Gait & Posture 38 (2013) 79–85

Contents lists available at SciVerse ScienceDirect

Gait & Posture

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

Trunk muscle action compensates for reduced quadriceps force during walking after total knee arthroplasty

Katherine Li [a], David C. Ackland [a], Jodie A. McClelland [b], Kate E. Webster [b], Julian A. Feller [b,c], Richard de Steiger [c], Marcus G. Pandy [a,*]

[a] Department of Mechanical Engineering, University of Melbourne, Parkville, Victoria 3010, Australia
[b] Musculoskeletal Research Centre, LaTrobe University, Bundoora, Victoria 3080, Australia
[c] Epworth HealthCare, Richmond, Victoria 3121, Australia

ARTICLE INFO

Article history:
Received 14 May 2012
Received in revised form 11 October 2012
Accepted 27 October 2012

Keywords:
Joint replacement
Gait biomechanics
Musculoskeletal model
Muscle function

ABSTRACT

Patients with total knee arthroplasty (TKA) frequently exhibit changes in gait biomechanics post-surgery, including decreased ranges of joint motion and changes in joint loading; however, the actions of the lower-limb muscles in generating joint moments and accelerating the center of mass (COM) during walking are yet to be described. The aim of the present study was to evaluate differences in lower-limb joint kinematics, muscle-generated joint moments, and muscle contributions to COM accelerations in TKA patients and healthy age-matched controls when both groups walk at the same speed. Each TKA patient was fitted with a posterior-stabilized total knee replacement and underwent patellar resurfacing. Three-dimensional gait analysis and subject-specific musculoskeletal modeling were used to determine lower-limb and trunk muscle forces and muscle contributions to COM accelerations during the stance phase of gait. The TKA patients exhibited a 'quadriceps avoidance' gait pattern, with the vasti contributing significantly less to the extension moment developed about the knee during early stance ($p = 0.036$). There was a significant decrease in the contribution of the vasti to the vertical acceleration (support) ($p = 0.022$) and forward deceleration of the COM (braking) ($p = 0.049$) during early stance; however, the TKA patients compensated for this deficiency by leaning their trunks forward. This significantly increased the contribution of the contralateral back extensor muscle (erector spinae) to support ($p = 0.030$), and that of the contralateral back rotators (internal and external obliques) to braking ($p = 0.004$). These findings provide insight into the biomechanical causes of post-operative gait adaptations such as 'quadriceps avoidance' observed in TKA patients.

1. Introduction

Total knee arthroplasty (TKA) is the most widely used treatment for restoring knee function in patients with end-stage osteoarthritis. Increased demand for TKA procedures, driven by increased prevalence of arthritic disease in the aging population, has resulted in a three-fold increase in primary TKA procedures since 1990 [1]. It is projected that the number of TKA procedures in the United States will increase to 3.5 million by 2030 [2]. While positive results have been reported, including reduced pain, improved joint mobility and increased patient satisfaction [3], gait aberrations are frequent following TKA procedures [4,5].

TKA patients have been shown to walk with a smaller range of knee-joint motion and hence a reduced knee extension moment during stance compared to healthy control subjects [6,7]. This adaptation, often referred to as a 'quadriceps avoidance' gait pattern, has been demonstrated in patients with a variety of knee replacement designs, for example, posterior-stabilized components [5]. While a number of factors are thought to contribute to abnormal knee-joint function post-operatively, including reduction in knee proprioception, changes in the quadriceps moment arm, atypical muscle electromyographic (EMG) activity, and the presence of various residual characteristics of pre-operative gait [8–11], the causes and effects of altered post-operative gait biomechanics are not well understood, and the implications for long-term patient outcomes remain unknown.

Knee-joint function in TKA patients is commonly assessed using isokinetic and isometric strength measurements [8,12,13] as well as three-dimensional gait analysis (see [5] for a review). Clinical gait analysis of TKA patients tends to focus almost exclusively on measurement of lower-limb joint kinematics and net joint moments [9,14]. Few studies have considered the role of the

* Corresponding author. Tel.: +61 3 8344 4054; fax: +61 3 9347 8784.
E-mail address: pandym@unimelb.edu.au (M.G. Pandy).

