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Do patients with knee osteoarthritis perform sit-to-stand motion efficiently?

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ABSTRACT

The sit-to-stand motion (STS) is a frequently executed activity that is affected by weakness in the quadriceps femoris muscle and knee joint pain in patients with knee osteoarthritis (OA). We investigated whether patients with knee OA can efficiently perform STS through mechanical energy transfer assessments. Participants were 20 women with knee OA and 17 age-matched asymptomatic controls. The center of mass (COM), segment angles, joint moments, and powers during STS were measured. The negative mechanical work in the proximal portion of the shank, negative mean powers in the distal portion of the pelvis and proximal portion of the shank, and the positive mean power in the proximal and distal portions of the thigh were significantly lower in the knee OA group than in the control group. Patients with knee OA primarily performed thoracic forward lean movement, shifting their COM closer to the base of support provided by the feet alone, in an attempt to achieve stability at and after buttocks-off. However, control ability, which generates and absorbs kinetic energy quickly, was not enhanced in these patients, and their motion was unable to increase absorption of the mechanical energy in hip extensors and reduce the load on knee extensors. Furthermore, STS in patients with knee OA had reduced energy absorption in the knee extensors from the shank forward lean movement after buttocks-off, had reduced knee extensor efficiency, and made greater use of physiological energy. These findings suggest that, from the standpoint of mechanical energy transfer, patients with knee OA do not perform STS efficiently.

1. Introduction

Knee osteoarthritis (knee OA) is a degenerative joint disease characterized by the accumulation of mechanical stress, leading to pathological changes, such as degeneration and failure of the articular cartilage and formation of osteophytes [1]. Knee OA is characterized by weakness in the quadriceps femoris muscle and knee joint pain [2], and affects the ability to perform various movements in daily life.

Sit-to-stand motion (STS) is a complicated motion routinely repeated and requires the coordination of multiple body segments. From the perspective of mechanical energy, total mechanical energy increases at motion termination compared to motion initiation. This underscores the importance of efficiency, in which work is done with joint moment, because the energy generated by this work is used to move body segments. Williams and Cavanagh [3] reported that mechanical energy transferred between segments increased the efficiency of utilized physiological energy, and that the increased mechanical energy transfer suppresses the generation of physiological energy by muscles, thereby enhancing their efficiency. In a previous study [4], we reported that trunk and shank forward lean movements in STS not only moved the center of mass (COM) forward, but also transferred energy to the thigh via muscle by rotating the trunk and shank in the same direction as the thigh. This decreased the generation of physiological energy by muscle in the buttocks-off task.

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Patients with knee OA have increased co-contraction of lateral knee muscles [5] and increased stiffness of the knee joint during walking [6]. Thus, STS in patients with knee OA might be an inefficient motion. In a previous study of STS for patients with knee OA, Patsika et al. [7] reported that the slower performance of STS is due to the less efficient use of knee extensor muscles. Turcot et al. [8] demonstrated that patients with knee OA lean their trunk forward to reduce pain and decrease the solicitation of weaker muscles. Although studies have shown that STS is a more energy-demanding and less efficient task for patients with low back pain [9], none of these published STS studies have addressed the actual mechanical energy transfer in patients with knee OA. The purpose of this study was to investigate whether patients with knee OA can perform efficient STS through mechanical energy transfer assessments.

2. Methods

2.1. Subjects

Subjects were 20 women who were diagnosed with knee OA (knee OA group) and 17 women who did not fulfill the knee OA clinical diagnostic criteria of the American College of Rheumatology [10] and were free from pain in the other lower extremity joints (control group) (Table 1). Anteroposterior X-ray images of the knee joint taken when subjects were standing on both legs were used to determine the severity of knee OA with the Kellgren-Lawrence grading scale [11]. Severity of knee pain was measured on the visual analogue scale (VAS). The knee OA group had presented with a complaint of knee pain more than once previously, and exhibited narrowing of the knee joint space and formation of osteophytes. Patients whose knee joint space was completely blocked were excluded from this study. Other exclusion criteria included a knee flexion contracture of 15° or more, a history of central nervous system disease, lower extremity artificial joint replacement, lower extremity trauma or surgery, serious heart or lung disease, and rheumatoid arthritis. Subjects using a cane in their daily living or those who had difficulty walking without an aid device were also excluded. This study was approved by the Ethics Committee of the Division of Physical Therapy and Occupational Therapy Sciences, Graduate School of Health Sciences, Hiroshima University (No. 0826). Subjects were explained the purpose of the study and provided both written and oral consent prior to participation.

