Clinical Biomechanics 28 (2013) 898–903

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Compensation by nonoperated joints in the lower limbs during walking after endoprosthetic knee replacement following bone tumor resection

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ARTICLE INFO

Article history:
Received 12 April 2013
Accepted 20 August 2013

Keywords:
Bone tumor
Gait
Knee endoprosthesis

ABSTRACT

Background: Endoprosthetic knee replacement is often used to preserve joint function in patients with bone tumors of the distal femur or proximal tibia. Recently, because of improved oncologic outcome, surgeons are focusing more on the functional outcome of patients with musculoskeletal tumors. We hypothesized that patients who have undergone endoprosthetic knee replacement are forced to compensate for deficiency in their operated joint during walking. In this study, we investigated differences in gait kinematics, kinetics, and energetics between patients with endoprosthetic knee replacement and healthy subjects.
Methods: We performed gait analysis for 8 patients who underwent endoprosthetic knee replacement after bone tumor resection and 8 matched healthy subjects. Gait kinematics, kinetics, and energetics of patients' ipsilateral and contralateral limbs were compared with those of healthy subjects by using Dunnett's test.
Findings: Compared with healthy subjects, patients showed increased negative joint power around the ipsilateral ankle, greater second peak in the contralateral vertical ground reaction forces, and abnormal hip movement on both sides after initial contact.
Interpretation: Patients tended to compensate for dysfunction of the reconstructed knee by muscles around the ipsilateral ankle and contralateral hip, with increased load on the contralateral limb during walking. These differences could lead to secondary impairments. Further analysis, including musculoskeletal simulation and assessment of long-term functional outcome with regard to secondary musculoskeletal impairment, is needed to verify the significance of the change in gait and to determine the need for special care for secondary musculoskeletal dysfunction in these patients.

1. Introduction

Endoprosthetic knee replacement is often used to preserve joint function in patients with bone tumors of the distal femur or proximal tibia. Recently, surgeons are focusing more on the functional outcome of patients with musculoskeletal tumor because of improved oncologic outcome (Whelan et al., 2011) with the help of advanced diagnostic imaging, chemotherapeutic agents, and surgical techniques. For orthopedic surgeons, gait function is one of the most important components of functional outcome in patients treated for a tumor in the lower extremity. Previous studies have reported slower walking speed (Carty et al., 2009; De Visser et al., 2000; Otis et al., 1985), longer step length of the nonoperated limb (Rompen et al., 2002), and decreased foot pressure (Tsuboyama et al., 1994), all of which can be attributed to insufficient muscle strength around the reconstructed knee.

These patients have to compensate for deficiency of the reconstructed joint by using muscles around adjacent or contralateral joints during walking. This compensation can be quantitatively evaluated by analyzing gait kinematics (e.g., joint angular movement), kinetics (e.g., ground reaction forces and internal joint moment), and energetics (e.g., joint power). However, because there is little knowledge on how joint kinematics, kinetics, and energetics change after endoprosthetic knee replacement following bone tumor resection, it is difficult to consider the potential overload on musculoskeletal tissue around the lower limb joints other than the reconstructed knee. Previous studies have

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http://dx.doi.org/10.1016/j.clinbiomech.2013.08.005

suggested the possibility of increased load on nonoperated joints during locomotion after bone or joint reconstruction (Beaulieu et al., 2010; Foucher and Wimmer, 2012; Taddei et al., 2011). The aim of this study was to verify compensation by nonoperated joints during walking in patients who underwent endoprosthetic knee replacement following bone tumor resection by evaluating differences in lower limb gait biomechanics between patients and healthy subjects.

2. Methods

2.1. Study design

This was a single-center, cross-sectional study based on measurements obtained from a group of patients and a group of healthy control subjects. Patients aged >15 years who underwent endoprosthetic knee replacement after bone tumor resection, were without neurologic musculoskeletal pathology that affected gait function, and were routinely followed-up at Kyoto University Hospital were included. Exclusion criteria were concurrent metastasis, local recurrence, unstable implant, period of less than 1 year since last surgery, daily use of walking aid or orthopedic shoes, and more than 3 cm of discrepancy in limb length. All eligible patients were asked to participate in the study at the outpatient clinic, and, if they agreed to be part of the study, measurements were obtained at a motion analysis laboratory on another day. After collecting the patients' data, we recruited matched healthy subjects whose data were compared with the patients' data. All procedures were approved by the Ethical Review Board of Kyoto University Graduate School of Medicine, and written informed consent was obtained from all subjects.