0966-6362/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gaitpost.2012.10.018

trunk in TKA gait, and little is known about how TKA affects lower-limb muscle function; specifically, the ability of the lower-limb muscles to accelerate the center of mass (COM) of the body in the vertical and fore-aft directions, or alternatively, to generate vertical support and modulate forward progression, respectively.

The objective of the present study was to combine three-dimensional gait analysis and musculoskeletal modeling to quantify differences in muscle function during walking between TKA patients and healthy aged-matched controls. The specific aims were to determine in these two populations the contributions of the individual muscles to the net joint moments developed about the back, hip, knee and ankle during the stance phase of walking, and to identify those muscles that contribute most significantly to vertical support and forward progression. Understanding how muscle function during gait varies between healthy individuals and TKA patients may help to explain the biomechanical causes of commonly observed post-operative adaptations such as 'quadriceps avoidance'.

2. Methods

Gait data for 14 TKA patients (age: 67 ± 7 years; height 171.9 ± 10.6 cm; mass: 88.9 ± 15.9 kg) and 14 healthy controls (age: 67 ± 7 years; height 169.2 ± 8.2 cm; mass: 80.5 ± 10.2 kg) were selected retrospectively from a larger database consisting of 40 TKA patients and 40 controls, each walking at their self-selected speed [7]. Specific trials were chosen for analysis in order to match walking speed at 1.30 m/s between the two groups (1.31 ± 0.03 m/s for the TKA patients and 1.30 ± 0.04 m/s for the controls). The speed of 1.30 m/s was chosen because it produced the largest number of speed-matched subjects between the two groups. All TKR patients underwent bi-lateral arthroplasty by an experienced knee surgeon (J.A.F.) between August 2004 and July 2006. TKA patients were posterior-cruciate-ligament-deficient and received a Genesis-II posterior-stabilized prosthesis (Smith and Nephew, Memphis, TN, USA) with patellar resurfacing. Gait data were collected 12 months post-operatively. All TKA patients were able to walk at least 10 m without an aid, and had no documented orthopedic, neurological or visual impairments that may have affected their gait, including hip and ankle joint replacements. The control subjects had no symptoms of osteoarthritis and had not undergone joint replacement surgery. Approval for the study was obtained from the relevant Human Research Ethics Committees, and written informed consent was provided according to the Committees' guidelines.

All subjects underwent three-dimensional gait analysis as described previously [15]. Fifteen reflective markers were attached to each subject according to the modified Helen Hayes marker set [16]. Joint kinematics was measured using an 8-camera video motion analysis system (Vicon, Oxford Metrics Ltd., Oxford), while ground reaction forces (GRF) were recorded simultaneously using two instrumented force platforms (Kistler, Switzerland and Advanced Mechanical Technology Inc., Watertown, MA). Video and analog force-plate data were sampled at 100 Hz and 1000 Hz, respectively. Marker data were filtered with a low-pass, fourth-order Butterworth filter using a cut-off frequency of 4 Hz.

A three-dimensional musculoskeletal model of the body was used to calculate lower-limb muscle forces during gait [17]. The skeleton was represented as a 10-segment, 23 degree-of-freedom linkage system. The head, arms and torso (HAT) were modeled as a single rigid body that articulated with the pelvis via a ball-and-socket back joint. Each hip was modeled as a ball-and-socket joint, each knee as a translating hinge joint, each ankle-subtalar complex

