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Short Communication

A Non-Invasive Method of Muscle Force Estimation After a Transmetatarsal Amputation

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Received: February 01, 2017; **Published:** March 14, 2017

Abstract

Previous gait analysis of partial foot amputee subjects has focussed on quantification of joint angles, moments and powers without quantifying muscle forces. This study aimed to develop a subject-specific musculoskeletal model for a participant with transmetatarsal amputation in order to quantify muscle forces during walking non-invasively. First, a generic musculoskeletal model was developed. Secondly, the generic model was scaled and the subject-specific model of the participant was developed 'for model prediction of joint angles and moments during stance. The results showed that the time history of joint angles and moments predicted by the model and reported in the literature were comparable. Thus, the static optimisation problem was solved to predict the time history of muscle forces by the musculoskeletal model. The comparison of timing of EMG data and forces predicted by the model for some muscles of the residual limb indicated that model predictions for individual muscle forces were reliable. The presented technique can help surgeons and prosthetists to investigate effects of amputation and prosthetic designs on muscle forces.

Keywords: *Transmetatarsal Amputation; Musculoskeletal Modelling; Muscle Forces*

Introduction

Partial foot amputation (PFA) is a common surgical intervention as a result of trauma, infection, birth defect and advanced vascular disease secondary to diabetes [1,2]. The risk of PFA in diabetic patients is 15 times greater than for normal population [3]. It is estimated that the worldwide diabetic population will rise from 171 million in 2000 to 366 million in 2030; therefore, the number of people requiring PFA will also increase [4].

Despite the prevalence of PFA, the effects of amputation on muscle adaptations have not been studied yet. The effects of amputation and prosthetic devices have been studied on joint angles, joint moments and joint powers [5,6]. It has been revealed that partial foot amputations proximal to toes reduce the ankle power of residual limbs. However, without quantifying individual muscles around the ankle, it is impossible to conclude that this reduced ankle power is caused by weakness of ankle plantar flexors.

Because the invasive techniques of quantifying individual muscle forces are limited to a small number of muscles and are discouraged by ethical considerations [7,8]. Computer-based musculoskeletal models help researchers to non-invasively quantify muscle forces during locomotion [9,10]. The objective of this study was to develop a computer-based musculoskeletal model of a participant with transmetatarsal amputation in order to quantify the muscle forces of the residual limb with transmetatarsal amputation.

Methods

The generic musculoskeletal model was developed and scaled for a participant with transmetatarsal amputation. The subject (age, 54; height, 1.8 m; mass, 84.5 kg) had toe filler and had traumatic amputation for more than 3 years. Because the available experimental data was collected for the residual limb of to the affected limbs of a subject with transmetatarsal amputation in the sagittal plane, a one leg musculoskeletal model was developed with six degrees of freedom. The modelled pelvis could move in x-direction and y-direction when it rotated in the sagittal plane. Hip, knee and ankle joint were modelled as hinge joints with only one degree of freedom as they could flex or extend in the sagittal plane. The simplified musculoskeletal model was actuated by 16 muscles that consisted of 25 muscle-tendon units, each unit represented as a Hill-type muscle [11]. The ethics approval was received for using the available experimental kinetic, kinematic and EMG data of a participant with transmetatarsal amputation as inputs for the proposed generic musculoskeletal model. The pipeline of this study was presented in Figure 1.

