
# Gait deviations of people with a trans-femoral amputation, during “step by step” stair climbing.

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**Abstract**

The majority of people with a unilateral trans-femoral amputation (PTFA) use the step by step strategy for stair climbing. In this study, the methods of PTFA to ensure foot, stair step clearance are investigated. 19 reference subjects (REF) and 6 PTFA were equipped with reflective markers. Subjects walked up an instrumented staircase using step by step strategy. PTFA had a reduced, but not significantly smaller, minimum foot, stair edge clearance compared to REF. PTFA showed a significantly smaller peak knee flexion, a significantly more extended hip and a greater anteriorly tilted pelvis and trunk during trailing limb in swing in comparison to REF. PTFA showed a significantly reduced dorsiflexion on the sound side during single support or involved side swing respectively, when compared to REF. PTFA showed a significantly greater peak internal knee and hip extension moment of the sound side in comparison to REF during weight acceptance and pull up phases.For adequate foot, stair edge clearance; REF participants functionally shorten the trailing limb via an increased hip and knee flexion. PTFA are unable to use such “folding mechanism”. PTFA show therefore a greater pelvis and trunk anterior tilt, a more extended hip and even show a vaulting strategy of the sound side, during trailing limb swing. This may further lead to greater sound side hip and knee moments in PTFA in contrast to REF.

**Keywords** Stair climbing, amputation, trans-femoral, above-knee, step by step, compensation, toe clearance

## Introduction

The majority of people with a unilateral trans-femoral amputation (PTFA) use the step by step strategy (SbS) for stair climbing (Reid, Lynn et al. 2007) (Figure 1). The step over step (SoS) strategy, the most common stair climbing patter, in which both limb contribute contribute to the stair climbing task in an alternating fashion, typically cannot be facilitated by PTFA. Mainly due to the fact that most prosthetic knee joint do not generate a concentric joint moment to lift the person to the next stair step, or alternatively the user is not capable to substitute the needed concentric knee joint moment with a proximal concentric hip extending moment, which is needed e.g. in microprocessor controlled prosthetic knees with a dedicated stair climbing mode (Bellmann, Schmalz et al. 2012).In SbS the sound side is the leading limb, and the prosthetic side is the trailing one. Therefore the sound side is already exposed to higher loads, as the sound side has to perform a “Pull-up” each stair step climbed. Additionally we detected in case studies that there seem to be an increase in sound side knee and hip moments in PTFA when compared to reference group of unimpaired individuals (REF). Potentially compensations in PTFA to guarantee foot clearance during SbS stair climbing may be responsible for that. Similar to level walking (Johnson, De Asha et al. 2014), adequate foot clearance in swing is a prerequisite in stair climbing to prevent falls. In this study, the approaches of PTFA to ensure foot, stair step clearance when using the SbS strategy are investigated. The possible impact onto the sound side is discussed in addition.

