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Functional gait asymmetry of unilateral transfemoral amputees

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ABSTRACT

The aim of prosthetic devices is to mimic the function of biological systems. Numerous investigations have demonstrated significant asymmetries in unilateral amputee gait. The underlying interactions of prosthetic and intact leg are not widely discussed, so far. To get more insight into the functionality of asymmetries, we investigated temporal and kinetic parameters of walking transfemoral amputees wearing the computerized C-Leg and the non-computerized 3R80.

Experiments were conducted on an instrumented treadmill at four different walking speeds (0.5, 0.8, 1.1, 1.4 m/s) measuring vertical and horizontal ground reaction forces. Single support, double support and contact times, vertical and horizontal impulses as well as their asymmetry factors were calculated.

Gait patterns were similar for both prosthetic knee joints, manifesting in (i) reduced stance times of the prosthetic leg, (ii) prolonged load transfer during double support from intact to prosthetic leg at lower speeds, (iii) reduced vertical and horizontal impulses of the prosthetic leg, (iv) net accelerating horizontal impulses during contact of the prosthetic leg, (v) missing impacts at touch-down of the prosthetic leg.

Our results suggest that deficits of the prosthetic leg like missing active knee extension and ankle push-off are compensated by the intact leg. The altered touch-down configuration for the prosthetic

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leg enables it to provide forward propulsion while load bearing is largely shifted to the intact leg.

1. Introduction

The fundamental aim of prosthetic devices is to mimic the function of biological systems. In case of the human lower limb, it is desired to restore functional and stable gait pattern. Especially for unilateral amputees, gait symmetry is an important goal to prevent excessive loading of the intact leg, which is caused by compensating the missing functionality of the prosthetic leg (Nolan & Lees, 2000; Nolan et al., 2003), such as missing knee extension and active ankle push-off. To achieve gait symmetry, the functionality of the prosthesis needs to replace the functionality of a healthy leg. Another way to achieve gait symmetry would be that the intact leg was forced to copy the reduced functionality of the prosthetic leg which does not strike as the preferred solution.

During stance in walking, the main requirement for stable leg function is to avoid knee buckling while the leg is loaded. At the end of the stance phase, knee flexion is required to facilitate pre-swing (Lipfert, 2010), and during swing, knee flexion provides the necessary ground clearance. For transfemoral amputees, the transition between load support during stance and knee flexion during swing can be achieved with modern prostheses, which change their knee joint function based on mechanical conditions. This can be realized either mechanically (e.g. 3R80, Otto Bock Health Care GmbH, Duderstadt, Germany) or by feedback control using sensory information (e.g., C-Leg, Otto Bock; Rheo Knee, Össur, Reykjavik, Iceland; ProprioFoot, Össur).

Based on microprocessor technology, the functionality of prosthetic devices can be enhanced. The C-Leg, for example, controls the function of the knee joint during swing phase as well as during the stance phase. By measuring the angle and angular velocity of the knee joint and the bending moment of the shank, the C-Leg detects specific phases within the gait cycle and adjusts the corresponding resistance. Here, advantages in metabolic cost, gait smoothness, symmetry and speed adaptability are proclaimed (Cochrane, Orsi, & Reilly, 2001; Dietl, Kaitan, Pawlik, & Ferrara, 1998; Michael, 1999). Those are, however, only partially supported in literature. While improvements in swing phase kinematics are indicated when walking with the C-Leg at a self selected speed (Johansson, Sherrill, Riley, Bonato, & Herr, 2005; Kastner, Nimmervol, & Wagner, 1999; Orendurff et al., 2006; Segal et al., 2006), the advantages in leg function during stance phase are less obvious. Kastner et al. (1999) compared the function of the C-Leg with two other knee joints (3R80 and 3R45, Otto Bock) and found similar patterns of vertical ground reaction force (GRF) between both prosthetic knee joints (PKJs). Also, the differences in contact times between both sides remained unchanged with the two PKJs. In fact, the asymmetry of vertical GRF parameters was even slightly higher for the C-Leg than the other two prosthetic knee joints (PKJ). This was also found by Segal et al. (2006) and related to shorter step lengths with the C-Leg as compared to the other investigated PKJ (Mauch SNS, Össur, Reykjavik, Iceland). Johansson et al. (2005) showed a decrease in both positive and negative hip work with the C-Leg. The sensory feedback provided by the C-Leg seems to reduce the effort of the hip muscles, which are typically used by transfemoral amputees to secure the knee joint during stance. However, main deficits in the leg function such as the missing knee flexion during stance, a deficit in most modern knee prostheses (Cochrane et al., 2001), are still remaining. Although the C-Leg allows knee flexion under load, most amputees do not use this feature in walking on level ground (Johansson et al., 2005; Kaufman et al., 2007; Segal et al., 2006). The reason for this is not well understood.

With few exceptions (Kastner et al., 1999; Nolan et al., 2003), the majority of previous studies was constrained to the individually preferred walking speed. Nolan et al. (2003) found decreased asymmetry in temporal parameters and increased asymmetry in vertical GRF with higher speed for transfemoral amputees. In general, they reported less speed adaptation of the prosthetic leg compared with the intact leg.