Chapter 6

Biomechanical and neuromuscular adaptations during a stepping-down task in relation to self-reported instability in patients with early or established knee osteoarthritis

D. C. Sanchez-Ramirez

B. Malfait

I. Baert

M. van der Leeden

J. van Dieen

W. Lems

J. Dekker

Frank P. Luyten

S. Verschueren

Submitted

Abstract

Purpose. To compare the knee joint kinematics, kinetics and muscle activity patterns during a stepping-down task in patients with knee osteoarthritis (OA) with control subjects, and to assess associations with self-reported knee instability.

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 20cm box. Knee joint kinematics, kinetics and muscle 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. None of the characteristics studied during the stepping-down task were significantly different between patients with or without self-reported knee instability. Self-reported knee instability was significantly associated with lower knee muscle strength.

Conclusions. Greater muscle activity in established OA might suggest a less efficient use of knee muscles or an attempt to compensate greater knee laxity usually present in patients with established OA. Muscle weakness was found to be a relevant factor associated with self-reported knee instability in patients with knee OA. Neuromuscular and strength training might help to enhanced co-activity patterns as well as contribute to counteract the feeling of instability in OA patients.

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). Previous studies in patients with OA have documented the use of compensatory strategies during activities including alterations in spatiotemporal kinematic and kinetic aspects of gait such as decreased walking speed (5) and cadence (6), decreased stride length (7), decreased knee flexion angle (8), increased step width (9), increased hip internal rotation and increased lateral trunk lean (9). Modifications in knee loading distribution such as increase in knee adduction moment and knee adduction angular impulse have also been reported (10;11). Moreover, changes in muscle activity patterns during gait including increased activity of hamstrings and increased co-contraction have been documented (12). Those modifications could interfere with the distribution of the load on the knee joint, leading to further joint damage and disease progression (8).

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). In addition some of those studies have differentiated between the characteristics of patients in different stages of the disease (early vs. established OA). However, previous studies often did not use MRI to define their groups. Knowledge of the stage in the process in which modification in movement patterns occur might be helpful in the understanding 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 (15), respond better to certain interventions. Additionally, analysis of the biomechanical characteristics involved in other activities of daily living like stepping-down from a sidewalk still need to be further analyzed.

Patients with knee osteoarthritis (OA) often complain of knee instability, defined as the sensation of buckling, shifting or giving way, which usually translates into activity limitations (16). 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 (17;18). 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 (17;19;20). Previous studies have shown an association between self-reported knee instability and isokinetic average knee muscle weakness (18), but not with passive knee laxity in this group of patients (21). However, failure to control the knee usually occurs during dynamic activities (16). 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 (22). 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, assessment of self-reported knee instability has not been specifically reported in patients with early OA.

The stepping-down task has been used to study movement strategies in elderly subjects (23) and dynamic knee instability in a patient with anterior cruciate ligament deficiency (24). This task has been considered helpful for the analyses of the knee under load-bearing conditions during a dynamic activity due to its similarity with common daily activities, such as going down from the sidewalk on the street, and to its challenge to muscle strength and neuromuscular control of the lower limb. Therefore, the purpose of this study was to investigate the joint kinematics, kinetics and muscle activity patterns in patients with early or established OA of the knee during a stepping-down task, and to assess their associations with self-reported knee instability.

We hypothesize that the analysis of knee kinematics, kinetic and muscle activity during the performance of the stepping-down task might elucidate relevant biomechanical characteristics associated with compensatory strategies 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.

Patients and Methods

Subjects

Forty seven females were included in this study. Patients' characteristics are presented in Table 1. Patients with OA (*n*=33) were remitted 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 (15). Nineteen patients were classified as unilateral or bilateral established knee OA based on the criteria from the American College of Rheumatology (ACR) (25) and KL≥2± (26;27). 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.

