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Comparison of the Power Knee and C-Leg during step-up and sit-to-stand tasks

Erik. J. Wolf [a,*], Vanessa Q. Everding [a,1], Alison A. Linberg [a,2], Joseph M. Czerniecki [b,c,3], COL Jeffrey M. Gambel [a,4]

[a] Walter Reed National Military Medical Center, Department of Orthopaedics and Rehabilitation, Bethesda, MD, United States
[b] Seattle Veterans Administration Medical Center, Seattle, WA, United States
[c] Department of Rehabilitation Medicine, University of Washington, Seattle, WA, United States

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ABSTRACT

For U.S. military service members with transfemoral amputations there are different prosthetic knee systems available that function differently. For example the C-Leg® (C-Leg, Otto Bock Healthcare, GmbH, Duderstadt, Germany) is a passive microprocessor knee, and the Power Knee™ (PK, Ossur, Reykjavík, Iceland) provides active positive power generation at the knee joint. This study examined both step-up and sit-to-stand tasks performed by service members using C-Leg and PK systems to determine if the addition of positive power generation to a prosthetic knee can improve symmetry and reduce impact to the remaining joints. For both tasks, average peak sagittal knee powers and vertical ground reaction forces (GRFs) were greater for the intact limb versus the amputated limb across PK and C-Leg groups. For the sit-to-stand task, peak knee power of the amputated limb was greater for PK users versus C-Leg users. Vertical GRFs of the intact limb were greater for the C-Leg versus the PK. The performance of the PK relative to the C-Leg during a STS task illustrated few differences between components and no effect on the intact limb.

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1. Introduction

U.S. military service members who have sustained a transfemoral amputation as a result of their involvement in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) are a cohort of young adults, many of whom are capable of high function. These "tactical athletes" may be among those most likely to benefit from the expanded performance capabilities claimed by powered prostheses. Powered prostheses may also be advantageous for those with limited function or strength deficits.

The restoration of functional mobility in persons with transfemoral amputation has been limited in part by an absence of prosthetic knees that provide positive power generation to simulate the concentric function of the quadriceps. The Power Knee™ (PK, Ossur, Reykjavík, Iceland) represents the first commercial attempt to restore these functional characteristics. The PK technology purports to not only enhance safe and efficient level walking but also to further augment users' capabilities during ambulation on stairs and inclines, as well as performance of transfer functions (sit-to-stand). Active propulsion may also help reduce compensatory loads on the non-amputated (intact) limb and prevent secondary injuries.

Secondary musculoskeletal disability in amputees may be related to excessive loading of musculoskeletal structures. Asymmetrical gait and compensatory actions by amputees may cause pain, specifically in lower extremity joints and the back. Multiple studies reported that 50–52% of amputees reported back pain and 19–25% reported that pain as severe [1,2]. Another study reported increased forces on the intact limb at higher walking speeds [3]. This increased force could account for joint pain and degeneration, as well as development of osteoarthritis [2–9].

Previous research has shown that a microprocessor knee is not only preferred but also more functional than a mechanical knee [9]. Studies have demonstrated increased performance descending stairs with the C-Leg (C-Leg, Otto Bock Healthcare, GmbH, Duderstadt, Germany) versus a mechanical knee [9,10]. The C-Leg has also outperformed other microprocessor knees, offering

* Corresponding author at: Walter Reed National Military Medical Center, America Building #19, Room B320, 8901 Rockville Pike, Bethesda, MD 20889, United States. Tel.: +1 301 400 2082.

E-mail addresses: erik.wolf@med.navy.mil, erik.wolf1@gmail.com (Erik. J. Wolf), vanessa.gatmaitan@med.navy.mil (V.Q. Everding), alison.linberg@med.navy.mil (A.A. Linberg), joseph.czerniecki@va.gov (J.M. Czerniecki), jeffery.m.gambel.mil@health.mil (C.J.M. Gambel).

[1] CAREN Operator, Walter Reed National Military Medical Center, America Building #19, Room B328, United States.

[2] DoD-VA Extremity Trauma and Amputation Center of Excellence (EACE), Walter Reed National Military Medical Center, America Building #19, Room B315, 8901 Rockville Pike, Bethesda, MD 20889, United States.