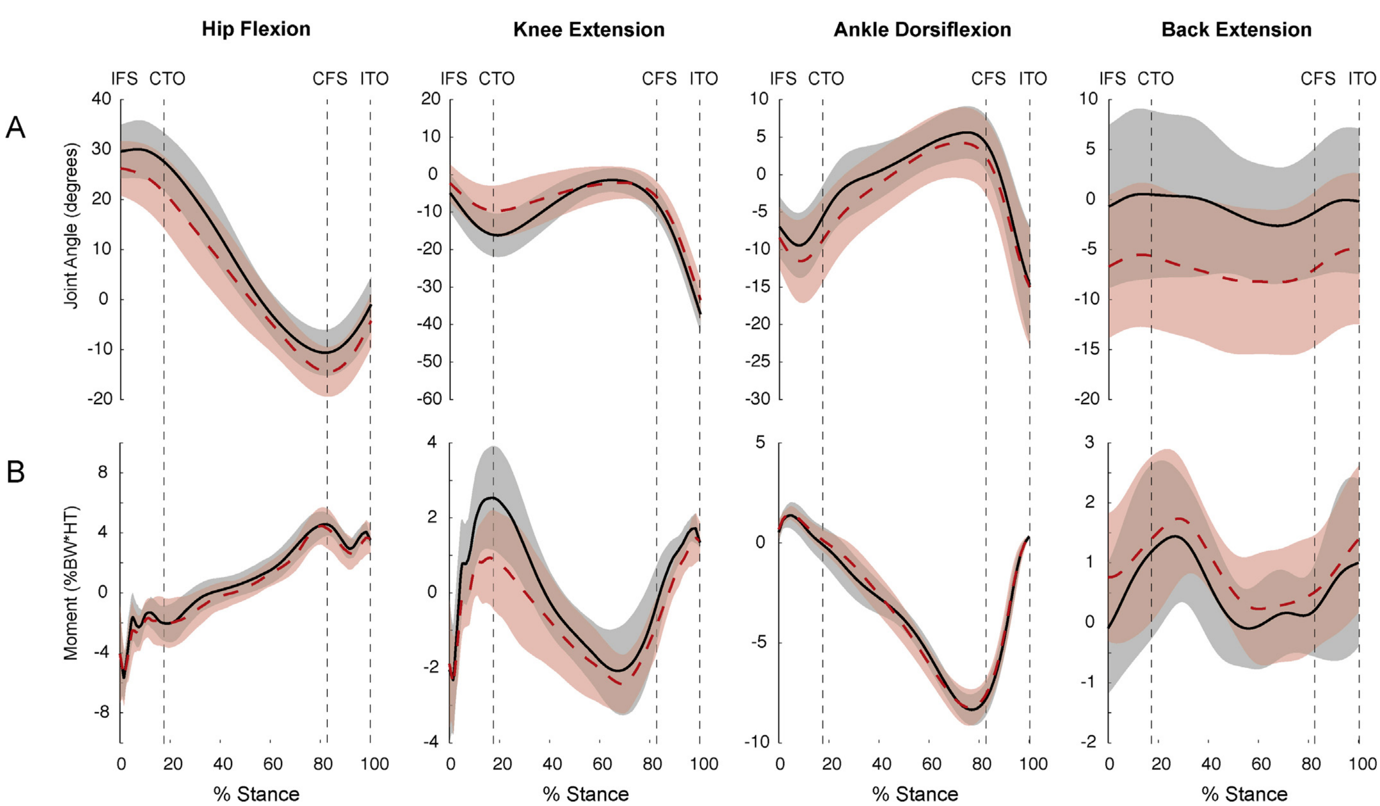

Fig. 1. Joint angular displacements (A) and net moments (B) for the hip, knee, ankle and back joints for TKA patients and controls. Red dashed lines and solid black lines represent mean quantities for the TKA patients and controls, respectively. The shaded regions show one standard deviation about the means. Positive joint angles and moments represent hip flexion, knee extension, ankle dorsiflexion and back extension; negative joint angles and moments represent hip extension, knee flexion, ankle plantarflexion and back flexion. IFS, ipsilateral foot strike; CTO, contralateral toe-off; CFS, contralateral foot strike; ITO, ipsilateral toe-off. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)