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Biomechanical and neuromuscular adaptations during the landing phase of a stepping-down task in patients with early or established knee osteoarthritis

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A B S T R A C T

Background: To compare the knee joint kinematics, kinetics and EMG activity patterns during a stepping-down task in patients with knee osteoarthritis (OA) with control subjects.
Methods: 33 women with knee OA (early OA, $n = 14$; established OA $n = 19$) and 14 female control subjects performed a stepping-down task from a 20 cm step. Knee joint kinematics, kinetics and EMG activity were recorded on the stepping-down leg during the loading phase.
Results: During the stepping-down task patients with established knee OA showed greater normalized medial hamstrings activity ($p = 0.034$) and greater vastus lateralis-medial hamstrings co-contraction ($p = 0.012$) than controls. Greater vastus medialis-medial hamstrings co-contraction was found in patients with established OA compared to control subjects ($p = 0.040$) and to patients with early OA ($p = 0.023$). Self-reported knee instability was reported in 7% and 32% of the patients with early and established OA, respectively.
Conclusions: The greater EMG co-activity found in established OA might suggest a less efficient use of knee muscles or an attempt to compensate for greater knee laxity usually present in patients with established OA. In the early stage of the disease, the biomechanical and neuromuscular control of stepping-down is not altered compared to healthy controls.

1. Introduction

Osteoarthritis (OA) is a highly prevalent joint disease [1], which has been counted globally as the sixth leading cause of moderate-to-severe disability and the eight cause of burden disease in the European region [2]. Patients with OA commonly experience pain, stiffness, reduction in the range of motion and muscle weakness, factors associated with activity limitations such as the difficulty to stand up from a chair, walk or climb stairs [3,4]. Studies carried out in patients with OA have documented the use of compensatory strategies during gait such as decreased walking speed [5], decreased cadence [6], decreased stride length [7], decreased knee flexion angle during the loading response phase [8], increased step width [9], increased hip internal rotation and increased lateral trunk lean [9]. Modifications in knee loading distribution such as increases in knee adduction moment (KAM) and knee adduction angular impulse have also been reported [10,11]. A direct association between higher KAM and severity of knee AO has been found [10,11].

Changes in electromyography (EMG) activity patterns during gait including increased activity of hamstrings and increased co-contraction have been documented [12]. This increased co-activation might be an adaptation of the individual with OA to deal with pain and instability generated by the loss of joint integrity. In this view, this co-activation could increase the stiffness of the joint promoting knee stability [9]. On the other hand, those gait modifications and increased co-activation could interfere with the distribution of the load on the knee joint, leading to further joint damage and disease progression [8].

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The kinematic and kinetic characteristics during gait and stair climbing have been extensively studied in patients with knee OA in comparison with healthy subjects [8,13,14]. However, analysis of the biomechanical characteristics involved in other activities of daily living like stepping-down from a sidewalk still need to be further analysed, as stepping-down is a task that elicits complaints of instability and pain [15–17]. In addition some studies have differentiated between the characteristics of patients in different stages of the disease (early vs. established OA) but they often did not use MRI to define their groups. Knowledge of the stage in the process in which modifications in movement patterns occur might be helpful in the understanding of disease development and/or progression. It is possible that patients at risk or with early OA, defined as joint pain with structural damage detected on MRI but hardly visible on X-rays [18], respond better to certain interventions than patients with established OA.

Patients with knee OA often complain of knee instability, defined as the sensation of buckling, shifting or giving way, which usually translates into activity limitations [19]. Previous studies have estimated that between 12% and 65% of this group of patients have reported at least one episode of knee instability during the past three months [20,21].

Knee joint stabilization is thought to be influenced by active muscle force contraction and passive ligaments restraints, both of which are usually affected in patients with knee OA [20,22,23]. Evidence has shown an association between self-reported knee instability and isokinetic average knee muscle weakness [21], but not with passive knee laxity in this group of patients [24]. However, failure to control the knee usually occurs during dynamic activities [19]. Therefore, in an attempt to further explore knee stability in patients with OA, recent studies have aimed to identify the objective biomechanical and/or neuromuscular performance characteristics associated with knee instability. Those studies have reported an association between greater knee adduction moment and medial knee laxity during gait [10], and lower medial knee muscle co-contraction prior to platform perturbations in patients with medial compartment knee OA [25]. Nevertheless, to the best of our knowledge the biomechanical and neuromuscular components associated with the sensation of knee instability in those patients have not been fully recognized. In addition, further study of knee instability in patients with early OA might help to clarify the association between knee instability and disease severity. In knee OA, disease progression leads to a structural deterioration which subsequently can cause joint instability, as often mentioned in OA. Nevertheless, joint instability can also contribute to further disease progression [26].