[3] Regional Amputation Center, VA Puget Sound Health Care System, 1660 S. Columbian Way, Seattle, WA 98108, United States.

[4] Department of Orthopaedics and Rehabilitation, Walter Reed National Military Medical Center, America Building #19, Room 1604, 8901 Rockville Pike, Bethesda, MD 20889, United States.

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greater functionality and safety, including decreased loading of the contralateral limb during stair and ramp ascent [11]. Published research testing the PK is sparse; however one study reported improved walking speed and step length [12]. A case study that focused on the task of standing presented reduced sound limb knee and hip moments during a sit-to-stand task while wearing the PK compared to wearing the C-Leg [13].

The sit-to-stand (STS) task is often used in clinical assessments to measure the functional level of a person [14]. It is considered "the most mechanically demanding functional task routinely undertaken during daily activities" [15]. Stair climbing is a functional task that poses a significant challenge to those with transfemoral amputation. These individuals commonly employ a "step to" pattern where they step up with the intact extremity and then bring the prosthetic up to that step. This is the result of absent quadriceps like function on the prosthetic knee. The step-up (SU) task has been used to simulate a stair ascent task [16,17], and is also functionally relevant because it simulates the functional task of stepping up a curb. It has not however been used to study the biomechanical characteristics or adaptations of function for those with amputation.

1.1. General and specific aims

The objective of this study was to examine if there are functional and clinically relevant differences among users of the PK compared with the C-Leg. The specific aim was to determine if the use of the either knee unit results in more normal and symmetrical kinematics and kinetics during SU and STS tasks. We hypothesized that (1) for the SU task, subjects would demonstrate improved symmetry in knee kinetics while using the PK as opposed to the C-Leg; and that (2) for the STS task, subjects would demonstrate improved symmetry in limb loading while using the PK as opposed to the C-Leg.

2. Methods

Approval to conduct this study was granted by the Institutional Review Board. Ten service members with unilateral transfemoral amputations and 10 non-injured controls were recruited to participate in this study. Inclusion criteria for subjects included a comfortable total surface bearing suction seal socket as a part of an existing C-Leg prosthetic system; independence as a community ambulator without an assistive device other than a prosthesis; and no contralateral limb injuries or co-morbidities that significantly affected gait, joint range of motion, or limb muscle activity. A crossover study design was used to evaluate differences between knees. Following informed consent, the first five subjects were organized into the PK user group (Group A). The second five were organized into the C-Leg user group (Group B).

Group A subjects were fit with a custom PK prosthetic system and given six-weeks of training which taught users to navigate inclines/declines and stairs, transfer from a sitting to a standing position, and walk on level ground. The training was carried out by a physical therapist that had expertise in use of the PK.

Subjects in Group B began in their existing C-Leg prosthetic system and received six weeks of C-Leg specific training with a physical therapist on the same basic tasks as Group A. This six-week period allowed participants to become familiar with the prosthetic systems and allowed for observation of the impact of the tested knee technologies on mobility. At the end of the six-week period, data were collected from each subject, in their assigned prosthetic system. Participants from Group A were returned to their C-Leg prosthetic system and participants from Group B were fit with custom PK fitting prosthetic knee systems. Training specific to each knee resumed for both groups for another six weeks. Data were again collected at the end of these six weeks from each subject in their assigned prosthetic system.

Four platforms, each with a height of 20 cm, were used for the SU task (Fig. 1). Step Platforms 1, 3, and 4 were arranged around Step Platform 2, which was placed on an instrumented force platform, to provide an even surface for the subject. Step Platforms 1, 3, and 4 were not instrumented. All subjects were instructed to begin with one foot on Force Plate 1 and the other foot on the floor beside it. They were then asked to initiate a single upward step from Force Plate 1 onto Step Platform 2. The trailing foot followed onto Step Platforms 1 or 3, depending on the side of the trailing foot. The subject was asked to continue with a step onto Step Platform 4. The motion was completed when both of the subject's feet were on Step Platform 4. This motion was repeated five times initiating with the right leg, and five times initiating with the left leg. Rest intervals were taken as needed on an individual basis to avoid fatigue effects.