2.2. STS measurement

2.2.1. Task

The ordinary sitting position was used as the initial sitting posture. Subjects sat on a chair without a backrest, armrests, and wheels. The seat height was adjustable and the vertical distance between the lateral knee joint space and floor was adjusted for each subject. Shanks were maintained in the vertical position. Subjects were barefoot, and the width between the feet was set as the distance between the anterior superior iliac spines. Subjects sat in a position in which the midpoints between the greater trochanter and lateral epicondyle of the femur were aligned to the front edge of the seat. They were instructed to face forward while sitting and to fold their arms on the chest to avoid masking the reflective markers. Subjects performed the motion of rising from the initial sitting posture at a comfortable speed for each trial. The timing of initiation after being provided the oral cue was left to the subjects' discretion. Subjects sufficiently practiced the motions prior to measurements.

Table 1
Characteristics of the knee OA and control groups.

	Knee OA group (n = 20)	Control group (n = 17)	p-Value
Age (years)	69.7 ± 4.4	69.8 ± 4.3	0.937
Height (cm)	150.2 ± 4.7	152.1 ± 4.6	0.232
Body weight (kg)	55.0 ± 5.8	49.1 ± 6.1	$<$0.01
BMI (kg/m^2)	24.4 ± 2.8	21.3 ± 2.7	$<$0.01
VAS (mm)	18.7 ± 19.6		
OA grade	I: 4, II: 7, III: 9		

Mean ± standard deviation.

2.2.2. Measurement methods

Kinematic data during STS were collected using Vicon MX, a three-dimensional motion analysis system (Vicon, Oxford, UK) with six infrared cameras. Kinetic data were collected using four force plates (Tec Gihan, Uji, Japan) to measure ground reaction forces under the buttocks and each individual leg (Fig. 1). Infrared-reflecting markers (diameter, 14 mm) were attached to 40 landmarks (i.e., the temples, lateral ends of the superior nuchal line, tragi, acromia, olecranon processes, styloid processes of the ulnae, inferior edges of the last ribs, superior edges of the iliac crests, anterior superior iliac spine, posterior superior iliac spine, great trochanters, lateral and medial epicondyles of the left and right femurs, lateral and medial condyles of the left and right tibiae, lateral and medial malleoli, the first and fifth metatarsal heads, and the calcaneal tuberosities). These three-dimensional coordinates were collected by the three-dimensional motion analysis system at a sampling rate of 100 frame/s. At the same time, three-dimensional ground reaction forces were collected by the force plates at a sampling frequency of 1000 Hz.

2.2.3. Data analysis

The coordinates of each joint center were calculated according to previous studies [12]. The collected marker coordinates were used to define the respective local coordinate systems of an eight-rigid body link model consisting of the thorax, pelvis, both thighs, both shanks and both feet. COM locations in each segment or the whole body were calculated using coefficients of each body segment inertia obtained from the report by Okada et al. [13]. Segment angles, segment angular velocities, and joint moments were calculated using the processing software BodyBuilder (Vicon, Oxford, UK) based on collected marker coordinates and data for the ground reaction force. Segment angles refer to the orientation of a segment relative to the global space, and variations in the thorax, pelvis and shank forward lean angles were calculated. The maximum and mean values of hip extension, knee extension, and ankle plantar-flexion joint moments were calculated. The impulse of each joint moment was calculated by integrating each joint moment according to time. To investigate the position relation between base of support (BOS) provided by feet alone and COM, the anteroposterior horizontal distance from the COM to heel (DCH) at the buttocks-off was calculated.

Net joint power was calculated as the product of joint moment and joint angular velocity. Joint power reflects the net effect of a joint moment on the mechanical energy of the whole body, and not the effect on any particular body segment [14]. Robertson and Winter [15] reported that each joint moment can simultaneously absorb, generate, and transfer energy, depending on the adjacent segments' angular velocities. To investigate mechanical energy transfer at the endpoints of adjoining segments, power at the endpoints of adjoining segments of the hip and knee joints was each calculated as the product of the joint moment and segment angular velocity (i.e., joint powers of the pelvic distal, thigh proximal, thigh distal, and shank proximal joints) (Fig. 2) [4,16]. In this study, the expression of the proximal or the distal portions in segments was based on the distance from the top to the bottom.