support and swing phases when fitted with basic components during descending ramp.
Fig. 12. Box plots showing low and high 95% confidence interval, mean and outliers of the loading boundaries including minimum (Min) and maximum (Max) of forces and moments applied when fitted with basic components during descending ramp.
Fig. 13. Mean and standard deviation of the pattern as well as dispersion (cross) and mean (circle) for first (red) and second (blue) local extremum of forces and moments for cohort of participants fitted with basic components during descending ramp (N = 566 gait cycles).
Fig. 14. Box plots showing low and high 95% confidence interval, mean and outliers of the onset expressed in percentage of support phase (%SUP) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during descending ramp.
Fig. 15. Box plots showing low and high 95% confidence interval, mean and outliers of the magnitude expressed in percentage of bodyweight (%BW, %BWm) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during descending ramp.
Fig. 16. Box plots showing low and high 95% confidence interval, mean and outliers of the spatio-temporal gait characteristics including cadence, duration of gait cycle (GC) as well as support and swing phases when fitted with basic components during ascending stairs.
Fig. 17. Box plots showing low and high 95% confidence interval, mean and outliers of the loading boundaries including minimum (Min) and maximum (Max) of forces and moments applied when fitted with basic components during ascending stairs.
Fig. 18. Mean and standard deviation of the pattern as well as dispersion (cross) and mean (circle) for first (red) and second (blue) local extremum of forces and moments for cohort of participants fitted with basic components during ascending stairs (N = 284 gait cycles).
Fig. 19. Box plots showing low and high 95% confidence interval, mean and outliers of the onset expressed in percentage of support phase (%SUP) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during ascending stairs.
Fig. 20. Box plots showing low and high 95% confidence interval, mean and outliers of the magnitude expressed in percentage of bodyweight (%BW, %BWm) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during ascending stairs.
Fig. 21. Box plots showing low and high 95% confidence interval, mean and outliers of the spatio-temporal gait characteristics including cadence, duration of gait cycle (GC) as well as support and swing phases when fitted with basic components during descending stairs.
Fig. 22. Box plots showing low and high 95% confidence interval, mean and outliers of the loading boundaries including minimum (Min) and maximum (Max) of forces and moments applied when fitted with basic components during descending stairs.
Fig. 23. Mean and standard deviation of the pattern as well as dispersion (cross) and mean (circle) for first (red) local extremum of forces and moments for cohort of participants fitted with basic components during descending stairs (N = 253 gait cycles).
Fig. 24. Box plots showing low and high 95% confidence interval, mean and outliers of the onset expressed in percentage of support phase (%SUP) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during descending stairs.
Fig. 25. Box plots showing low and high 95% confidence interval, mean and outliers of the magnitude expressed in percentage of bodyweight (%BW, %BWm) of up to three local extremum (PT1, PT2, PT3) of forces and moments applied with basic components during descending stairs.
the box plot showing low and high 95% confidence interval, mean and outliers were created using SigmaPlot 11.

Acknowledgments

The author would like to express his gratitude to Dr Kerstin Hagberg, Dr Eva Haggstrom and Prof Rickard Branemark from Centre of Orthopaedic Osseointegration at Sahlgrenska University Hospital, in Göteborg, Sweden for their participation to the recruitment of participants and data collection.

The data collection and initial analysis was partially supported by the ARC Discovery Project (DP0345667), ARC Linkage Grant (LP0455481), a QUT Strategic Link with the Industry and IHBI Advanced Diagnosis in Medical Device Grant.

The post-data collection analysis conducted by Adj/Prof Laurent Frossard was partially supported by the Office of the Assistant Secretary of Defense for Health Affairs, through the Orthotics and Prosthetics Outcomes Research Program — Prosthetics Outcomes Research Award under Award No. W81XWH-16-1-0475. Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the Department of Defense.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] W. Lee, L. Frossard, K. Hagberg, et al., Kinetics analysis of transfemoral amputees fitted with osseointegrated fixation performing common activities of daily living, Clin. Biomech. 22 (6) (2007) 665—673.

