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Full Length Article

Potential of muscles to accelerate the body during late-stance forward progression in individuals with knee osteoarthritis

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ABSTRACT

Many individuals with knee osteoarthritis (OA) generate low forward center of mass (COM) acceleration during the late stance phase, consequently making it difficult to walk fast. This study analyzed individual muscle contributions to forward COM acceleration and the muscle potential (i.e., acceleration by unit force) to clarify whether reduced acceleration was related to decreased muscle potential of forward progression by the triceps sure. Twelve individuals with knee OA and 12 healthy age-matched individuals participated in this study. All participants underwent kinetic measurements during normal gait. The simulation involved 92 Hill-type muscle–tendon units with 23 degrees of freedom. We analyzed how each muscle contributed to forward COM acceleration during the 70–100% stance phase using an induced acceleration analysis. Next, the muscle potential of forward COM acceleration was calculated. Our results showed that individuals with knee OA had significantly lower forward COM acceleration with the soleus, gastrocnemius, and iliopsoas muscles compared with controls. Lower muscle potential in the soleus was found in those with knee OA. These findings implied that improving the contribution of the soleus to forward body progression would be effective for increasing the gait speed of those with knee OA during the late stance phase.

1. Introduction

Knee osteoarthritis (OA) is a prevalent musculoskeletal condition that significantly contributes to functional limitations and disabilities. One disability relevant to daily life is decreased walking speed caused by pain, muscle weakness, joint instability, or other factors. Because slow walking limits participation in community activities and outside interests, the resulting reduction in physical activity may accelerate and worsen disabilities in individuals with knee OA (White et al., 2013). Maintenance of gait speed is essential for knee OA patients; therefore, when planning rehabilitation programs, it is important to understand how gait speed can be maintained.

One of the roles of the lower limb muscles during the late stance phase is generation of forward body progression. The main muscles that generate the forward center of mass (COM) acceleration are the soleus and gastrocnemius (Pandy & Andriacchi, 2010).

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Fast walking requires higher forward acceleration generated by the triceps surae (Liu, Anderson, Schwartz, & Delp, 2008). Therefore, even for individuals with knee OA, the contributions of the soleus and gastrocnemius muscles to forward progression during the late stance would have a principal role in maintaining gait speed.

Forward COM acceleration by muscle tension force is dependent on posture in the context of human multibody dynamics. For example, compared with normal gait, crouch gait with flexed knees and hips produces inefficient forward COM progression by the contraction of plantar flexors during the late stance phase (Steele, Seth, Hicks, Schwartz, & Delp, 2010). Posture during the late stance phase will influence the muscle potential to generate forward COM acceleration (i.e., acceleration by unit force). If the muscle potential of acceleration decreases, then the walker will fail to achieve sufficient forward acceleration, consequently leading to slow walking. A previous muscle-driven simulation study reported that the soleus and gastrocnemius muscles, which are powerful generators of forward COM progression during the late stance phase, typically decrease the potential of forward body progression and anterior-posterior COM acceleration by unit force in stroke patients who walk with less hip extension (Allen, Kautz, & Neptune, 2013). Less hip extension is commonly observed in those with knee OA (Astephen, Deluzio, Caldwell, & Dunbar, 2008; Ouellet & Moffet, 2002). Therefore, the decreased muscle potential of forward COM acceleration by the ankle plantar flexors might result in difficulty generating forward progression and walking because of the typical posture of those with knee OA.

Clarification of potential acceleration by muscle force will contribute to the planning of clinical rehabilitation programs targeting muscles in knee OA patients. Therefore, the aims of this study were to investigate the potential forward COM acceleration by unit muscle force and to clarify the contribution of plantar flexor force to forward body progression in knee OA patients. A musculoskeletal simulation analysis was used to investigate the direct effect of muscle force on COM acceleration. We hypothesized that muscle potentials of plantar flexors during forward progression of the late stance phase would decrease in individuals with knee OA.

2. Methods

2.1. Participants

Twelve patients with medial knee OA and 12 healthy age-matched control subjects were recruited from the community. All participants provided written consent, and the study was approved by the institutional review board. Individuals with knee OA were included if they had Kellgren-Lawrence grade of 2 or greater radiographic changes in the medial tibiofemoral compartment. Exclusion criteria were as follows: a history of other orthopedic injury in the lower extremities, neurologic injury, or rheumatoid arthritis; joint surgery on either lower extremity; or use of an assistive device. If a patient had bilateral knee OA fitting the criteria, then the more involved knee was identified by the patient and was used in the analysis. Control subjects were included if they reported no history of knee dysfunction or previous lower extremity injury. The study protocol was approved by the local institutional ethics review committee, and the subjects provided written informed consent to participate.

2.2. Experimental data

Three-dimensional (3D) coordinates of reflective markers and ground reaction force were obtained during standing and gait using a 3D motion analysis system (Locus 3D MA-300; Anima, Chofu, Japan). This system consisted of 8 infrared cameras with a sampling rate of 100 Hz and 2 force plates (MG-1190; Anima) with a sampling rate of 100 Hz. The measurement methods were described in a previous study (Ogaya et al., 2017). Nine markers were attached to the skin of each subject at the following anatomical landmarks: acromions, C7, first metatarsal head, fifth metatarsal head, and heel. We also used one pelvis and two shank devices, to which three markers were attached. Distances between these three markers were fixed because the markers were firmly fixed on inflexible hard devices.

The devices were used to define the positions of imaginary markers (Cappozzo, Catani, Croce, & Leardini, 1995). The shank device was used to define four imaginary markers on each leg: medial/lateral malleolus and medial/lateral knee. The device, which is shaped like a leg guard, was fixed to the shank and strapped firmly by a hook and loop fastener. Before measurement, imaginary markers were defined using a pointing device connected to the 3D motion analysis system. The tip of the pointing device was located at a body landmark to set the imaginary marker, and the relative position of the imaginary marker was defined by the position of the three markers on the shank device. The pelvis device, which is shaped like a belt, was also used to define imaginary markers of the anterior superior iliac spine and posterior superior iliac spine. During a preliminary trial, the root mean difference between imaginary and real marker positions attached at the same location was 19.8 mm during gait measurement. Subjects were instructed to stand on the platform to capture static standing data and to walk on the platform at their preferred speed twice to capture gait data. Gait Kinematic data were low-pass-filtered using a Butterworth filter with a cut-off frequency of 6 Hz. Walking speed, position of the hip center (Besier, Sturnieks, Alderson, & Lloyd, 2003), and relative angles between the coordinate systems of each segment in the lower limb were calculated.

2.3. Modeling and simulations

Subject-specific simulations were created using OpenSim software (Delp et al., 2007). A simulation model was created based on a generic musculoskeletal model involving the lower extremity and trunk with 92 Hill-type muscle–tendon units (Hamner, Seth, & Delp, 2010). Deformation of the knee joint was achieved with the assumption that patients with knee OA usually have varus knees. To include varus alignment in the analysis, the degree of knee adduction–abduction was added to the model. The subtalar and