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A gait analysis of simulated knee flexion contracture to elucidate knee-spine syndrome

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Abstract

Knee flexion contracture influences the physiological movements in lower extremities and may cause the kinematic changes of the trunk. Our purpose was to investigate static and dynamic changes in trunk kinematics with simulated knee flexion contracture. Ten healthy females averaged 62 years participated in our study. Unilateral knee flexion contractures of 15° and 30° were simulated with a knee brace. Relaxed standing and level walking were measured at our laboratory using a motion analysis system which consisted of five cameras, a force plate, and thirteen retro-reflective markers. Three-dimensional trunk kinematics and vertical knee forces (% Body Weight) with the contractures were compared with those without the contracture. The 15° contracture did not significantly change trunk kinematics. However, the 30° contracture significantly changed the kinematics in each of the following planes. In the coronal plane, the trunk tilted to the contracture side in standing and walking. In the sagittal plane, posterior inclination of the pelvis in standing significantly increased. In addition, anterior inclination of the trunk and pelvis during walking significantly increased. In the axial plane, trunk rotation to the unaffected side significantly decreased during walking. The vertical knee force in the contracture limb decreased, being accompanied by the increase of the force in the unaffected limb during standing and walking. Results of our study suggest that knee flexion contracture significantly influences three-dimensional trunk kinematics during relaxed standing and level walking, and will lead to spinal imbalance. These facts may explain the onset of the ‘‘Knee-Spine Syndrome’’.

Keywords: Simulated knee flexion contracture; Trunk kinematics; Standing; Gait; Knee-spine syndrome

1. Introduction

Severe knee osteoarthritis often causes a flexion contracture, which affects daily activities [1]. In addition, the contracture influences the physiological movements in other body parts such as the hip and ankle joints [2,3], as well as the spine [4]. Previous studies demonstrated the effect of knee flexion contracture using gait analysis [5,6]. Cerny et al. investigated the effect of unilateral knee flexion contracture on gait using knee contracture simulation and showed that velocity and stride length significantly decreased [2]. Perry et al. examined the knee joint forces required to stabilize the flexed knee during weight bearing using a cadaveric lower extremity. They concluded that a rapid rise in the quadriceps force was required to stabilize the knee between 15° and 30° of flexion [3]. In addition, Potter et al. evaluated standing balance in simulated unilateral and bilateral knee flexion contracture, using a knee brace [7]. They found that the center of pressure moved anteriorly as the bilateral knee flexion contracture increased. It also shifted towards the non-contracture side with unilateral knee flexion contracture. However, to our knowledge, most of these studies concentrated on the kinematics and kinetics of the lower extremities. Only a few papers demonstrated the relationship between knee flexion contracture and trunk kinematics. In these studies, limitation in knee extension was related to a decrease in lumbar lordosis on the sagittal plane radiographs [4,8]. Clinically, back pain is present in 54.6% of patients with knee osteoarthritis, and is more common than in normal population

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[9]. Furthermore, back pain appears to be associated with the decrease of lumbar lordosis, progression of degenerative scoliosis, and progression of rotational deformity [10]. Although it has been demonstrated that back pain and the decrease of lumbar lordosis are related to knee flexion contracture, the relationship between the knee and the spine in the coronal and axial planes has not been investigated [4,8].

We hypothesized that the knee flexion contracture would influence three-dimensional kinematics of the trunk and pelvis. The purpose of the current study was to investigate static and dynamic changes in trunk kinematics of older females with simulated knee flexion contracture during standing and walking.

2. Materials and methods

2.1. Subjects

Ten healthy women, 60–64 years of age (average 62), participated in the current study. Subjects had no history of lower extremity surgery and no pain around the knee. All the subjects provided informed consent and the study was approved by our institution. All methods and procedures were also approved by our institution's ethics committee.

2.2. Gait analysis system and marker locations

The subjects were tested at our gait laboratory using a motion analysis system which consisted of five cameras (120 frames/s; Pro-reflex, Qualisys, Sweden) and a force plate (Frequency 600 Hz, Type 4060-10, Bertec, Columbus, OH, USA). Sample frequency for the force plate was synchronized to the camera sampling rate (120 Hz). Thirteen retro-reflective markers were placed as follows; six markers bilaterally (on the acromion, anterior and posterior superior iliac spines), seven markers on the side to be measured only (lateral epicondyle of the humerus, lateral aspect of the iliac crest, greater trochanter, lateral joint line of the knee, lateral malleolus, lateral aspect of the calcaneus, and head of the fifth metatarsal) (Fig. 1) [11,12].