2.2. Data collection and processing

We performed gait analysis using a 7-camera 3-dimensional motion analysis system (Vicon MX; Vicon, Oxford, United Kingdom) with 2 force plates (9286A; Kistler Japan, Tokyo, Japan). All participants (patients and healthy subjects) walked along a 6-m walkway at a self-selected speed with 35 retroreflective markers on their body landmarks, according to the Plug-in Gait protocol (Vicon). All healthy subjects also walked at a slightly slower speed because patients who have undergone endoprosthetic knee replacement may walk more slowly than healthy subjects (Carty et al., 2009; De Visser et al., 2000; Otis et al., 1985). The walking speed of each healthy subject (either self-selected or slower) that was closer to the mean walking speed of the patients was used in analysis. At least 5 successful trials were collected for each walking speed (self-selected for both groups and slower for healthy subjects) to assure repeatability of the results. Data were collected at a sampling rate of 100 Hz for marker trajectories and 1000 Hz for force plates.

Marker trajectories were filtered using a Woltring filter (Woltring, 1986), with a mean-squared error value of 10. Joint kinematics and kinetics were generated using inverse dynamics analysis within Nexus version 1.7.1 software (Vicon). Joint moments were filtered using a 0-lag fourth-order Butterworth filter. Joint powers were calculated from the dot product of the joint angular velocities and joint moments on the sagittal plane. Joint moments and powers were normalized to body weight and height. Joint power is the energy generated (positive value) or absorbed (negative value) around a joint per unit of time. All data were processed using Nexus software and MATLAB 2012a (MathWorks, Natick, MA).

2.3. Statistical methods

Walking speeds were reported as the mean and SD for patients and healthy subjects. Ground reaction forces, joint angles, joint moments, and joint powers were averaged for each of 3 groups (ipsilateral and contralateral sides of the patients, and the right side of healthy subjects). We compared the joint kinematic, kinetic, and energetic parameters described in Table 1 between the 3 groups using Dunnett's multiple comparison test, performed on R version 2.41.0 (R Development Core Team, http://www.R-profect.org) with an R library multcomp (Hothorn et al., 2008), setting the right side of healthy subjects as the control group. Significance was set at $P < .05$. The patients' ipsilateral limb was not compared with the contralateral limb because the presence of a compensatory mechanism cannot be determined by comparing data obtained from the same patient. All graphics were generated by R.

3. Results

Of 17 eligible patients, 9 were excluded: because of implant instability in 3, daily use of crutches or a cane in 2, metastasis in 1, and refusal to participate in 3. Finally, 8 patients (mean [SD, range] age, 30 [12, 19–59] years; height, 1.67 [0.7, 1.58–1.78] m; weight, 59.9 [20.2, 45.0–108.5] kg) who underwent endoprosthetic knee replacement following bone tumor resection participated in this study at a mean (SD) of 91 (41) months after primary endoprosthetic replacement. Demographic data of the patients are shown in Table 2. Of the 8 patients, 6 had osteosarcoma, 1 had giant cell tumor, and 1 had chondrosarcoma. Five patients had a tumor in the distal femur and 3 in the proximal tibia. Four patients had undergone revision surgery; only a femoral component had been replaced in 1, only a tibial component had been replaced in 1, and all components had been replaced in 2. All patients were continuously disease free and could walk without an assistive device. Three types of endoprosthesis were used for reconstruction: Kyocera Limb Salvage System (KYOCERA Medical Corp., Osaka, Japan) in 3 patients, Howmedica Modular Resection System (Stryker Orthopaedics, Mahwah, NJ) in 3, and Japan Medical Materials K-MAX KNEE System K-5 (KYOCERA

Table 1
Kinematic, kinetic, and energetic gait parameters of interest.

Name	Description
Ground reaction forces	
GF1	Max. aft force
GF2	Max. fore force
GF3	Max. vertical force during early stance
GF4	Max. vertical force during late stance
Joint angles	
H1	Hip flexion at initial contact
H2	Max. hip flexion during early stance
H3	Max. hip extension
H4	Max. hip flexion during swing
H5	H2–H1
K1	Knee flexion at initial contact
K2	Max. knee flexion during early stance
K3	Knee flexion at toe-off
K4	Max. knee flexion during late stance
A1	Ankle dorsiflexion at initial contact
A2	Max. plantarflexion during early stance
A3	Max. dorsiflexion during stance
A4	Ankle plantarflexion at toe-off
Internal joint moments	
HM1	Max. hip extension moment during stance
HM2	Max. hip flexion moment during stance
KM	Max. knee extension moment during early stance
AM1	Max. dorsiflexion moment during stance
AM2	Max. plantarflexion moment
Joint powers	
HP1	Max. hip joint power during early stance
HP2	Min. hip joint power during late stance
KP1	Min. knee joint power during early stance
KP2	Max. knee joint power during early stance
AP1	Min. ankle joint power
AP2	Mean negative ankle power during stance
AP3	Max. ankle joint power

Abbreviations: Max., maximum; Min., minimum.