Measures

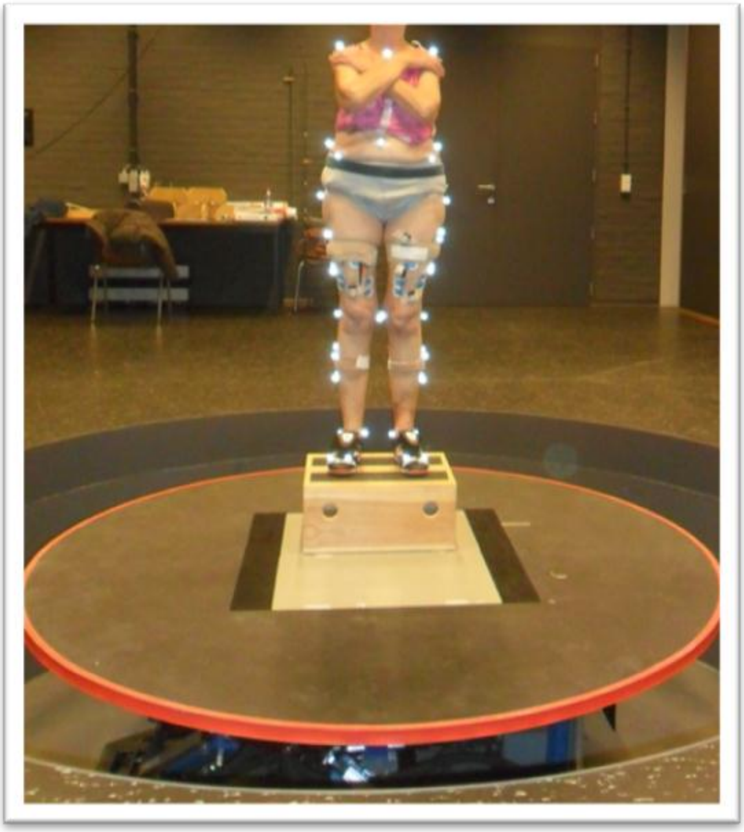


Figure 1. Subject in the initial position

Stepping-down task. The subjects were instructed to step down from a wooden step (20cm) (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.

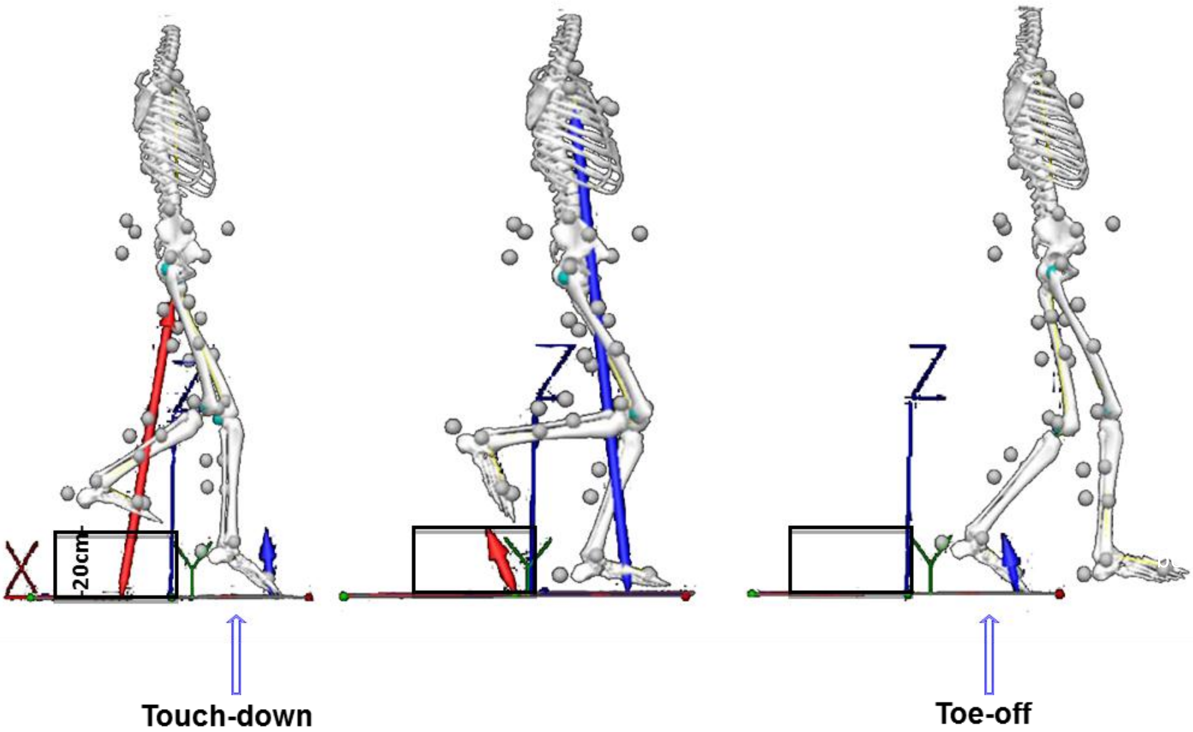


Figure 2. Stepping-down task

Knee instability. Self-reported knee instability was evaluated based on a questionnaire from Felson et al. (16;17) in which a sensation of knee buckling, shifting or giving away during the past 3 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 1 or more episodes of instability during the past 3 months.

Muscle strength. Knee muscle strength was assessed using the Biodex System 3 Pro (Biodex Medical System, Shirley, NY, USA). An initial practice attempt was used for the participants to become familiar with the movements required. The patients performed three maximal test repetitions to measure isokinetic strength of the quadriceps and hamstrings for each knee, at 60°/second (28). Isometric knee extension and flexion were measured in 60° flexion position. The average peak quadriceps and hamstrings torques of the three tests per leg was calculated (Nm) and divided by patient's weight (kg). This measure (in Nm/kg) has excellent intra-rater reliability (ICC 0.93) in knee OA patients (29;30).

Knee joint alignment. Knee alignment was measured from anterior-posterior weight bearing radiograph of the lower limbs (Oldelft, Triahlon, Afga ADC M Compact Plus) by a single experienced observer. The alignment of the mechanical axis was reported as varus if ≤-3°or valgus if ≥3°. Knee alignment between -3° and 3° was classified as neutral (31;32).