2.3. Contracture simulation and testing procedures

Unilateral knee flexion contractures of 15° and 30° were simulated for each subject using a hard knee brace (G II Rehabilitation Brace, ALCARE, Tokyo, Japan). In this study, the right limb was selected for the contracture simulation. All the subjects were asked to stand relaxed and to walk on a level floor about 10 m at their preferred speed, with or without the contracture simulation. The walking trials included warm ups, and two trials for each of three conditions were measured until clear contact with the force plate was achieved. The measurements for each leg were undertaken independently as follows; first, the measurement of the contracture limb during relaxed standing (placing one foot on a force plate) and walking trials without the contracture (with brace and no restriction of knee extension) were carried out. The measurements of the contracture limb were then repeated with the simulated flexion contractures. Thereafter, the measurements of the contralateral side were carried out during the same procedure with or without the contracture.

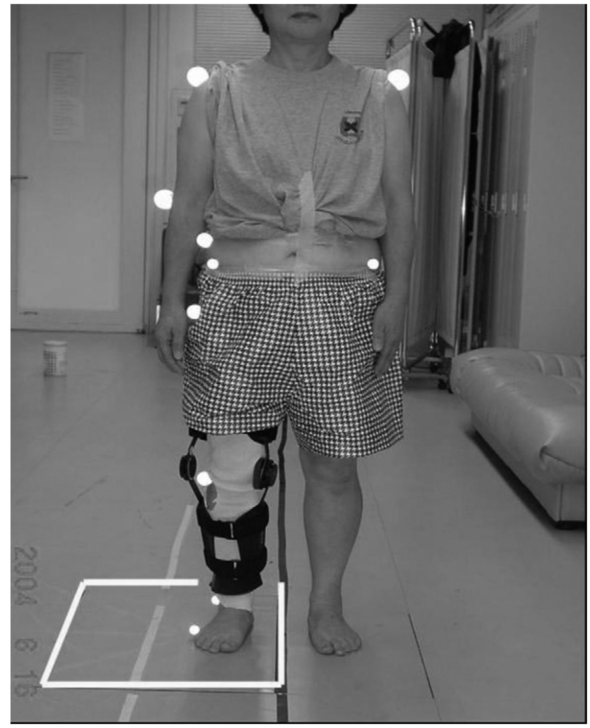

Fig. 1. Relaxed standing and level walking, placing one foot on a force plate.

2.4. Evaluation of the shoulder and trunk motion and knee kinetics

In the coronal plane, the shoulder tilting angle was defined by the height difference in right and left acromions, and the pelvic tilting angle was defined by the height difference in the right and left anterior superior iliac spines (Fig. 2A-a, b). To evaluate trunk tilting in the coronal plane, the shoulder–pelvis bending angle was defined as the angle between the shoulder girdle line (right–left acromion line) and the pelvic line (right–left anterior superior iliac spine line) (Fig. 2A-a, b). To evaluate trunk motion in the sagittal plane, the anterior inclination of the trunk was defined by the slope linked to the contracture side markers on the acromion and iliac crest. Inclination of the pelvis was evaluated by the slope linked to the contracture side markers on the superior anterior iliac spine and superior posterior iliac spine (Fig. 2B-c, d). To evaluate trunk rotation in the axial plane, shoulder–pelvis rotation angle was defined as the angle between the shoulder girdle line and the pelvic line in the axial plane (Fig. 2C-e) [11].

The vertical knee force was calculated with the inverse dynamics approach [13]. The long axis of the tibia was defined as superior–inferior axis, and the external force parallel to this axis was defined as the vertical knee force. The force was normalized to percent body weight of the subjects (%BW). We also evaluated walking velocity (m/s) in each condition.

2.5. Statistical analysis

We evaluated tilting angles of the shoulder and pelvis, anterior inclinations of the trunk, and pelvis, shoulder–pelvis bending angle, shoulder–pelvis rotation angle and bilateral vertical knee force. Maximum of these values during relaxed standing and during