Clinical Biomechanics 27 (2012) 460–465

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Gait asymmetry of transfemoral amputees using mechanical and microprocessor-controlled prosthetic knees

Kenton R. Kaufman [a,*], Serena Frittoli [a,b], Carlo A. Frigo [b]

[a] Mayo Clinic, Motion Analysis Laboratory, 200 First Street SW, Rochester, MN 55905, USA
[b] Polytechnic Institute of Milan, Bioengineering Department, via Golgi, 39, 20133 Milan, Italy

ARTICLE INFO

Article history:
Received 24 May 2011
Accepted 30 November 2011

Keywords:
Amputee
Artificial limbs
Gait
Knee
Microprocessor

ABSTRACT

Background: Amputees walk with an asymmetrical gait, which may lead to future musculoskeletal degenerative changes. The purpose of this study was to compare the gait asymmetry of active transfemoral amputees while using a passive mechanical knee joint or a microprocessor-controlled knee joint.

Methods: Objective 3D gait measurements were obtained in 15 subjects (12 men and 3 women; age 42, range 26–57). Research participants were longtime users of a mechanical prosthesis (mean 20 years, range 3–36 years). Joint symmetry was calculated using a novel method that includes the entire waveform throughout the gait cycle.

Findings: There was no significant difference in hip, knee and ankle kinematics symmetry when using the different knee prostheses. In contrast, the results demonstrated a significant improvement in lower extremity joint kinetics symmetry when using the microprocessor-controlled knee.

Interpretation: Use of the microprocessor-controlled knee joint resulted in improved gait symmetry. These improvements may lead to a reduction in the degenerative musculoskeletal changes often experienced by amputees.

1. Introduction

Mobility is an important aspect of an individual's quality of life. Walking is more difficult for transfemoral amputees to perform because they need to depend on an artificial limb for body weight support and gait mobility. Walking biomechanics is altered with the use of prosthesis. The gait of persons with a unilateral transfemoral amputation is asymmetrical (Jaegers et al., 1995). Altered load distribution may lead to back and/or intact limb pain (Burke et al., 1978; Ephraim et al., 2005) osteoarthritis in the intact limb (Burke et al., 1978; Kulkarni et al., 1998), osteopenia/osteoporosis in the residual limb (Kulkarni et al., 1998), and other musculoskeletal problems (Ephraim et al., 2005). These degenerative changes can prevent the performance of everyday tasks and lead to a reduction in the quality of life.

Prosthetic knee joints for unilateral transfemoral amputees have undergone many design improvements over the past three decades. At present, transfemoral amputee prosthetic knee control is achieved through either mechanical mechanisms (non-microprocessor knee, NMPK) or microprocessor controls (MPK) (Michael, 1999). Mechanical mechanisms include single axis, constant-friction, weight activated, stance-phase control knee joints; single-hinge fluid-controlled (pneumatic or hydraulic) knee systems (with fluid swing phase control and variable methods of stance stability); and polycentric knee components that allow designers to optimize stance and swing features. Microprocessor controls regulate knee joint dynamics through analysis of several kinematic and kinetic variables, allowing more precise adjustment of knee resistance and providing the user to walk in more demanding situations such as descending stairs, step over step, or traversing a hillside.

For the above-knee amputee, the prosthetic knee joint is a critical component because it plays a complex role by providing stability in the absence of knee extensors. Several studies have compared various outcomes associated with the use of different prostheses. Most studies reported a benefit when using a MPK including lower oxygen/energy consumption (Johansson et al., 2005; Perry et al., 2004), increased walking velocity (Hafner et al., 2007; Orendurff et al., 2006; Perry et al., 2004), reduction in stumble and falls (Hafner et al., 2007; Orendurff et al., 2006; Segal et al., 2006), improved performance on stairs (Orendurff et al., 2006) and hill descent (Hafner et al., 2007), capability to adapt to any walking speed (Orendurff et al., 2006), and decreased cognitive effort (Hafner et al., 2007; Heller et al., 2000). Studies have reported kinetics and kinematics closer to the normal knee (Kaufman et al., 2007) and increased satisfaction (Hafner et al., 2007; Kaufman et al., 2008) when using a MPK. In other studies, no significant difference in the walking speed (Segal et al., 2006) or in the cognitive demand (Heller et al., 2000) was reported between the two prostheses.

* Corresponding author.
E-mail address: kaufman.kenton@mayo.edu (K.R. Kaufman).

0268-0033/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2011.11.011

Asymmetry, or lack of symmetry, appears to be a relevant aspect for differentiating a normal and pathological gait. Several methods have been used to determine asymmetry between the lower limbs. Gait asymmetry is often described as a ratio of the kinematic or kinetic parameters between the right and left sides. This has most often been assessed by calculating a symmetry index (SI) (Robinson et al., 1987), a ratio index (RI) (Ganguli et al., 1974), or a symmetry angle (SA) (Zifchock et al., 2008). All these indices have major limitations because these ratios are reported as a single point in the gait cycle. Gait asymmetry has also been reported as the difference between parameters recorded on the two limbs using a t-test, MANOVA, variance ratios (Winter and Yack, 1987), principal component analysis (Sadeghi, 2003), correlation coefficients (Arsenault et al., 1986), coefficients of variation (Hershler and Milner, 1978), cross-correlation, and root-mean-square (RMS) difference measures (Haddad et al., 2006). Unfortunately, these statistical tests do not provide a measurement of the asymmetry magnitude. Accordingly, it is not possible to quantify the asymmetry effect.