Activity Limitation. Activity limitations were assessed subjectively using the Dutch version of the Knee Injury and Osteoarthritis Outcome Score (KOOS) (33) which ranges from 0 (bad outcome) to 100 (good outcome), and objectively using the stairs test and the get up and go test (GUG). In the stairs test (29), subjects were instructed to climb 5 stairs steps (15cm high), turn around and descend the stairs. Participants were encouraged no to use the handrail, but were not prohibited from doing so for safety. In the GUG test (29), subjects were sitting on a high standard chair (49cm), they were told to stand up without help of the arms on the command "go", and walk 3 metres through an unobstructed corridor as fast as possible, without running. Once they reached a mark on the floor, the subjects turned around, returned to the chair and sat down. Patients who normally used walking devices were allowed to use them during the test. All subjects were wearing standard sport shoes during the performance of the tests. The time in seconds was recorded for both tests; longer time was considered a higher activity limitation. For each test, the mean value of three trials was calculated. Both tests have shown good reliability and validity (29).

Pain and symptoms. Pain was assessed with the visual analogue scale (VAS), the patient was asked to range the sensation of pain during the last week from 0 (none) to 10 (high pain). The Dutch version of the KOOS questionnaire was also used to assess pain and general symptoms, ranging them from 0 (bad outcome) to 100 (good outcome) (33).

Data capture

The stepping-down task was tracked using 6 MX-T20 optoelectronic cameras (Vicon, Oxford Metrics, UK) collected at 100Hz in Nexus (Vicon). Eight body segments (trunk, pelvis, upper-lower legs and feet) were identified by 46 spherical reflective markers of 14 mm diameter (34). Simultaneously (time synchronized), data from the force plate (AMTI Watertown, MA, USA) and the electromyography (EMG) were sampled at 1000 Hz.

Muscle activity of the vastus medialis (VM), vastus lateralis (VL), medial hamstrings (MH) and lateral hamstrings (LH) was recorded bilaterally using a 16-channel system wireless surface EMG system (Aurion, Italy) and silver-silver chloride, pre-gelled bipolar surface EMG electrodes (Ambu Blue Sensor, Ballerup, Danmark). The electrodes were placed over the muscle belly 2cm center-to center in line with the muscle fibres, and with an inter-electrode distance of 3cm to reduce the possibility of cross-talk between neighbouring muscles (35). Isolated manual muscle test (36) were used to validate the placement of the electrodes and to assess for cross talk (37). Skin surface was previously shaved and cleaned with 70% isopropyl alcohol to reduce impedance.

Data processing and analysis

Separate trials were used for anatomical calibration and for calculation of hip and knee joint centres and functional axis of the model (38-40). Marker trajectories and force plate data were both filtered using a 4^{th} order low pass Butterworth filter with a cut off frequency of 20 Hz (41). Touch-down and toe-off events were defined based on the vertical force crossing a 20N threshold. Joint knee flexion angles were calculated at touch-down and at the point of peak knee flexion during the task (PKFA) (Figure 3). Knee adduction moment, defined as the external load applied at the joint moving the tibia to varus position was calculated using inverse dynamics and normalized to body weight (Nm/kg). The peak knee adduction moment (PKAM) as well as the integral of the knee adduction angular impulse (KAAI) over the stance phase (Nms/kg) were included in the analyses. The average of 3 stepping-down trials was calculated for all biomechanical parameters for each participant. All modelling and analyses were undertaken in Visual 3D (v.4.83, C-motion, Germantown, MD, USA).

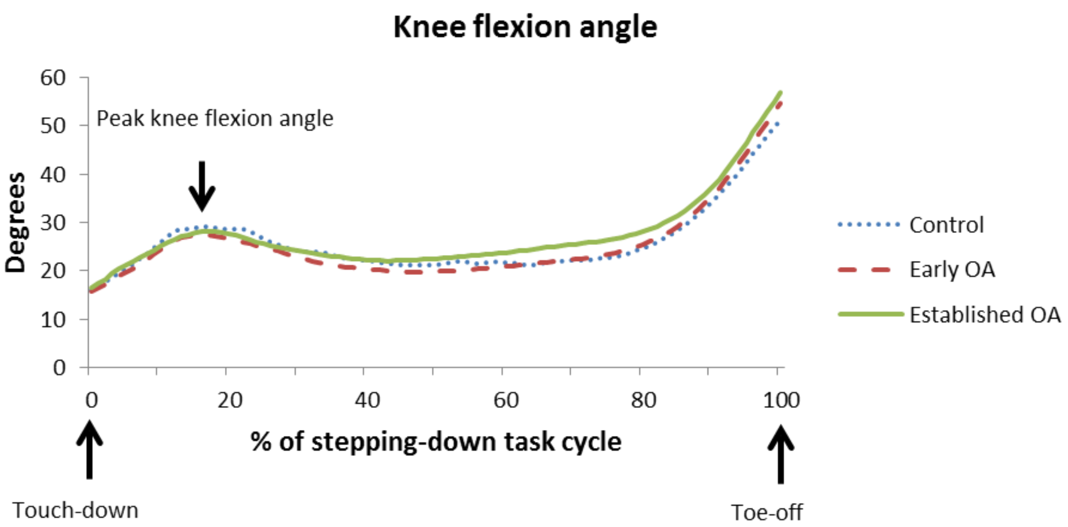
EMG signals were high pass filtered at a cut-off frequency of 10 Hz (42). The rectified EMG signals were also filtered with a 4^{th} order zero-lag low pass Butterworth filter at a cut-off frequency of 50 Hz and subsequently normalized to the peak muscle activity of each muscle during the stepping-down task cycle (43;44). Figure 4 shows the EMG amplitude of the muscle activity from touch-down to the PKFA during the stepping-down task (Figure 4). The root mean square (RMS) from touch-down to the PKFA was calculated for each muscle on the stepping-down leg.

