Available online at www.sciencedirect.com
ScienceDirect
Gait & Posture 25 (2007) 112–120
GAIT & POSTURE
www.elsevier.com/locate/gaitpost

Organization of postural responses following a rotational support surface perturbation, after TKA: Sagittal plane rotations

William H. Gage [a,b,*], James S. Frank [b], Stephen D. Prentice [b], Peter Stevenson [b]

[a] Toronto Rehabilitation Institute, 550 University Avenue, Toronto, Ont., Canada M5G 2A2
[b] University of Waterloo, 200 University Avenue West, Waterloo, Ont., Canada N2L 3G1

Received 15 June 2005; received in revised form 27 September 2005; accepted 14 February 2006

Abstract

Proprioceptive dysfunction, related to osteoarthritis and total knee arthroplasty (TKA) may be related to changes in gait, and may result in balance impairment. This study examined the organization of postural responses to rotational support surface perturbations after TKA. Eight TKA patients and nine control participants volunteered. EMG was collected bilaterally from lower limb muscles. Kinematic data were collected using an OPTOTRAK system. The temporal pattern of muscle activation was preserved in both the surgical and sound limbs of the patient groups, while muscle activation amplitude was reduced. Knee joint angular displacement was reduced in both limbs among patients. COM displacement was not different. Patients demonstrated a different method in recovering posture control following a postural perturbation. Bilateral changes appear to reflect a simplification in the organization of the motor response, in response to the needs of the injured, or previously injured limb.

Keywords: Total knee arthroplasty; Osteoarthritis; Balance control; Postural perturbation

1. Introduction

Total knee arthroplasty (TKA) has become a common surgery in the treatment of severe osteoarthritis. The incidence rate of TKA has grown over the last 20 years, and is projected to continue to grow, in light of changing population demographics [1]. This surgery is performed most often for the dual purpose of reducing pain and improving function. The majority of patients report satisfaction with their surgical outcomes [2]. Despite remarkable pain reduction and functional improvement, previous work has revealed residual functional deficits following surgery; TKA patients have demonstrated reduced walking velocity, and reduced stride length during level walking [3,4], reduced work at the knee joint, with compensatory changes observed at the hip, when ascending a single step [5], and reduced external knee joint moments when climbing stairs [6,7]. These performance deficits may be associated with pre-surgical adaptive gait patterns, alterations in muscle strength, and proprioceptive dysfunction [4]; the preponderance of research to date has not favored one explanation over all others, though these collective results suggest balance impairment following TKA.

Translational and rotational support surface perturbation studies have provided good insight into the organization of balance control, and the effect of disease and injury on this organization. Following a disturbance, balance is recaptured and maintained using a flexible set of strategies, which may involve movement at the ankle and hip joints, and changes in base-of-support related to stepping [8,9]. Changes in peripheral sensory function have been shown to alter muscle activity latencies and amplitudes, and scaling of joint torques following a support surface translation [10]. Carpenter and colleagues [11] have described the postural response to sagittal plane rotations of the support surface. The reported changes in ankle, knee, and trunk angular displacement, related to the direction of support surface rotation, with stretch-related and balance-correcting muscle

* Corresponding author at: Toronto Rehabilitation Institute, Suite 1209, 550 University Avenue, Toronto, Ont., Canada M5G 2A2.
Tel.: +1 416 597 3422x3868.
E-mail address: whgage@healthy.uwaterloo.ca (W.H. Gage).

0966-6362/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2006.02.003

activity in the lower limbs and trunk. Similar to responses following support surface translations, patients with vestibular loss or proprioceptive loss show changes in muscle activity onset latency and amplitude [12,13]. The human postural control literature has focused on the roles of the ankle and hip joints during quiet standing, and in response to postural perturbations [8,14–16]. Only recently has the knee joint been examined in postural control and balance recovery. Gage et al. [17] reported large angular displacements of the knee joints, relative to the ankles, in young healthy adults during quiet standing. Carpenter et al. [11] reported peak knee joint angular velocities of up to 60°/s in response to sagittal and frontal plane support surface rotations. Recently, Bloem et al. [13] suggested that the proprioceptive information from the knee joint might contribute to the trigger of postural responses following a perturbation.