[2] B. Helgason, H. Palsson, T.P. Runarsson, et al., Risk of failure during gait for direct skeletal attachment of a femoral prosthesis: a finite element study, Med. Eng. Phys. 31 (5) (Jun, 2009) 595—600.

[3] L. Frossard, N. Stevenson, J. Sullivan, et al., Categorization of activities of daily living of lower limb amputees during short-term use of a portable kinetic recording system: a preliminary study, Journal of Prosthetics and Orthotics 23 (1) (2011) 2—11.

[4] L. Frossard, N. Stevenson, J. Smeeathers, et al., Monitoring of the load regime applied on the osseointegrated fixation of a trans-femoral amputee: a tool for evidence-based practice, Prosthet. Orthot. Int. 32 (1) (Mar, 2008) 68—78.

[5] S.U. Raschke, M.S. Orendurff, J.L. Mattie, et al., Biomechanical characteristics, patient preference and activity level with different prosthetic feet: a randomized double blind trial with laboratory and community testing, J. Biomech. 48 (1) (Jan 2, 2015) 146—152.

[6] M.S. Orendurff, Literature review of published research investigating microprocessor-controlled prosthetic knees: 2010—2012, JPO J. Prosthetics Orthot. 25 (4S) (2013) 41—46.

[7] 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. 30 (7) (Sep, 2008) 825—833.

[8] OPRA Implant System Instructions for Use, 2016. https://www.accessdata.fda.gov/cdrh_docs/pdf8/H080004D.pdf.

[9] S.R. Koehler, Y.Y. Dhaher, A.H. Hansen, Cross-validation of a portable, six-degree-of-freedom load cell for use in lower-limb prosthetics research, J. Biomech. 47 (6) (Apr 11, 2014) 1542—1547.

[10] 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 15 (4) (2003) 135—142.

[11] L. Frossard, K. Hagberg, E. Hagstrom, et al., Load-relief of walking aids on osseointegrated fixation: instrument for evidence-based practice, IEEE Trans. Neural Syst. Rehabil. Eng. 17 (1) (Feb, 2009) 9—14.

[12] L. Frossard, K. Hagberg, E. Hagstrom, et al., Functional outcome of transfemoral amputees fitted with an osseointegrated fixation: temporal gait characteristics, Journal of Prosthetics and Orthotics 22 (1) (2010) 11—20.

[13] L. Frossard, E. Hagstrom, K. Hagberg, et al., “Load applied on a bone-anchored transfemoral prosthesis: characterisation of prosthetic components — a case study “, J. Rehabil. Res. Dev. 50 (5) (2013) 619—634.

[14] L. Frossard, N. Stevenson, J. Smeeathers, et al., Monitoring of the load regime applied on the osseointegrated fixation of a trans-femoral amputee: a tool for evidence-based practice, Prosthet. Orthot. Int. 32 (1) (Mar, 2008) 68—78.

[15] L. Frossard, D.L. Gow, K. Hagberg, et al., Apparatus for monitoring load bearing rehabilitation exercises of a transfemoral amputee fitted with an osseointegrated fixation: a proof-of-concept study, Gait Posture 31 (2) (Feb, 2010) 223—228.

[16] L. Frossard, L. Cheze, R. Dumas, Dynamic input to determine hip joint moments, power and work on the prosthetic limb of transfemoral amputees: ground reaction vs knee reaction, Prosthet. Orthot. Int. 35 (2) (Jun, 2011) 140—149.

[17] R. Dumas, R. Branemark, L. Frossard, Gait analysis of transfemoral amputees: errors in inverse dynamics are substantial and depend on prosthetic design, IEEE Trans. Neural Syst. Rehabil. Eng. 25 (6) (Jun, 2017) 679—685.

[18] S. Pather, S. Vertiést, P. Sondergeld, et al., Load characteristics following transfemoral amputation in individuals fitted with bone-anchored prostheses: a scoping review protocol, JBI Database System Rev. Implement Rep. 16 (6) (Jun, 2018) 1286—1310.