Muscle co-contraction index (CCI) for the medial (VMMH=vastus medialis-medial hamstrings) and lateral (VLLH=vastus lateralis-lateral hamstrings) sides of the knee joint, as well as for the oblique surface of the knee joint (VLMH= vastus lateralis-medial hamstrings), were calculated from touch-down to the PKFA according to the following equation (45):

$$CCI = EMGS/EMGL \times (EMGS + EMGL)$$

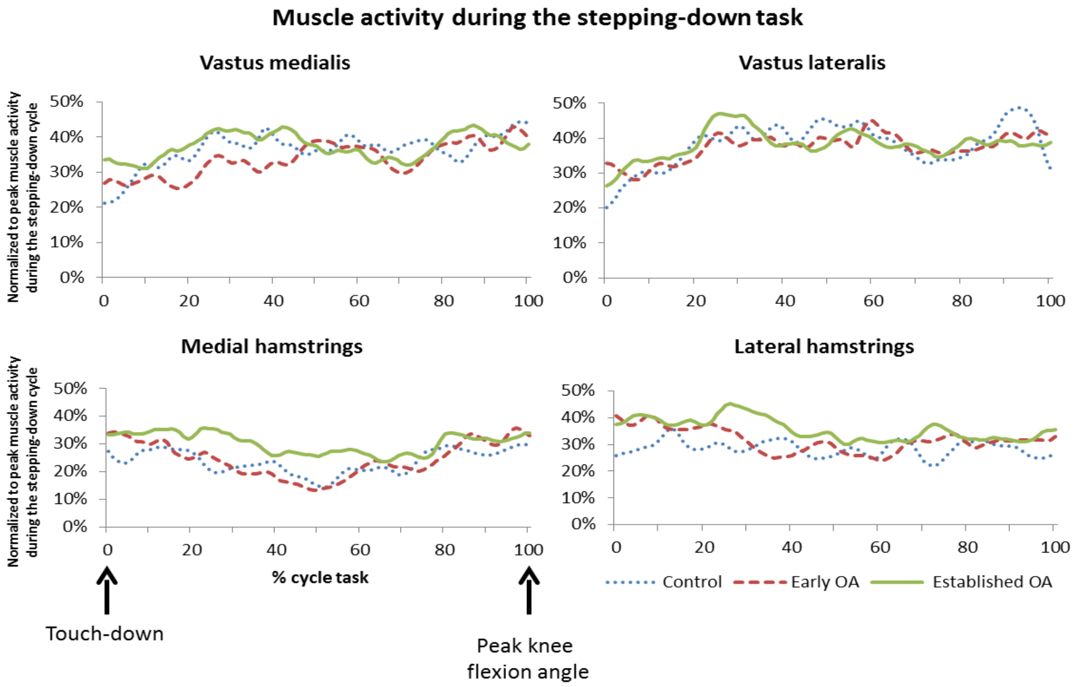
in which EMGS is the normalized magnitude of the EMG signal for the less active muscle and EMGL is the normalized magnitude of the EMG signal for the most active muscle. To determine whether medial to lateral co-contraction was imbalanced muscle co-contraction medial to lateral ratio was calculated dividing medial co-contraction index with lateral co-contraction index (46).

Figure 3



Lines represent the mean knee flexion angle per groups.

Figure 4



Muscle activity of the loading leg was analyzed during the stepping-down cycle from the touch down (0%) to the peak knee flexion angle (100%). Lines represent the mean muscle activity per groups.

Statistical analysis

For the patients with knee OA an index knee was selected using the following decision tree: 1) knee with established or early OA (ACR and KL score), if OA diagnosis was the same in both knees, 2) instable knee and 3) painful knee. In participants in whom an index knee could not be defined based on these signs, a random index joint was assigned. For the control subjects the right knee was used as reference. The variables related to the index knee were used in the analyses.

Descriptive statistics were used to characterise the study population, as well as the patients with knee OA and control subjects separately. Percentages were used for categorical variables, and means and SDs for continuous variables. ANOVA and chi-square tests were used to analyse the differences in the distribution of the variables between the three subgroups.

