Trunk movement compensations and corresponding core muscle demand during step ambulation in people with unilateral transtibial amputation

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ABSTRACT

The objective of this investigation was to identify demands from core muscles that corresponded with trunk movement compensations during bilateral step ambulation in people with unilateral transtibial amputation (TTA). Trunk rotational angular momentum (RAM) was measured using motion capture and bilateral surface EMG was measured from four bilateral core muscles during step ascent and descent tasks in people with TTA and healthy controls. During step ascent, the TTA group generated larger mediolateral ($P = 0.01$) and axial ($P = 0.01$) trunk RAM toward the leading limb when stepping onto the intact limb than the control group, which corresponded with high demand from the bilateral erector spinae and oblique muscles. During step descent, the TTA group generated larger trunk RAM in the sagittal ($P < 0.01$), frontal ($P < 0.01$), and transverse planes ($P = 0.01$) than the control group, which was an effect of falling onto the intact limb. To maintain balance and arrest trunk RAM, core muscle demand was larger throughout the loading period of step descent in the TTA group. However, asymmetric trunk movement compensations did not correspond to asymmetric core muscle demand during either task, indicating a difference in motor control compensations dependent on the leading limb.

1. Introduction

Rehabilitation following transtibial amputation (TTA) aims to maximize functional independence by retraining movement patterns during gait to lower the risk of secondary overuse injuries, such as low back pain (LBP) (Cutson and Bongiorni, 1996). Although the underlying mechanisms behind the development of LBP following amputation remains idiopathic, asymmetric trunk movement patterns are known to increase the risk of LBP (Kumar, 2001; McGill, 2007). Trunk movement asymmetry during gait is often associated with asymmetric core muscle demand, which can indicate poor control of the trunk muscles (Tsao et al., 2008).

Muscle demand is associated with the net joint moments during gait, which represent the net agonist and antagonist muscle activity spanning joints (Winter, 1984; Sanderson and Martin, 1997; Powers et al., 1998; Bateni and Olney, 2002). Thus, clinicians target interventions to minimize asymmetric trunk compensations adopted in the absence of ankle plantarflexion after TTA. However, rehabilitation in people with dysvascular TTA is exceedingly complex due to common neurovascular comorbidities and poor physical health (Cutson and Bongiorni, 1996), which compounds the risk of LBP (Shiri et al., 2010).

To achieve independence of mobility, people with TTA must daily perform high-demand functional tasks that increase the demand on the musculoskeletal system compared to level-ground walking, such as step ambulation (Nadeau et al., 2003; De Laat et al., 2013). To maximize early functional recovery, people with TTA may initially adopt a movement pattern ascending steps by leading with the intact limb and descend steps leading with the amputated limb (Schmalz et al., 2007; Barnett et al., 2014). Even when rehabilitation has completed, habitual disuse of the amputated limb may continue. In addition, during both step ascent and descent, people with TTA typically adopt a "quadriceps avoidance" strategy, which improves trunk and pelvic stability, and has been linked with a forward trunk lean (although not directly measured) (Schmalz et al., 2007). We recently associated changes in trunk kinematics with large low back internal extension moments in people with TTA compared to healthy participants during step ambulation (Murray et al., 2017). However, the muscle demand resulting from trunk movement compensations during stepping tasks after TTA remains unknown. In addition, it is unknown if motor control patterns, as evidenced by muscle activation patterns, differs when leading with intact versus amputated limbs during stepping tasks.

We previously quantified asymmetric trunk movement

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compensations in people with TTA using segmental angular momentum during walking (Gaffney et al., 2016). Through Newton-Euler mechanics, momentum is embedded within the three common descriptors of human movement (kinematics, kinetics, and neuromuscular control) (Gaffney et al., 2017). We have used RAM to describe movement compensations in patients with TTA because it provides a measure that is clinically interpretable and more sensitive than traditional observational analyses, which lacks sensitivity and standardization (Coutts, 1999; Toro et al., 2003; Shull et al., 2014), particularly when assessing movement in the lumbopelvic region outside of level walking. Patients with TTA generated larger amount of trunk RAM during over ground walking, which is dependent upon the angular velocity of that segment, and associated to a change in segment position (i.e. range of motion). Through the inclusion of speed and mass, and because segmental RAM is foundational in joint moments calculated via inverse dynamics (Gaffney et al., 2017), which represent the net effect of all agonist and antagonist muscle activity spanning a joint, we interpreted our previous findings of larger asymmetric generation of segmental RAM to potentially correspond with movement strategies that result in high asymmetric eccentric muscle demand needed to arrest segmental momentum. However, it is not clear that asymmetric generation of momentum corresponds with asymmetric muscle demand. Furthermore, it is unknown how asymmetric movements quantified using segmental RAM correspond to muscle demand during stepping tasks, which are more difficult than level-ground walking for this population.