During stair descent loading forces across the knee joints are higher than during stair ascent and level walking, making it a more challenging task requiring good neuromuscular control to obtain good shock absorption and knee stability [27,28]. Particularly the early stance phase is important during which the ground reaction forces need to be attenuated (by eccentric muscle activity) as weight is loaded onto one limb [27]. Therefore, the stance phase of a step-down task was assessed in the present study to represent the stance phase of stair descent. The stepping-down task has been used successfully to study movement strategies in elderly subjects [29] and dynamic knee instability in a patient with anterior cruciate ligament deficiency [16,30]. Therefore, the purpose of this study was to investigate the joint kinematics, kinetics and EMG activity patterns in patients with early or established OA of the knee during a stepping-down task.

We hypothesise that the analysis of knee kinematics, kinetic and EMG activity during the performance of the stepping-down task might elucidate relevant biomechanical characteristics associated with compensatory strategies for instability or pain used by patients with knee OA (early and established). Secondarily, this task might help to explore biomechanical and neuromuscular strategies associated with self-reported knee instability in this group of patients. The results might contribute to the design of intervention strategies directed to treat difficulties of mobility and knee instability in patients with knee OA.

2. Methods

2.1. Subjects

A convenience sample of 47 females was included in this study (Table 1). Patients with OA ($n = 33$) were recruited by a rheumatologist or orthopaedic surgeon from the University Hospitals Leuven. Fourteen patients were classified as early OA based on a combination of pain, Kellgren/Lawrance (KL) score = 0 or 1 on radiography and presence of at least two of four MRI criteria: (1) ≥BLOCKS grade 2 for size cartilage loss, (2) ≥BLOCKS for percentage full-thickness cartilage loss, (3) signs of meniscal degeneration, and (4) ≥BLOCKS for size of BMLs in any compartment [18]. Nineteen patients were classified as unilateral or bilateral established knee OA based on the criteria from the American College of Rheumatology (ACR) [31] and KL ≥ 2 ± [32,33]. Control subjects ($n = 14$) with no history of knee symptoms or characteristics associated with knee OA and KL = 0 were recruited from cultural or social organizations. Demographic, clinical, radiographic, neuromuscular and biomechanical factors related to OA were assessed. Total knee replacement, rheumatoid arthritis or any other form of inflammatory arthritis (i.e. crystal arthropathy, septic arthritis, spondylarthropathy) were considered exclusion criteria. All the participants provided written inform consent before testing. The study was approved by the local Ethics Committee.

2.2. Measures

2.2.1. Loading phase of stepping-down task

The subjects were instructed to step down from a wooden step (20 cm) (Figure 1) onto a force plate with the evaluated limb and to step forward with the other limb. Subjects ended in quiet stance on both legs in front of the force plate (Figure 2). The arms were kept flexed across the chest to avoid obstruction of the visibility of the reflective markers. All patients wore standard sport shoes (kelme indoor copa). A task cycle was considered from the first contact with the force plate (touch-down) until the toe-off from the force plate with the evaluated limb. In a single session, three trials per patient were recorded. Both limbs were assessed but only the index leg (see statistical analysis) was included in the analysis.

2.2.2. Knee instability

Self-reported knee instability was evaluated based on a questionnaire from Felson et al. [19,20] in which a sensation of knee buckling, shifting or giving away during the past three months was inquired. Persons reporting knee instability were additionally asked for the number of episodes of instability, on which leg it was experienced. Knee instability was dichotomized as "0" if they did not report episodes and "1" if they reported episodes of instability during the past three months [18]. An additional question about history of knee injury ("Did you ever have a knee injury?" yes/no) was formulated to persons who reported to have had at least one episode of knee instability, this with the intention to explore whether the sensation of instability could be due to another cause such as traumatic injury.

2.2.3. Muscle strength

Knee muscle strength was assessed using the Biodex System 3 Pro (Biodex Medical System, Shirley, NY, USA). An initial practise attempt was used for the participants to become familiar with the movements required. The patients performed three maximal test repetitions to measure the isokinetic strength of the knee extensor muscles (mainly quadriceps) and knee flexor muscles (mainly hamstrings) for each knee, at 60°/s." [34]. Isometric knee extension and flexion were measured in 60° flexion position. The peaks of three trials were averaged in each leg separately for isometric and isokinetic assessments (quadriceps and hamstrings torques (Nm)) and divided by patient's weight