One-way analyses of variance (ANOVA -Tukey post hoc tests) were used to test the group difference in knee joint angles, external moments and muscle activity between subjects with established OA, early OA and control subjects. Chi square tests (χ^2) were used to compare self-reported knee instability between the study groups. Independent t-tests were used to compare the patients' characteristics, joint kinematics, kinetics and muscle activity patterns during a stepping-down task in patients with and without self-reported knee instability. Pearson correlation coefficients were used to analyse the correlation between the main variables of the study and self-reported knee instability in patients with OA. Statistical significance was accepted at p-values ≤ 0.05. All analyses were performed using SPSS software, version 17.0 (SPSS, Chicago, IL).

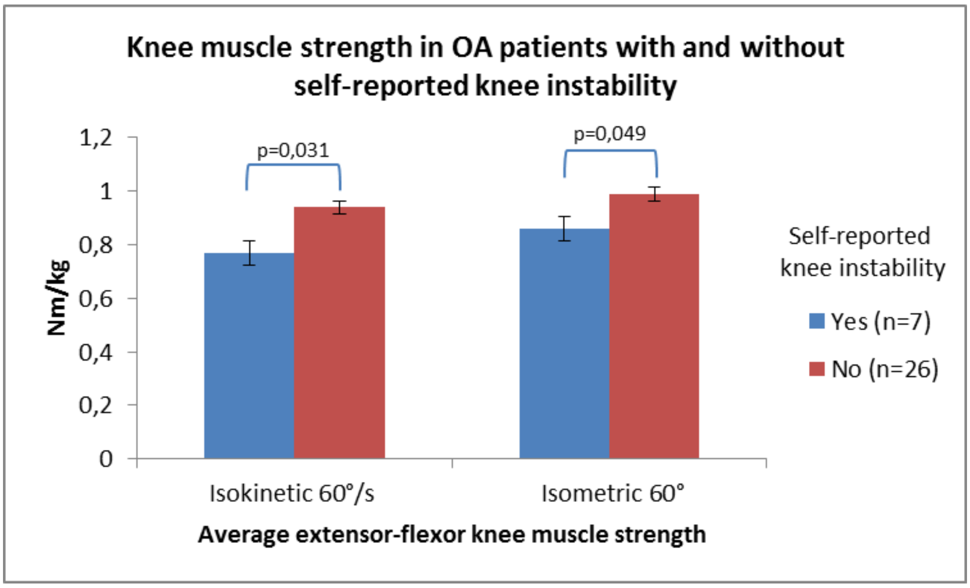
RESULTS

Descriptives. The mean age of the females that participated in the study was 68.9 years (SD 5.4). Patient with established knee OA had significantly more knee pain (p=0.029) and lower isometric knee flexor muscle strength than the control group (p=0.011). No significant group differences were found in other variables assessed including activity limitations. Further, demographic, clinical and neuromuscular characteristics are shown in the Table 1.

Knee biomechanics and muscle activity patterns during the stepping-down task. There were no significant differences in kinematics or kinetics between the groups with knee OA (early-established) and/or the control group 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) compared with the control subjects. Higher vastus medialis-medial hamstrings co-contraction was found in patients with established OA compared with control subjects (p=0.040) and to patients with early OA (p=0.023)(Table 2).

Self-reported knee instability. Seven patients (15%) with knee OA (early n=1; established n=6) reported to have at least one episode of knee instability during the past three months. The incidence of instability was significantly higher in the group with established OA compared with the control (p=0.020). None of the characteristics studied such as the biomechanics and muscle activity patterns during the performance of the stepping-down task (Table 3), knee joint alignment or activity limitations (Table 4) were significantly different between patients with or without self-reported knee instability. However, patients with self-reported knee instability showed significantly lower knee muscle strength compared with subjects without self-reported knee instability (Figure 5).

Figure 5



DISCUSSION

This study investigated the biomechanical and neuromuscular strategies during a stepping-down task in a group of patients with early or established knee OA compared to a healthy control group. Furthermore, the association of these strategies with self-reported knee instability was explored. The main study results showed no difference in the kinematic or kinetic characteristics during the stepping-down task between the three groups. However, greater muscle (co-)activity patterns were observed in patients with established knee OA compared with control subjects and patients with early OA. In patients with knee OA, lower muscle strength was associated with self-reported knee instability.

There were no significant differences in kinematics or kinetics during the stepping-down task between patients with early or established OA, and control subjects. Previous studies have reported greater knee flexion angle at touch-down during gait in patients with knee OA which might influence the decreased flexion excursion of the knee during the loading response of the stance phase (7;8;13). Decreased knee flexion angle excursion was reported in patients with established knee OA also during a step task (8). However, in the present study, we found no significant difference on the knee flexion angle at touch-down, at peak knee flexion during the stance phase or in flexion excursion between the three groups studied during the performance of the stepping-down task.

