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# Gait variability and regularity of people with transtibial amputations☆

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ABSTRACT

Gait temporal-spatial variability and step regularity as measured by trunk accelerometry, measures relevant to fall risk and mobility, have not been well studied in individuals with lower-limb amputations. The study objective was to explore the differences in gait variability and regularity between individuals with unilateral transtibial amputations due to vascular (VAS) or nonvascular (NVAS) reasons and fall history over the past year. Of the 34 individuals with trans-tibial amputations who participated, 72% of the 18 individuals with VAS and 50% of the 16 individuals with NVAS had experienced at least one fall in the past year. The incidence of falls was not significantly different between groups. Variability measures included the coefficient of variation (CV) in swing time and step length obtained from an electronic walkway. Regularity measures included anteroposterior, medial-lateral and vertical step regularity obtained from trunk accelerations. When controlling for velocity, balance confidence and time since amputation, there were no significant differences in gait variability or regularity measures between individuals with VAS and NVAS. In comparing fallers to nonfallers, no significant differences were found in gait variability or regularity measures when controlling for velocity and balance confidence. Vertical step regularity ($p = 0.026$) was found to be the only significant parameter related to fall history, while it only had poor to fair discriminatory ability related to fall history. There is some indication that individuals who have experienced a fall may walk with decreased regularity and this should be explored in future studies.



## 1. Introduction

Individuals with lower-limb amputations have altered static postural sway and reduced capabilities for maintaining balance, which increase the risk of fall [1]. When using a prosthetic device, individuals with transtibial and transfemoral amputations have altered gait biomechanics which also contribute to fall risk. A study found that 52% of community-living persons with lower-limb amputations had fallen within the past year [2]. Previous studies have explored the variability and regularity of gait, step-to-step gait temporal-spatial changes over time or the regularity of trunk accelerometry signals, and the relationship of these measures to fall risk [3–6]. However, few studies have utilized these measures to categorize the gait of individuals with lower limb amputations.

In a commentary on the measurement of gait variability, Hausdorff suggested that "gait variability may serve as a sensitive and clinically relevant parameter in the evaluation of mobility, fall risk and the response to therapeutic interventions" [7]. The variability in stride-to-stride velocity has indicated age-related changes in gait [8,9]. Temporal-spatial gait variability measures have differentiated between patient groups, including fallers and non-fallers [4,10]. Recent research has focused on the use of accelerometers to measure lower trunk accelerations and to compute the between-step and between-stride signal regularity as a methodology of evaluating gait stability [11]. This measurement technology has been shown to be reliable in young and elderly adults and those at risk of falling [3,12]. Accelerometer regularity measures have shown to discriminate between fit and other clinical populations [3,13,14].

A few researchers have objectively measured the gait and balance characteristics of people with amputations, specifically using measures to differentiate the population based on fall history, or reason for amputation [15–17]. In a study comparing people with transtibial amputations who have fallen and not fallen, differences were measured in the variability of swing time duration of the prosthetic limb along with kinematic and kinetic measures. No other differences were found in gait temporal-spatial or variability measures [15]. Step and stride regularity have been

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shown to have good sensitivity and specificity in classifying the gait of transfemoral amputees as normal or pathological as defined by step time symmetry [17]. Step and stride regularity measures as measured by an accelerometer located at the thorax were able to discriminate between able-bodied and transfemoral amputees [17].

The primary function of the prescription of a lower limb prosthetic device is to provide increased stability and function. A better understanding of gait differences based on etiology of amputation or fall history may provide useful information to help guide prosthetic prescription or rehabilitation interventions. Individuals with amputations due to vascular reasons tend to be older, less healthy and have greater restrictions in mobility. In other populations, increased age has been shown to be related to an increase in fall risk and gait measures have been shown to differ between fallers and non-fallers [4,8–10]. Temporal-spatial gait variability, step and stride regularity as measured by accelerometry are measures that are relatively easy to obtain in a clinical setting. We must first establish that gait variability and regularity measures reflect the differences in mobility related to etiology of amputation or fall history.

Our primary objective was to explore the differences between temporal-spatial gait variability and accelerometer regularity measures in a group of individuals with transtibial amputations grouped according to reason for amputation and fall history. A secondary objective was to explore the relationship between gait variability and regularity to fall risk in people with transtibial amputations.

## 2. Methods

### 2.1. Participants

This study received ethical approval from the Research Ethics Board of the Capital District Health Authority. Participants were a sample of convenience, 34 of whom were recruited through the Department of Prosthetics at a tertiary rehabilitation centre. All participants were 18 years of age or older, had been fit with a lower-limb prosthesis for at least 6 weeks to help ensure accommodation to their device and were able to walk for a minimum of two minutes with or without additional walking aids. Participants were classified into 2 diagnostic groups based on the reason for amputations, vascular (VAS) or non-vascular (NVAS). VAS included amputations due to thrombosis or peripheral vascular disease, while NVAS included amputations due to trauma, cancer or congenital reasons. Participants were also classified by their 12 month fall history as either a faller, someone who has had 1 or more falls, or non-faller. A fall was described as an "event which caused you (or a part of your body other than your feet) to unintentionally end up on the ground or lower surface. Do not include falls that were due to an acute illness (stroke, seizure), violent blows or lost consciousness" [15,18]. All participants provided informed consent.