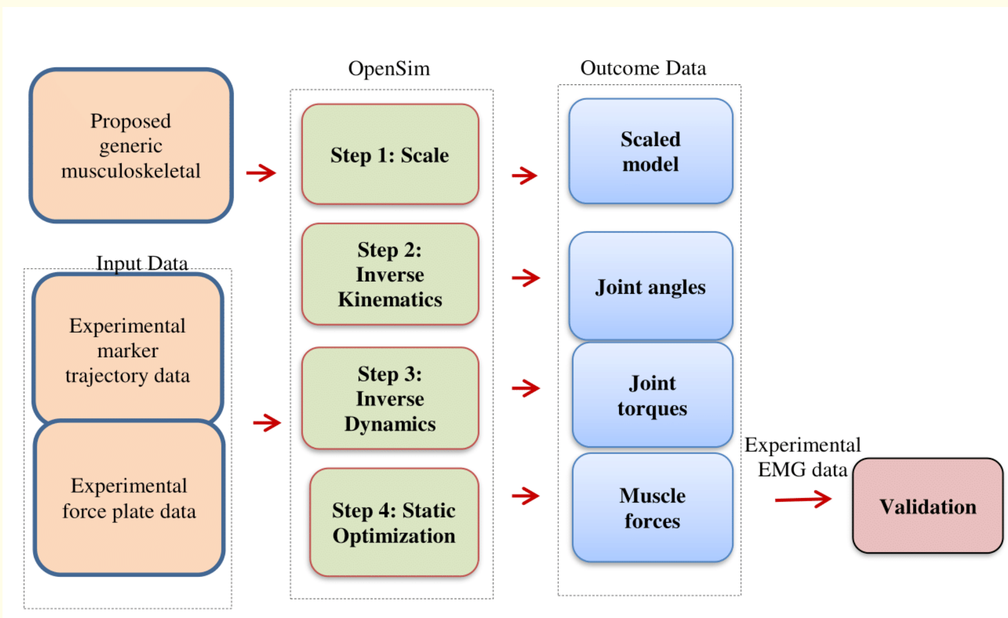

Figure 1: *The experimental and computational pipeline.*

Discussion and Conclusion

The proposed musculoskeletal model re-produced very similar sagittal plane joint angles and moments to that reported in another study [5]. The timing of EMG activity of some muscles (Rectus femoris, lateral gastrocnemius, medial gastrocnemius, gluteus maximus, vastus lateralis, soleus, tibialis anterior) were consistent with the timing of muscle forces estimated by the musculoskeletal model. This was a good indicator for reliability of muscle contraction predicted by the musculoskeletal model.

Knee extensors, hip extensors and knee flexors had a peak maximum muscle contraction during the first 40% of the stance without generating much force during the rest of the stance phase (Figure 2).

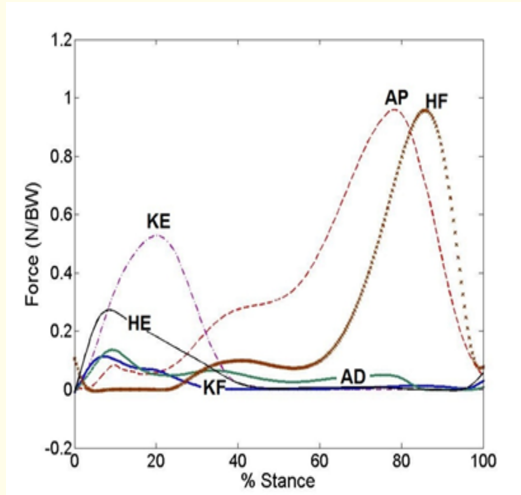

Figure 2: *The forces for a residual limb with a transmetatarsal amputation. KE: Knee extensors including rectus femoris, vastus intermedialis and vastus lateralis; HE: Hip extensors including biceps femoris and gluteus maximus; AD: Ankle dorsiflexors including extensor digitorum, extensor hallucis and tibialis anterior; KF: Knee flexors including biceps femoris, gastrocnemius, gracilis, sartorius, semitendinosis and semimembransis ; HF: Hip flexors including iliacus psoas and rectus femoris ; AP: ankle plantarflexors including flexor digitorum, flexor hallucis, gastrocnemius, soleus and tibialis posterior.*

From mid-stance to terminal stance (50 - 86% stance), knee flexor and extensor muscles did not contract (Figure 2). The participant might maintain the knee extension by placing the ground reaction force line in front of the knee joint perhaps by adjusting the position of the trunk. Because the trunk was not included in the model, it was difficult to explain the reason of this phenomenon. During terminal stance, knee flexors were contracted to avoid knee hyperextension.

There are some limitations in this study: only the gait of one participant with transmetatarsal amputation was simulated; experimental data was limited to residual limbs, and the model was simplified to simulate the gait in the sagittal plane. Although this study had some limitation, the main objective was to demonstrate the methodology and framework for further research in people with partial foot amputation.

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Volume 5 Issue 4 March 2017