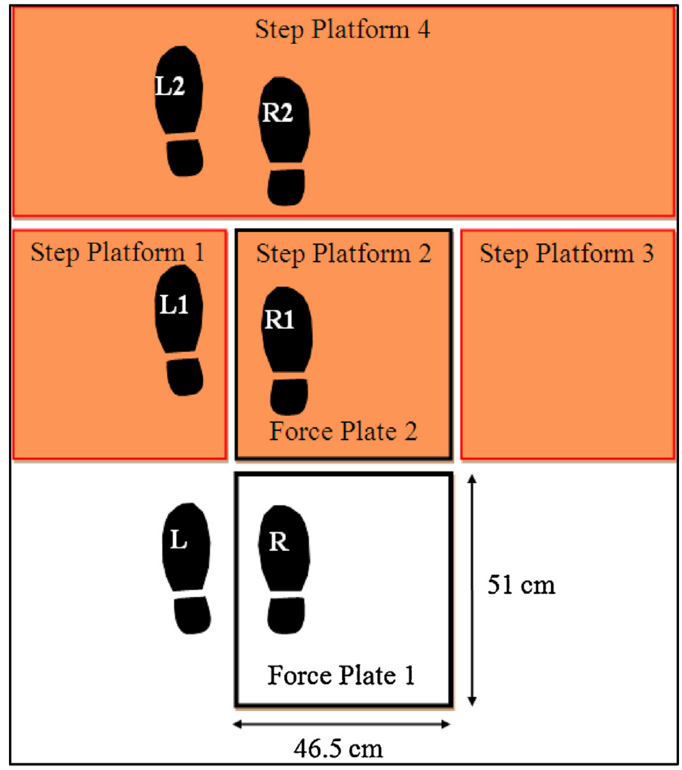

Fig. 1. Example of platform configuration for a right step up. The black footprints indicate foot placement; L indicates a left foot placement and R indicates a right.

For the STS task, subjects were instructed to sit on a stable, backless, armless stool placed adjacent to two force plates. The height of the seat was adjusted to match the height of the center of rotation of the intact knee such that a 90° angle was formed between the thigh and the intact shank. Subjects were instructed to place one foot on each force plate and then to rise to a standing position with their hands placed on their hips. Fig. 2 displays a snapshot of (a) a test subject and (b) a control subject performing the STS task. Subjects were asked to repeat this task eight times. Rest intervals were taken as needed on an individual basis to avoid fatigue effects.

A 23 camera Vicon motion capture system (Vicon, Oxford, UK) with two instrumented force plates (AMTI Corp, Watertown, MA) was used to capture lower body and trunk kinematics along with ground reaction forces for both tasks. Kinematic and kinetic data were simultaneously collected at 120 Hz and 1200 Hz respectively using Vicon Nexus software (Vicon, Oxford, UK) and processed using Visual 3D (C-Motion, Germantown, MD). For the SU task, the capture interval began when the initiating foot left Force Plate 1 and ended when that same foot left Force Plate 2. For the STS task, the capture interval began with the initiation of standing and ended with its completion. Initiation was defined by forward motion of the trunk, and completion was defined by the first instance of fully upright posture [18]. Kinematic and kinetic data were filtered with a bi-directionally passed, 2nd order, Butterworth filter at 6 Hz and 50 Hz, respectively. Average peak sagittal joint powers (hip, knee, and ankle), as well as vertical GRFs were compared for the amputated and intact limbs of the PK and C-Leg groups. Peak data were extracted between the times when the subject broke contact with the stool until the prosthetic knee reached full extension. This end point was used as a time when the subject had completed the standing action and had begun to assume a standing posture. Joint powers were examined to provide clinical significance and to directly assess the design intentions of the powered prosthesis. Symmetry in these measures, between the amputated and intact limbs of the PK and C-Leg groups, was calculated using the symmetry index (Eq. (1)) [19]. This provided a symmetry index ranging from −200 to 200 where a value of zero represents perfect symmetry.

$$\mathrm{SI} = \frac{\mathrm{intact} - \mathrm{affected}}{0.5 \times (\mathrm{intact} + \mathrm{affected})} \times 100 \tag{1}$$

A one-factor repeated measures analysis of variance (ANOVA) was performed to determine if there were limb (intact vs. amputated), knee device (PK vs. C-Leg), and/or limb by device interaction effects. Where an interaction effect was significant, a post hoc paired samples t-test was used to determine whether there were differences between knee devices within each limb. Paired samples t-tests were