Table 1. Characteristics of study group

	Total group (n=47)	Control subjects (n=14)	Early Knee OA (n=14)	Established Knee OA (n=19)	*P*- value	Post hoc *P*- value		
						Established vs control	Early vs control	Established vs early
Basic characteristics								
Age, in years	68.85±5.4	68.0±3.9	70.4±4.6	68.37±6.7	0.457			
Height, m	1.62±0.1	1.63±0.1	1.63±0.1	1.59±0.1	0.080			
Weight, kg	71.9±9.9	69.9±9.3	73.6±10.3	72.1±10.4	0.621			
Body Mass Index, kg/m²	27.6±4.2	26.2±2.9	27.8±4.7	28.5±4.6	0.290			
K/L score, n (%)								
0	14(30)	14(100)	-	-				
1	14(30)	-	14(100)	-				
≥2±	19(40)	-	-	17(100)				
Clinical characteristics								
Knee Pain (0-10)	1.94±2.4	0.86±1.3	1.64±2.2	2.95±2.7	0.033*	0.029*	0.624	0.233
KOOS Pain score (0-100)	84.39±14.0	91.24±8.4	82.71±15.7	80.36±14.8	0.078			
KOOS Symptoms score (0-100)	80.54±16.2	89.50±10.1	78.77±15.4	74.96±18.2	0.033*	0.028*	0.163	0.764
Self-reported knee instability, n (%)	7(15)	0(0)	1(7)	6(32)	**0.026***	**0.020***	**0.309**	**0.090**
Knee static alignment								
Varus (-) or valgus (+), degrees	0.14±2.9	1.06±2.1	-0.56±2.5	-0.61±3.6	0.216			
Neutral (-3 and 3 degrees), n (%)	31 (66)	11(79)	12(86)	8(42)	**0.027***	**0.051**	**0.622**	**0.017***
Varus ≤ -3 degrees, n (%)	7(15)	2(14)	1(7)	5(26)	**0.164**			
Valgus ≥3 degrees, n (%)	8(17)	1(7)	1(7)	5(26)	**0.337**			
missing, n (%)	1(2)	0(0)	0(0)	1(6)				

continue table 1

	Total group (n=47)	Control subjects (n=14)	Early Knee OA (n=14)	Established Knee OA (n=19)	*P*- value	Post hoc *P*- value		
						Established vs control	Early vs control	Established vs early
Muscle strength								
Isokinetic 60°/s								
Average knee muscle strength (Nm/kg) α	0.93±0.2	1.00±0.2	0.88±0.2	0.91±0.2	0.242			
Extensor muscle strength (Nm/kg)	1.09±0.3	1.20±0.3	1.01±0.2	1.08±0.3	0.227			
Flexor muscle strength (Nm/kg)	0.74±0.2	0.81±0.2	0.76±0.2	0.68±0.2	0.085			
Isometric 60°								
Average knee muscle strength (Nm/kg) α	1.01±0.2	1.10±0.2	0.99±0.2	0.95±0.1	0.078			
Extensor muscle strength (Nm/kg)	1.34±0.3	1.43±0.4	1.28±0.2	1.30±0.3	0.362			
Flexor muscle strength (Nm/kg)	0.68±0.1	0.76±0.1	0.68±0.2	0.62±0.1	0.015*	0.011*	0.217	0.445
Activity Limitations								
KOOS ADL score (0-100)	86.96±12.9	94.21±6.5	83.56±13.2	83.78±14.7	0.037*	0.058	0.066	0.999
Stair climbing test, seconds	5.72±1.1	5.67±1.1	5.50±1.1	5.94±1.0	0.510			
Get up and go test, seconds	6.68±1.6	6.53±1.7	6.28±1.4	7.09±1.6	0.338			
Cycle time stepping-down task §, seconds	1.06±0.2	1.07±0.2	1.09±0.2	1.04±0.2	0.734			

Mean ± standard deviation (sd), unless other stated. OA= osteoarthritis; K/L= Kellgren/Lawrence; α Average knee extensor and flexor muscle strength; §Time from touch-down to toe-off. **Bold χ^2.** *$p \leq 0.05$ significant difference between groups.

