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Relationships between performance and kinematic/kinetic variables of stair descent in patients with medial knee osteoarthritis: An evaluation of dynamic stability using an extrapolated center of mass

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A B S T R A C T

Background: The ability to descend stairs independently is impaired from a relatively early stage in patients with knee osteoarthritis. The purpose of this study was to evaluate the performance in patients with knee osteoarthritis when stepping down a step by evaluating the dynamic stability using the extrapolated center of mass.

Methods: Twenty-three individuals with medial knee osteoarthritis were evaluated during step descent without any assistance. Kinematic/kinetic data were collected using a three-dimensional motion analysis system and force platforms. The extrapolated center of mass and its deviation from the anterior boundary on the base of support (margin of stability) were calculated at the initiation of descent. Joint angles and internal joint moments were collected at the stance limb. The relationship between patients' dynamic stability control, which was measured by the timed up and go test, and the length of margin of stability was analyzed. Relationships between the length of the margin of stability and each kinematic/kinetic variable were also evaluated.

Findings: The margin of stability positively correlated with the time taken for a timed up and go test. A positive correlation was additionally observed between the ankle dorsiflexion angle and the margin of stability. It was also found that a higher ratio of ankle plantar flexion moment by support moment was associated with a larger margin of stability.

Interpretation: Patients with knee osteoarthritis who had high ability in dynamic stability control were observed to move their center of mass anteriorly at the initiation of stepping down. It was also suggested that these patients could dorsiflex their ankle joint and generate sufficient ankle plantar flexor torque.

1. Introduction

Knee osteoarthritis (knee OA) is one of the most common lower extremity diseases in the elderly (Muraki et al., 2012; Yoshimura et al., 2009) known to cause pain, joint stiffness, and limitations in activities of daily living (van Dijk et al., 2010; Bedson et al., 2007; Jevsevar et al., 1993). The ability to independently negotiate stairs is frequently required in daily living. However, this ability, particularly the action of descending stairs, is easily impaired to the extent that many patients with knee OA are unable to ascend or descend stairs without any assistance, even if these patients' conditions are not severe enough to indicate surgery. Previous studies have described that patients with knee OA demonstrated a slower stair descent than their healthy elderly counterparts (Hicks-Little et al., 2012) and patients gradually developed difficulties in stair decent with disease progression (Kaufman et al., 2001; Costigan et al., 2002). It was also reported that knee OA patients who underwent knee replacement could not completely recover from their abnormality in descending stairs, such as a decrease in descent speed (Marmon et al., 2014) and the use of a handrail (Zeni and Snyder-Mackler, 2010), even several months after surgery. Based on these studies, it was supposed that the decline in the ability to descend stairs caused by knee OA would limit mobility independence in the long term. In addition, 10% of falls in the elderly happen during stair negotiation (Startzell et al., 2000), which also indicates that changes in the method used to descend stairs caused by a decline in physical function could lead to an increased risk of falling. Although it was expected that stair descending would influence mobility independence and risk of falls, few studies have investigated the performance of stair descending in patients with knee OA by analyzing their motions. Moreover, while some previous studies have investigated the time-spatial variables in stair descent in patients with knee OA (Marmon et al., 2014), further analysis is needed to consider the lower extremity joint mechanics during stair descent.

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It is characteristic of the mechanics in descending steps that much more muscle force, which regulates the anterior–inferior rotation of the body caused by gravity, is required compared to level walking. Therefore, we considered that a quantitative evaluation of dynamic stability during the regulation of the anterior–inferior rotation of the body in stair descent would be valuable in clarifying the features in stair descent in patients with knee OA. In recent studies, dynamic stabilities in some locomotor activities, such as level walking, have been estimated by calculating the extrapolated center of mass (XcoM), which is a concept based on an inverted pendulum model (Hof, 2008). XcoM is obtained from the anterior–posterior position and the forward velocity of the center of mass (CoM). Dynamic stability in locomotor activities is evaluated by observing margin of stability (MoS), which represents the instantaneous distance between the XcoM and the anterior boundary of the base of support (BoS) (Hof et al., 2007; Major et al., 2013). One previous study used this method to evaluate dynamic stability while patients descended stairs and disclosed that older individuals showed reduced dynamic stability control compared with young individuals (Bosse et al., 2012). In patients with knee OA, the condition is also likely to alter their control strategies during stair descent because of such impairments as joint stiffness and muscle weakness, which are caused by their pathology. However, no study has evaluated performance of stair descent in patients with knee OA with regard to dynamic stability using the MoS calculated from XcoM as a measure, and the variables (e.g., joint angle and internal joint moment) associated with this performance are unclear.

The purpose of this study was to evaluate the performance in terms of dynamic stability while stepping down stairs in patients with knee OA through observation of XcoM and MoS behavior. We hypothesized that performance in descending a step is associated not with knee joint kinematics/kinetics but with other joints kinematics/kinetics because the hip/ankle joint would compensate for their failure of joint angular displacement or torque generation at the knee in patients with knee OA.

