

Plantar Pressures and Ground Reaction Forces During Walking of Individuals With Unilateral Transfemoral Amputation

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Objective: To describe and compare the plantar pressures, temporal foot roll-over, and ground reaction forces (GRFs) between both limbs of subjects with unilateral transfemoral amputation and with those of able-bodied participants during walking. We also verify the relevance of a force plate and a pressure plate to discriminate changes in gait parameters of subjects with limb loss.

Design: Cross-sectional study.

Setting: Biomechanics laboratory.

Subjects: A total of 14 subjects with unilateral transfemoral amputation and 21 able-bodied participants.

Methods: We used a force plate and a pressure plate to assess biomechanical gait parameters while the participants were walking at their self-selected gait speed.

Main Outcome Measurements: We measured plantar pressure peaks in 6 foot regions and the instant of their occurrence (temporal foot roll-over); and GRF peaks and impulses of anterior-posterior (braking and propulsive phases), medial-lateral, and vertical (load acceptance and thrust phases) components.

Results: The thrust, braking, and propulsive peaks, and the braking and propulsive impulses, were statistically significantly lower in the amputated limb than in the sound limb ($P < .05$) and in able-bodied participants ($P < .05$). In the amputated limb, we observed higher pressure peaks in the lateral rearfoot and medial and lateral midfoot, and lower values in the forefoot regions compared to those in the other groups ($P < .05$). The temporal foot roll-over showed statistically significant differences among the groups ($P < .05$).

Conclusions: The plantar pressures, temporal foot roll-over, and GRFs in subjects with unilateral transfemoral amputation showed an asymmetric gait pattern, and different values were observed in both of their lower limbs as compared with those of able-bodied subjects during walking. The force plate and pressure plate were able to determine differences between participants in gait pattern, suggesting that both plantar pressure and GRF analyses are useful tools for gait assessment in individuals with unilateral transfemoral amputation. Because of the convenience of pressure plates, their use in the clinical context for prosthetic management appears relevant to guide the rehabilitation of subjects with lower limb amputation.

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INTRODUCTION

As a consequence of the absence of a natural limb, subjects with unilateral transfemoral (TF) amputation often complain about pain in the sound limb (SL) [1]. They show a higher prevalence of osteoarthritis [2,3], scoliosis [4], and lumbar pain [5], as well as lower bone mineral density [4] and reduction in the ability to perform all desired tasks [6] compared to able-bodied (AB) subjects. Previous studies showed a longer stance phase and higher ankle, knee, and hip joint moments [7] and vertical ground reaction forces (GRFs) [7-9] in the SL compared with the amputated limb (AL) and AB subjects. These alterations in load distribution between lower limbs increase the risk of injuries such as anterior cruciate ligament

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tears [10] and knee joint osteoarthritis [3,9] in response to overload. Higher values for the step width [11] and displacement of the center of pressure in both limbs of the individuals with lower limb amputation compared to AB subjects have also been reported [12,13].

The prosthesis is limited in its mechanical functionality when the dynamic movement changes, resulting in movement-specific compensatory mechanisms in the residual joints and intact limb [14]. The alterations in gait features promoted by the adaptation to a prosthetic limb may cause or reinforce physical impairments. During the alignment process of the prosthesis and gait training in subjects with lower extremity amputation, a prosthetic foot roll-over as close as possible to the physiological foot [15] and bilateral symmetry [16] are pursued. This process is highly subjective and variable [17], leading to the need for instruments able to easily and reliably provide quantitative measurements of the gait of individuals with limb loss to help and improve the rehabilitation process [17].

The analysis of plantar pressures is considered clinically useful in identifying anatomical deformities on the foot, in guiding the diagnosis and treatment of gait disorders, and in preventing pressure ulcers [18,19]. The plantar pressure peak is the main parameter used in plantar pressure analysis, and reflects the highest pressure to occur in a specific region of the foot during the stance phase. The instant of the pressure peaks also can be calculated, allowing recognition of the sequence of recruitment of different regions of the foot (loosely referred to in the present study as temporal foot roll-over). However, the validity of the plantar pressure analysis is not yet well established, and its clinical applicability in the case of prosthetic feet is minimal. Geil and Lay [17] investigated the capacity of a plantar pressure analysis system to identify alterations in transtibial amputees' prosthetic alignment for clinical purposes. These authors observed that angular changes in the prosthetic alignment in the frontal plane produce predictable shifts in the plantar pressures between lateral and medial foot regions, concluding that plantar foot pressure analysis is a sensitive and feasible tool to help clinicians quantify gait parameters and the way in which these parameters are influenced by the prosthetic alignment [17].

Regarding the SL, although some studies have evidenced its overload during gait [1,7-9], to the best of our knowledge, the identification of the plantar pressure distribution pattern, temporal foot roll-over features, and specific overloaded regions were not yet addressed. This information may help clinicians to prevent plantar foot injuries such as blisters, callosity, or skin ulcerations by avoiding the development of regions with high pressure peaks, and may also guide gait training programs. The light-weight plantar pressure plates could be a feasible and practical way to record these data.

Information about mechanical stress can be obtained from vertical force analysis [20]. The vertical GRF provides the global aspect of the vertical forces, whereas the plantar pressure analysis informs about the distribution of this force

along the plantar surface of the foot [21]. The vertical GRF is related to joint contact forces and can therefore provide insights into the development of some pathological conditions, such as back pain and osteoarthritis [20]. Increased vertical forces represent a decreased capacity of the musculoskeletal system in absorbing the body loading during gait [22] and, as a consequence, express an increment on the likelihood of developing overuse injuries [23]. The anterior-posterior GRF informs about the friction between the sole and floor, relevant for assessing foot-related injuries (eg, blister or ulceration) and tendency to slip [24]. The medial-lateral GRF has been suggested to provide information about gait balance [23]. The GRF are influenced by gait speed, in which the increase of speed promotes linear increases in the GRF peaks [25] and decreases the GRF impulses [26]. In the present study, the GRF peaks and GRF impulses were calculated. Although the peak variables are widely used and inform about the highest forces experienced by the body, the impulse variables provide complementary information related to the amount of force received by the body during a given activity. Based on the viscoelastic properties of the musculoskeletal tissues, the peak variables appear to be more insightful in showing aggressive loads to the body. However, in terms of gait pattern and long-term adaptations, the impulse variables might also provide valuable information about the kinetic features of walking.

The GRFs provide global information about the vertical and shear stress forces, whereas the plantar pressure analysis identifies the distribution of the vertical GRF over the plantar foot surface [21]. The combination of both analyses provides more detailed and complementary information about specific features of forces acting on the prosthetic and the sound limbs. Such information might be useful in verifying the effects of adjustments in prosthesis components and different therapeutic approaches to gait performance. Hence, the aim of this study was to describe and compare plantar pressures, temporal foot roll-over, and GRF parameters between both limbs of subjects with unilateral TF amputation and with AB subjects during walking. The plantar pressure and GRF data were also analyzed to verify their relevance in determining differences between participants in gait parameters of individuals with unilateral TF amputation walking.

METHODS

This was a cross-sectional study with a convenience sample. This project was approved by the ethical board from the Professional Rehabilitation Center of Gaia (Arcozelo, Portugal), and all participants freely signed an informed consent based on the Declaration of Helsinki.

Subjects

Two groups of participants were analyzed. For the experimental group, patients with unilateral TF amputation were

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