Table 2. Kinematics, kinetics and muscle activity during the stepping-down task

	Control (*n*=14)	Early OA (*n*=14)	Established OA (*n*=19)	*P*- value	Post hoc *P*- value		
					Established vs control	Early vs control	Established vs early
Kinematics and kinetics							
Knee flexion angle at touch-down, degrees	16.01±3.0	15.66±3.5	16.78±4.0	0.651			
Peak knee flexion angle (PKFA), degrees	31.01±6.1	29.02±4.2	30.59±6.7	0.636			
Knee flexion excursion, degrees	15.00±4.4	13.36±3.8	13.81±4.3	0.568			
Peak knee adduction moment (PKAM), Nm/Kg	0.37±0.4	0.29±0.1	0.30±0.3	0.697			
Knee adduction angular impulse moment (KAAI), Nms/Kg	0.23±0.3	0.16±0.1	0.17±0.2	0.598			
Peak knee flexion moment, Nm/Kg	-0.68±0.4	-0.65±0.1	-0.69±0.3	0.908			
Peak knee external rotation moment, Nm/Kg	-0.07±0.1	-0.07±0.1	-0.10±0.1	0.617			
Muscle activity§							
Vastus Medialis (VM)	0.42±0.1	0.41±0.1	0.43±0.1	0.720			
Vastus Lateralis (VL)	0.44±0.1	0.43±0.1	0.43±0.1	0.902			
Medialis Hamstrings (MH)	0.29±0.1	0.30±0.1	0.37±0.1	0.025*	0.034*	0.909	0.093
Lateral Hamstrings (LH)	0.33±0.1	0.36±0.1	0.39±0.1	0.298			
VMMH co-contraction	0.50±0.2	0.48±0.1	0.64±0.2	0.012*	0.040*	0.976	0.023*
VLLH co-contraction	0.55±0.2	0.64±0.2	0.65±0.2	0.310			
VLMH co-contraction	0.47±0.2	0.51±0.2	0.64±0.2	0.009*	0.012*	0.791	0.064
VMMH/VLLH co-contraction ratio	0.98±0.3	0.89±0.5	1.04±0.4	0.605			

§Root Mean square from touch-down to PKFA during the stepping-down task. Mean ± standard deviation (sd). *$p \leq 0.05$ significant difference between groups.

Table 3. Kinematics, kinetics and muscle activity during the stepping-down task

	Patients with OA *n*=33				
	Self-reported knee instability				
	Yes (*n*=7)	No (*n*=26)	*p*-value	*r*	*p*-value
Kinematics and kinetics					
Knee flexion angle at touch-down, degrees	15.12±5.4	16.62±3.2	0.355	-0.166	0.355
Peak knee flexion angle, degrees	30.09±8.2	29.88±5.1	0.951	0.015	0.934
Knee flexion excursion, degrees	14.97±3.5	13.26±4.2	0.331	0.174	0.331
Peak knee adduction moment (PKAM), Nm/Kg	0.28±0.4	0.30±0.2	0.874	-0.029	0.874
Knee adduction angular impulse moment (KAAI), Nms/Kg	0.22±0.1	0.15±0.2	0.249	0.206	0.249
Peak knee flexion moment, Nm/Kg	-0.73±0.4	-0.65±0.2	0.659	-0.125	0.490
Peak knee external rotation moment, Nm/Kg	-0.11±0.2	-0.08±0.1	0.705	-0.102	0.572
Muscle activity§					
Vastus Medialis (VM)	0.43±0.1	0.41±0.1	0.566	0.104	0.566
Vastus Lateralis (VL)	0.43±0.1	0.43±0.1	0.948	0.012	0.948
Medialis Hamstrings (MH)	0.36±0.1	0.34±0.1	0.507	0.120	0.507
Lateral Hamstrings (LH)	0.38±0.1	0.38±0.1	0.857	0.033	0.857
VMMH co-contraction	0.60±0.2	0.57±0.2	0.683	0.074	0.683
VLLH co-contraction	0.63±0.2	0.65±0.2	0.841	-0.036	0.841
VLMH co-contraction	0.60±0..2	0.58±0.2	0.834	0.038	0.834
VMMH/VLLH co-contraction ratio	1.04±0.5	0.96±0.4	0.684	0.073	0.684

§Root Mean square from touch-down to PKFA during the stepping-down task. Data are presented as mean ± standard deviation (sd) and *r*= Pearson correlation coefficient.

Table 4. Correlations of self-reported knee instability with muscle strength, knee alignment and activity limitations

	Patients with OA *n*=33				
	Self-reported knee instability				
	Yes (n=7)	*No (n=26)*	*p*-value	*r*	*p*-value
Muscle strength					
Isokinetic 60°/s					
Average knee muscle strength (Nm/kg)	0.77±0.2	0.94±0.2	0.031*	-0.375	0.031*
Extensor muscle strength (Nm/kg)	0.96±0.4	1.07±0.3	0.372	-0.161	0.372
Flexor muscle strength (Nm/kg)	0.57±0.2	0.75±0.1	0.010*	-0.441	0.010*
Isometric 60°					
Average knee muscle strength (Nm/kg)	0.86±0.2	0.99±0.2	0.049*	-0.345	0.049*
Extensor muscle strength (Nm/kg)	1.14±0.4	1.34±0.2	0.084	-0.305	0.084
Flexor muscle strength (Nm/kg)	0.58±0.1	0.66±0.1	0.149	-0.257	0.149
Knee static alignment					
Varus (-) or valgus (+), degrees	0.20±3.6	-0.77±3.0	0.499	0.124	0.499
Activity Limitations					
KOOS ADL score	77.17±11.4	78.11±17.8	0.203	-0.235	0.203
GUG	7.34±1.7	6.59±1.6	0.272	0.197	0.272
SCT	5.90±1.0	5.71±1.1	0.687	0.074	0.687

OA= osteoarthritis; ADL= Activities of daily living; GUG= Get up and go test; SCT= Stair climbing test; α Average knee extensor and flexor muscle strength. Data are presented as mean ± standard deviation (sd) and *r*= Pearson correlation coefficient.