2. Methods

2.1. Participants

Twenty-three individuals with medial knee OA diagnosed by an orthopedic surgeon were recruited for this study. Patients with other types of arthritis (e.g., lateral knee OA, rheumatoid arthritis) or those who had undergone previous surgery in the lower extremities were excluded. Patients diagnosed with any other disease that could affect ambulation were also excluded from the study. All participants were able to descend at least one step without any assistance. Following Institutional Review Board approval, written informed consent was obtained from each participant before the study began.

While only the affected limb was analyzed in this study, the more symptomatic side of each patient was involved if patients had bilateral knee OA. The radiographic severity of each patient was determined using Kellgren–Lawrence classification by an experienced orthopedic surgeon. The disease-specific scale of the Japanese Knee Osteoarthritis Measure (JKOM) was used to evaluate their symptoms and physical functions. The JKOM is a self-administered measure consisting of 25 items, which include subjective pain in level walking, standing, or climbing stairs as well as physical functions related to the activities of daily living and social functions. The maximum score for the JKOM is 100 points, and higher scores indicate more impaired function. Pain in daily living was also quantified by using the visual analog scale (VAS). The participants' demographic characteristics are shown in Table 1.

2.2. Measure of functional balance ability

To evaluate each participant's ambulation and functional balance ability, the timed up and go test (TUG) was used. In this test, participants initially sat on a chair with a seat height of 42 cm. Each participant was instructed to stand up, walk toward a mark, which had been placed 3 m from the starting position, turn around, walk back to the chair, and sit down again. They were also asked to perform this sequence of activities as fast as possible. Each participant completed the trials twice, and the time taken to complete the test was recorded. The faster of the two trials was used for analysis.

Table 1
Demographic characteristics of the participants, mean (standard deviation).

Age (years)	66.7 (8.5)
Height (cm)	156.5 (4.7)
Weight (kg)	59.8 (6.8)
KL grade	I: 2 II: 13 III: 4 IV: 4
FTA (deg)	180.4 (4.3)
VAS (mm)	29 (21)
JKOM score	19.1 (13.1)

KL grade: Kellgren–Lawrence grade, FTA: femorotibial angle, VAS: visual analog scale.
JKOM: Japanese Knee Osteoarthritis Measure.

2.3. Motion capture of descending a step

All participants performed three trials of stepping one step down. The step riser height and tread width were 20 and 40 cm, respectively (Fig. 1). They were asked to descend at a self-selected speed and to lead with the uninvolved limb. In order to standardize the step length between participants, each trial began with the subjects standing with both toes against the anterior edge of the step. They were instructed not to cross their toes over a line that was drawn 25 cm from the edge of the step when they descended toward the lower step. Both arms were folded in front of their abdomen in an attempt to standardize the effects of motion of the upper extremities on their ambulation. Before the sampled trials, each participant completed a couple of trials for familiarization.

Kinematic and kinetic data were obtained using a three-dimensional motion analysis system (Vicon Nexus; Vicon Motion Systems Ltd.,

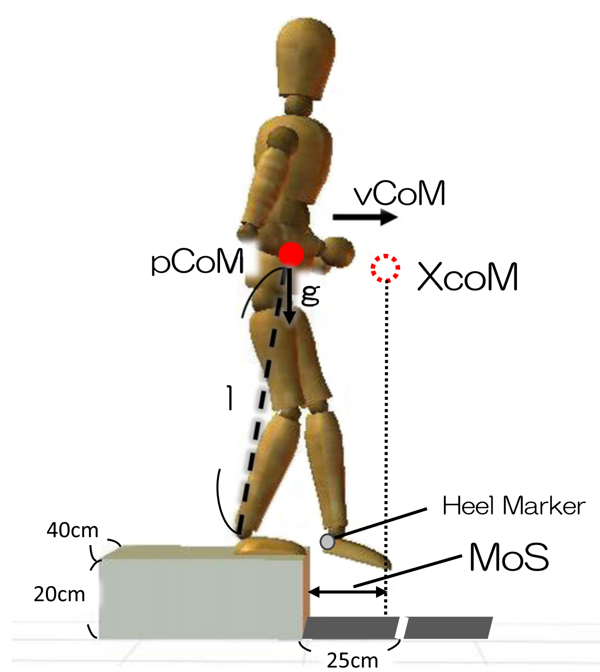

Fig. 1. Evaluation of dynamic stability during stepping down with XcoM, pCoM: anterior–posterior position of CoM, vCoM: the anterior–posterior velocity of CoM, g: acceleration of gravity (9.8 m/s^2), l: the distance between the CoM and the center of the ankle joint, XcoM: extrapolated center of mass, MoS: margin of stability.