Osteoarthritis pathology and TKA appear to alter the proprioceptive function of the knee joint [18–20]. Changes in the proprioceptive function of the knee joint may contribute to altered balance control during standing and walking. However, little is known regarding the role of knee joint mechanoreceptors in the control of posture, nor regarding the influence of TKA on postural control recovery strategies [21,22]. The purpose of this study was to examine the organization of balance correcting responses following TKA. This study examined the latency and amplitude of lower limb muscles in response to support surface rotations among TKA patients. We hypothesized that changes in muscle activity, knee joint movement, and center of mass displacement would be consistent with the notion of reducing the stress applied to the affected limb. The results of this study may influence clinical assessment and patient rehabilitation following TKA.

2. Methodology

Eight post-surgical patients (six female/two male; age = 62.9 ± 6.0; height = 170.2 ± 7.4 cm; weight = 95.4 ± 21.6 kg) and nine healthy, age-matched control participants (four female/five male; age = 62.1 ± 5.6; height = 169.9 ± 8.4 cm; weight = 75.7 ± 11.6 kg) volunteered to participate in this study. Each participant provided informed consent to the potential risks associated with their participation. Approval of this study was provided by the Office of Human Research, at the University of Waterloo, Waterloo, Ont., Canada. All patients had returned to their normal daily activities, and at least 6 months time had passed since the date of surgery. All patients had the right knee operated, and the date of surgery was 8 (±2) months prior to testing. Prior to undergoing testing, the referring orthopaedic specialist confirmed that patients had returned to their normal daily activities. Exclusion criteria for the patient group included: contralateral knee arthritis, left or right side hip joint arthritis, other orthopaedic injuries or surgeries other than knee replacement, post-operative infection, revision TKA surgery, vestibular or other balance disorders, and diabetes or other peripheral neuropathic conditions. All individuals in the control group reported that they had no history of orthopaedic injury or surgery, vestibular or other balance-related disorders, diabetes, or other peripheral neuropathic conditions.

Electromyographic (EMG) data were collected bilaterally from the following muscles: tibialis anterior (TA), soleus (SOL), medial head of gastrocnemius (GAS), rectus femoris (RF), biceps femoris (BF), and gluteus medius (GMED). Raw EMG were collected at a frequency of 512 Hz. Raw EMG signals were full-wave rectified and digitally low pass filtered offline using a dual pass Butterworth filter with a cut-off frequency of 100 Hz. Kinematic data were collected using an OPTOTRAK optoelectronic, three-dimensional camera system. Twenty-three infrared light emitting diodes (IREDs) were placed at the following anatomical landmarks: head of fifth metatarsal, ankles, knees, greater trochantors, radial styloid process, lateral humeral epicondyle, acromion process, anterior superior iliac spine, iliac crest, inferior angle of ribs, and xyphoid process. All marker locations were bilateral, except for xyphoid process. The collection frequency was 64 Hz. Three-dimensional IRED data were digitally low pass filtered offline using a dual pass Butterworth filter with a cut-off frequency of 6 Hz. Postural perturbations were delivered using an instrumented custom designed platform, with a support surface capable of rotating in the pitch (i.e. sagittal plane) and roll (i.e. frontal plane) directions. The platform rotated 7.5° at 50°/s.

Each participant completed 20 trials; for 10 trials the platform rotated in the sagittal plane (toes down (TD), toes up (TU)), and for 10 trials the platform rotated in the frontal plane (roll left (RL), roll right (RR)). Each participant completed a total of five trials in each of the four rotation directions. The order of the trials was completely randomized by direction of the perturbation, i.e. TD, TU, RL, or RR. Every participant reported that they were unable to predict the direction of the perturbation. Only the 10 sagittal plane perturbation trials (i.e. five TD trials and TU trials) are reported in this paper; results related to the frontal plane perturbations are reported elsewhere. Prior to the beginning of each trial, the participant was instructed to load both lower limbs equally; equal loading was confirmed visually using an oscilloscope display of the output signals from the two load cells mounted below the support surface. A random delay of 5–8 s was inserted prior to the movement of the platform to avoid the participant's anticipation of the perturbation. All data were collected for 10 s; approximately 3–5 s of this time passed prior to the movement of the platform. All data were stored on a dedicated computer for processing.

The onset of movement of the platform was determined from the change in angular displacement of the platform. Platform movement onset was considered as the time at which the angular displacement of the platform moved three standard deviations beyond the mean resting position of the platform. All EMG and kinematic data were windowed;