### 2.2. Procedure

Following informed consent, screening and recording of demographic and clinical data, balance confidence was obtained through the use of the Activities-specific Balance Confidence (ABC) Scale [19] which has been a validated measure for the lower-limb amputee population [20]. Gait temporospatial parameters were quantified with the GAITRite$^{TM}$ system (CIR Systems Inc., Clifton, NJ), a 6.1 m long and 0.6 m wide electronic walkway. Data were collected (80 Hz) and stored on a personal computer. The GAITRite system has been shown to be valid and reliable in healthy young and old adults [21,22]. The electronic walkway was placed in the middle of a 13 m walkway and participants walked eight times over the 13 m at their self-selected walking speed with other walking aids if normally used.

The acceleration of the trunk was simultaneously measured through the use of a triaxial piezoresistant accelerometer (Crossbow CXL04LP3 range ±4 g). The accelerometer was rigidly attached to a small plate and held in place on the participant's low back using a belt to reduce unwanted movement. It was aligned with the mediolateral direction level to the ground approximately at the L3 region of the spine similar to previous study protocols [11]. The accelerometer was connected to a lightweight (0.23 kg) battery powered data logger. Accelerometer data were sampled (200 Hz), stored to the data logger and downloaded following the gait assessment to a computer for analysis.

The accelerometer data were processed in Matlab 7.4 (The Mathworks Inc., Natick, MA, USA). Data were filtered with a low-pass zero phase Butterworth digital filter at 20 Hz. Accelerometer data were corrected for unwanted measurement of the gravity signal due to possible tilt of the sensor [23]. Each step was digitally identified and visually verified similar to Zijlstra et al. [24]. The steady-state portion of the gait signal was analyzed. The first and last 2 strides of each walking pass were removed from the accelerometer signal prior to processing to eliminate the acceleration and deceleration portion of the gait signal. Between-step and -stride regularity of the vertical (V), anterior–posterior (AP) and medial-lateral (ML) trunk acceleration was assessed through the use of unbiased autocorrelation procedures. This procedure correlates the acceleration time series signal with the overlapping portion of the same acceleration time series signal that has been phase shifted by one stride. Coefficient values range from 0.0 to 1.0 indicating no association to perfect replication or high gait regularity respectively. A full description of the unbiased autocorrelation mathematical procedure can be found elsewhere [11,25].

Gait temporal-spatial and variability parameters were obtained from the GAITRite$^{TM}$ system. Parameters included for analysis were average gait velocity, time spent in stance, swing, double support, and step length. Measures indicating gait variability included the coefficient of variation (CV) in step time, step length, swing time and double support time. CV was calculated for each participant as the standard deviation divided by the mean of the measure and expressed as a percentage. Gait CV step parameters were chosen based on some of their improved clinimetric properties over stride based measures [12], and so to allow comparison to previous studies on individuals with lower limb amputations [15]. Measures indicating gait regularity included for analysis were V, AP and ML step regularity values obtained from trunk accelerometer measures. These parameters were selected based on suggestions by Moe-Nilssen et al. due to higher reliability with step measures as compared to stride measures [12].

## 3. Statistical analysis

Statistical analyses were performed using SPSS version 15.0 (SPSS Inc., Chicago, IL). Descriptive statistics (means, medians,

**Table 1**
Demographic and clinical characteristics.

| | Diagnostic classification | | Fall history classification | |
|---|---|---|---|---|
| | VAS $N=18$ | NVAS $N=16$ | F $N=21$ | NF $N=13$ |
| Female/male | 7/11 | 5/11 | 7/14 | 5/8 |
| Age (years) | 66.7 (12.1) [40.1–89.4] | 57.0 (16.4) [24.4–83.8] | 64.0 (13.2) [40.1–89.4] | 59.1 (17.5) [24.4–85.8] |
| Body mass index (kg/m$^2$) | 28.7 (6.1) [21.0–38.2] | 29.2 (8.2) [17.6–57.1] | 27.9 (8.3) [17.6–57.1] | 30.6 (4.0) [25.7–37.7]$^{\dagger}$ |
| Amputated limb Right/left | 7/11 | 7/9 | 9/12 | 5/8 |
| Time since amputation (years) | 8.4 (9.3) [0.6–37.0] | 23.0 (21.5)$^{*}$ [0.5–70.4] | 10.8 (14.0) [0.5–59.3] | 22.5 (20.7) [0.9–70.4] |
| Type of prosthetic foot SACH/single or multiaxial/energy storing | 2/12/4 | 1 missing 2/7/6 | 2/14/5 | 1 missing 2/6/4 |
| ABC score | 71.6 (19.4) [31.3–96.3] | 85.0 (14.1)$^{*}$ [52.5–100.0] | 71.42 (19.40) [31.3–96.9] | 87.31 (11.21)$^{\dagger}$ [62.5–100.0]$^{\dagger}$ |

Mean (SD) and [range] or count. VAS: vascular related amputation; NVAS: non-vascular related amputation; F: one or more falls in the past year; NF: no falls in the past year.
$^{*}$ Significantly different from VAS ($p < 0.05$).
$^{\dagger}$ Significantly different from F ($p < 0.05$).