The primary objective of this investigation was to identify demands from core trunk/pelvis muscles (bilateral erector spinae, external oblique, gluteus maximus, and gluteus medius) that correspond with trunk movement compensations, quantified with segmental RAM, during step ascent and descent in people with unilateral TTA. The secondary objective was to establish if asymmetric movements (trunk RAM that is asymmetric and different than that of the HC group) corresponded with asymmetric core muscle demand. We hypothesized that trunk movement compensations adopted by people with TTA would correspond with higher muscle demand than seen in healthy individuals with symmetrical trunk movement. We also hypothesized that differences across limbs in the TTA group would identify motor control patterns that were habituated following amputation.

2. Methods

2.1. Participants

Ten male participants with unilateral dysvascular TTA and ten male healthy control (HC) participants were enrolled (Table 1). Eligibility criteria included: BMI ≤ 40 kg/m^2, age: 50-–85 years, independent community amputation (ability to walk for four minutes without rest or assistive device); 1-–3 years post amputation (TTA group); controlled Type-II diabetes (TTA group); no traumatic or cancer-related amputation cause (TTA group); no major amputation on contralateral limb (TTA group); no cardiovascular, orthopaedic, or neurologic wounds, or ulcers that limit physical function; no history of LBP (HC group); no diagnosed rheumatoid arthritis (HC group); no diagnosed osteoarthritis (HC group); and no total hip/ knee joint arthroplasty (HC group).

Each participant visited the laboratory for one data collection in which whole body kinematics and core muscle activity were collected during bilateral stepping tasks. Three of the ten TTA participants were

unable to perform the tasks bilaterally, and were excluded from the analysis along with the corresponding control of each patient. Each participant provided written, informed consent in accordance with the Colorado Multiple Institutional Review Board.

2.2. Instrumentation and experimental protocol

Each participant was instrumented with 63 reflective markers used to obtain whole-body kinematics during step ascent and descent (Gaffney et al., 2016). Marker trajectories were recorded from eight infrared cameras surrounding the motion capture volume (100 Hz sampling frequency) (Vicon, Centennial, CO).

Core muscle activity was recorded from round bipolar Ag/AgCl surface electrodes (inter-electrode distance: 1cm; CMRR > 100 db) (Vermed, Buffalo, NY) placed on the bilateral lumbar erector spinae (ES), external oblique (OBL), gluteus maximus (GMAX), and gluteus medius (GMED) according to SENIAM guidelines (2000 Hz sampling frequency) (Merletti and Hermens, 2000) (Measurement Systems Inc., Livonia, MI). A ground electrode was placed at the C7 vertebrae. Prior to electrode placement, the skin was prepared by shaving and lightly abrading using sterilizing alcohol wipes. Maximum voluntary contractions (MVCs) for these muscles were measured across three trials for approximately three seconds each. For ES MVCs, each participant laid prone and were instructed to extend their trunk while resisting a downward force applied at the shoulders. For OBL MVCs, each participant was seated and instructed to rotate their trunk while resisting a force opposite the direction of the axial rotation applied at the ipsilateral shoulder of the OBL of interest. For GMAX MVCs, each participant laid prone and were instructed to extend their hip while resisting a downward force applied above the knee. For GMED MVCs, each participant laid side-lying and were instructed to abduct their hip while resisting a downward force applied above the knee.

Each participant performed three step ascent and descent trials with each limb onto a 20-cm platform. Each participant instructed to begin the task from a standstill, ascend/descend by leading with the limb instructed, and complete the task in a bilateral standstill. The TTA group was instructed to first perform the task leading with the limb that was most commonly taught in movement retraining (ascent: leading with intact limb; descent: leading with amputated limb), and then was instructed to perform the task leading with the contralateral limb. The HC group was first instructed to perform the task leading with the dominant limb (right limb for all participants), and then instructed to perform the task leading with the non-dominant limb. To limit the potential confounding effect of assistive device use across groups, handrail use was not provided during the ascent/descent tasks. No instructions were provided regarding the speed at which to complete each task.

2.3. Data analysis

Trunk movements were quantified using RAM and muscle demand was quantified using surface EMG measured from the four bilateral core muscles. Kinematic data were low-pass filtered with a 4th-order Butterworth filter (6 Hz cutoff frequency). A 15-segment subject-specific model was created in Visual 3D and used for analysis (C-Motion, Inc., Germantown, MD).

Trunk RAM is described as:

Table 1

Participant characteristics for patients with dysvascular unilateral transtibial amputation (TTA) and healthy control (HC) groups. *Indicates significant difference in age across groups ($P < 0.05$).

Group	Age (Years)	BMI (kg/m^2)	Time since amputation (Months)	Residual limb length (cm)	Socket type	Prosthetic foot
TTA	56.3 ± 4.5*	28.3 ± 2.7	16.7 ± 5.2	14.4 ± 2.9	Total contact carbon fiber	Dynamic elastic response
HC	64.6 ± 5.5*	27.4 ± 3.3	N/A	–	–	–