The purpose of this study was to compare the gait symmetry of active transfemoral amputees while using a passive mechanical knee joint (NMPK) or a microprocessor-controlled knee (MPK) joint. Unlike previous studies, this study used the entire gait waveform rather than a limited set of points from the gait cycle. Specifically, we looked at the effect of the prosthetic knee component on the kinematic and kinetic characteristics of walking on flat, level ground. We hypothesized that the patient would have improved gait symmetry when wearing a MPK compared to a NMPK.

2. Methods

2.1. Subjects

The protocol was approved by the Institutional Review Board at the Mayo Clinic. These subjects were recruited on a volunteer basis. The experimental procedures were explained to the subjects and consent was obtained prior to enrollment into the study. Before inclusion in the study, an experienced ABC certified prosthetist, certified by Otto Bock Healthcare to properly fit the MPK, examined each amputee. The prosthetist verified that the socket fit was comfortable, the overall mechanical function of the prosthesis was sound and properly aligned for stability and comfort, and the attachment mechanism of the prosthetic knee to the prosthetic socket would accommodate the Otto Bock C-Leg, First Generation. Inclusion criteria to participate in this study were unilateral transfemoral amputation, age 18 years and older, amputation for any reason, at least two years' experience using a prosthesis, Medicare Functional Classification Level 3 or 4, utilization of a passive mechanical prosthetic knee, no significant fluctuation in stump volume within the last 6 months, no other neuromuscular problems or a partial amputation of the contralateral limb, no acute illness or chronic illness, assistive aids for ambulation, and no dialysis. Control subjects were recruited by word of mouth. All control subjects were screened for previous or current back, hip, knee, or ankle joint disease, pain, or injury; previous lower limb fractures; lower limb injury and/or laxity; circulatory or neurologic conditions; or any other disease or injury that may have affected their gait patterns. No restrictions were placed on gender or race for either cohort.

2.2. Study design

The study employed a repeated-measures experimental design whereby only the prosthetic knee joint was changed. The independent variable in this study was the type of prosthetic knee. The design and function of the prosthetic knee is of particular importance because it is the most proximal artificial joint that the amputee must stabilize and control to effectively ambulate (Hafner et al., 2007). The same socket, suspension, and prosthetic foot were used for both studies to eliminate any confounding effect of these variables. The inertial characteristics of the limb were unchanged for the two prosthetic knees. Subjects were tested in an array of domains, including gait biomechanics, balance, energy expenditure, activity level, and prosthetic evaluation questionnaires. Only the gait symmetry is reported in this article. Results of the balance (Kaufman et al., 2007) as well as the energy expenditure and activity level (Kaufman et al., 2008) assessments are published elsewhere.

Data collection was performed over two sessions. During the first session, subjects performed three walking trials at a comfortable, self-selected pace along a 20 m gait pathway with the NMPK. The speed averaged 1.11 m/s (SD = 0.22 m/s). At the end of the first session, the knee joint in the subject's prosthesis was exchanged for a MPK. Subjects were instructed to use the MPK until they felt their gait had stabilized with the new prosthesis. The acclimation time averaged 18 weeks (SD = 8 weeks). Subjects returned to the gait laboratory for a second data collection session while wearing the MPK prosthesis. Data were again collected at the self-selected pace. Speed averaged 1.19 m/s (SD = 0.23 m/s). This acclimation period is similar to the time reported by other studies (Hafner and Smith, 2009; Kahle et al., 2008). All subjects completed the full protocol with each type of knee prosthesis.

2.3. Fitting and alignment of prosthesis

Alignment of the prosthesis is the relative position and orientation of the prosthetic components and affects comfort, function, and cosmesis. Improper alignment can contribute to poor socket fit, and would result in undesirable pressure distribution at the residual limb/socket interface which would cause discomfort, pain, and potentially tissue damage (Yang et al., 1991). Further, poor alignment can cause difficulty with flexing or stabilizing the knee. Alignment was quantified using the Otto Bock Laser Assisted Static Alignment Reference (LASAR) system (Blumentritt, 1997).

2.4. Gait analysis

Kinematic parameters were acquired with a computerized video motion analysis system utilizing ten infrared cameras (EvaRT 4.0, Motion Analysis Corporation, Santa Rosa, CA, USA). The spatial distribution of the cameras was optimized to yield reliable motion data at the hip, knee, and ankle, bilaterally. The motion capture system recorded and processed the locations of passive reflective markers placed at bony prominences for establishing anatomic coordinate systems for the pelvis, thigh, shank, and foot. A modified Helen Hayes marker configuration was used. One set of data corresponding to the standing position (static data) were recorded in order to calculate the location of the joint centers. Ground reaction forces were measured using four force plates (two AMTI and two Kistler) embedded in a 10 m walkway synchronized to the video system. Kinematic and ground reaction force data were collected at 120 and 360 Hz, respectively. The 3D marker coordinates and force plate data were used as input to a commercial software program (OrthoTrak 5.0, Motion Analysis Corp., Santa Rosa, CA, USA) to calculate the 3D joint kinematics and kinetics. Gait cycle periods were selected by heel strike to heel strike events. Timing of all intra-cycle gait events was expressed as a percentage of the gait cycle, irrespective of the actual time for a stride, to yield a normalized gait cycle (Kaufman et al., 2007).

2.5. Symmetry index

The symmetry index compared the kinematics and kinetics of the non-prosthetic leg (NPL) to the prosthetic leg (PL) for each type of prosthesis used. The symmetry index was calculated during the stance and swing phase of the gait cycle for each subject (Shorter et al., 2008). The method utilized expanded the method proposed by