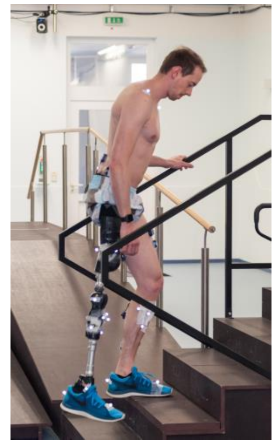


**Figure 1** Person with an trans femoral amputation climbing stairs with a step by step strategy

## Methods

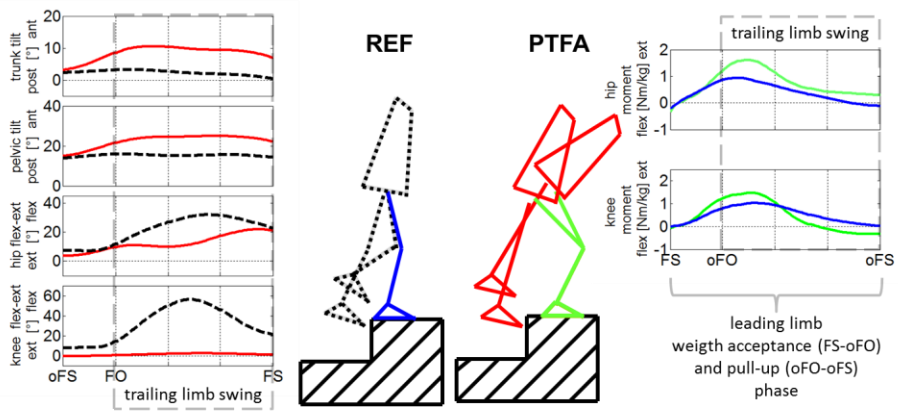
19 participants without an impairment served as reference subjects (REF / mean weight 74.5 ± 7.8kg; mean height 175.9 ± 7.8cm; mean age 27.4 ± 5.1 years) and 6 PTFA (76.0 ± 11.6kg; 179.5 ± 4.7cm; 36.2 ± 11.7 years) were equipped with reflective markers according to the Plugin-Gait model (Vicon, Oxford, UK). Four markers on the shoulder griddle were used to track trunk motion as described previously (Krautwurst, Wolf et al. 2013). A 12 camera motion capture system (Vicon, Oxford, UK) was utilized to track marker trajectories. Kinematics and kinetics were calculated in accordance to the Plugin-Gait model. Subjects walked up an instrumented staircase with 5 steps (AMTI force platforms for the left and right side, Watertown, USA). The Staircase had a width of 100cm, a 16cm step rise and a 27cm step run. All Subjects used the SbS strategy for stair climbing. Foot edge clearance was defined as the minimal distance between the Plugin-Gait TOE marker on the fore-foot and the stair edge of the climbed step. It is important to know that this does not reflect the true distance of the tip of the toe to the stair edge. However it is valid to analyse this distance as the TOE marker was placed similarly between all subjects. Parameters were compared using an independent samples Mann-Whitney U Test and the level of significance was set to $p<0.05$.

**Table1** Mean values of the trailing (involved side in PTFA) and the leading limb (sound side in PTFA); (parameters were compared using an independent samples Mann-Whitney U Test / level of significance was set to p<0.05)

| limb | parameter | PTFA N=6 | | REF N=19 | | PTFA vs REF |
|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | |
| trailing | minimum anterior foot marker clearance to stair edge in swing [mm] | **78.6** | (± 12.10) | **91.8** | (± 26.98) | p=0.303 |
| | peak knee flexion in swing [deg] | **2.8** | (± 3.81) | **56.4** | (± 8.04) | **p<0.001** |
| | peak hip flexion in swing [deg] | **9.0** | (± 5.20) | **15.1** | (± 4.74) | **p=0.011** |
| | peak anterior pelvic tilt in swing [deg] | **26.2** | (± 2.30) | **16.5** | (± 3.31) | **p<0.001** |
| | peak anterior trunk tilt in swing [deg] | **11.4** | (± 3.21) | **3.3** | (± 3.61) | **p<0.001** |
| leading | minimum dorsiflexion during single support in stance [deg] | **5.0** | (± 6.32) | **9.0** | (± 7.34) | **p<0.001** |
| | peak internal knee extension moment in stance [Nm/kg] | **1.33** | (± 0.26) | **0.97** | (± 0.19) | **p<0.001** |
| | peak internal hip extension moment in stance [Nm/kg] | **0.82** | (± 0.16) | **0.39** | (± 0.13) | **p=0.004** |

**Figure 2** Compensation strategy in individuals with a trans-femoral amputation (PTFA) for adequate toe clearance and its potential influence on sound side kinetics

(FS = foot strike; oFO = opposite foot off; oFS = opposite foot strike; FO = foot off)




## Results

PTFA had a reduced, but not significantly smaller, minimum foot/ stair edge clearance compared to REF and had a significantly smaller peak knee flexion, a more extended hip and a greater anteriorly tilted pelvis and trunk in comparison to REF. PTFA showed a significantly greater peak internal knee and hip extension moment of the sound side in comparison to REF during weight acceptance and pull up phases Further when compared to REF a significant reduction in minimum sound side dorsiflexion for the PTFA was evident during single support. See figure 2 and table 1 for specific results.

## Conclusion and discussion

For adequate foot/stair edge clearance, REF participants functionally shorten the trailing limb via an increased hip and knee flexion. PTFA are unable to use such “folding mechanism”. They show therefore a greater pelvis and trunk anterior tilt and a more extended hip, during trailing limb swing. Secondly we noticed a decreased sound side dorsiflexion in the PTFA during single support. In this case this is an additional possible compensation mechanism in order to increase stair step clearance. The trunk compensation may lead to greater sound side hip and knee moments in PTFA in contrast to REF. The “vaulting” compensation may lead to greater loads on the sound side ankle joint, which has to be proven in future studies.

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