Peak knee adduction moments and knee adduction angular impulse during the stepping-down task were not significantly different between the groups. Previous studies have found higher adduction moments during gait in patients with established knee OA in the medial compartment (10;11;47). The discrepancy with the present study might be explained by the more heterogeneous distribution of the structural features in the knee joint (48). Though patients of the present study exhibited more structural damage in the medial compartment of the knees, radiographic and MRI features in the lateral tibio-femoral compartment of the osteoarthritic knees were also present within the study group. In addition, differences with previous studies with respect to knee adduction moments might be due to the different task analyzed in the present study (stepping-down task).

Greater medial hamstrings (MH) activity was exhibited in patients with established knee OA compared with control subjects. Additionally, greater medial muscle co-contraction (VMMH) was found in patient with established OA compared to control subjects and to patients with early knee OA. These are in accordance with previous studies on gait and may reflect an effort to compensate higher medial knee laxity, usually present in patients with established OA (20-22). Additionally, greater co-contraction of the posterior-medial (MH) and the lateral-anterior (VL) side of the knee was found in the group of patients with established knee OA compared with the control subjects. According to Rudolph et al. (45) high-level co-contraction of opposing muscle groups could result in higher joint compression. These findings suggest not only a higher medial compression of the medial knee compartment of the knee, but also an overall increase in the compressive load through the knee surface in patients with established OA. Previous studies have suggested that an increase in muscle co-contraction may lead to an increase of the cumulative load on the knee, which in turn might translate in further knee joint damage and disease progression (8).

Neuromuscular training, such as agility and perturbation training, directed to decrease knee muscle co-contraction might help to protect the knee from further joint damage (49). Studies carried out in other patient´s populations (50;51) have demonstrated that neuromuscular training can improve instability and promote more selective muscle recruitment. In addition, greater muscle activity might be associated to a less efficient use of the knee muscles (52). Therefore, it is possible that muscle training might also contribute to counteract greater muscle activity patterns present in patients with established OA. On the other hand, greater muscle co-contraction patterns in combination with other movement modifications such as decreased knee flexion angles and knee flexion excursion contribute to stiffness of the joint in absence of sophisticated adaptations to compensate knee instability and/or avoid knee pain (50) in patients with established OA (8;22). Those performance characteristics might be necessary to achieve more effective ambulatory strategies. Therefore, if patients are treated with the intention to decrease joint compression, functionality may be sacrificed (53). Further studies are needed to clarify the different perspectives mentioned and to accurately propose the intervention most suitable for each particular case.

We are aware of the fact that difference in patients' height might have a potential influence on descending from a step (54). However, there were no statistical differences in height between the 3 study groups (Table 1). Additionally, a 20cm step is considered a standard step height mimicking daily live scenarios involving stairs regardless of the patients´ height.

Seven patients with knee OA without known history of knee injury reported to have at least one episode of knee instability during the past three months. However, none of the participants reported to have a feeling of knee instability during the performance of the stepping-down task in our laboratory. In the present study, incidence of instability seems to increase with the severity of the disease. However, to the best of our knowledge there is no existing evidence to prove this finding and the sample of patients with knee instability in this study is too small to draw this conclusion. We hypothesized that the study of biomechanical characteristics of subjects with self-reported knee instability during the stepping-down task might be useful to objectively identify performance characteristics associated with knee instability, which could contribute to develop appropriate strategies oriented to counteract instability in those patients. However, probably due to the small number of patients with self-reported knee instability within our study group, the results of this study do not support our hypothesis. Therefore, studies in a larger sample population with self-reported knee instability during the performance of a more challenging task might be needed to further clarify whether or not biomechanical and neuromuscular performance based characteristics might be associated with the feeling of instability in patients with knee OA.

Self-reported knee instability was associated with lower muscle strength. This association has been previously reported in patients with knee OA (18) and in the general population (17). However, studies have focused mainly on the analysis of the average (18) and extensor (17) knee muscle strength and their association with knee instability. In the present study, we incorporated isokinetic and isometric knee muscle strength in the analysis. We found lower average knee muscle strength, as well as lower extensor and flexor muscle strength separately, in the group of patients with self-reported knee instability. From the clinical perspective, muscle strength training of both extensor and flexor seems to be a potentially effective mechanism to counteract self-reported knee instability in patients with knee OA until now.

In patients with established knee OA, neuromuscular training leading to a selective muscle activity instead of co-contraction patterns, as well as static and dynamic muscle strength training (both extensor and flexor knee muscles) may be recommended to preserve joint integrity and to reduce knee instability. Nevertheless, it is possible that a decrease in muscle co-contraction might affect knee stability. Further studies are needed to disentangle which of the biomechanical and neuromuscular performance based characteristics are driven by pain, instability, structural changes and/or other factors. Overall, it appears necessary to optimize the rehabilitation strategies directed to decrease an abnormal joint loading during diverse activities of daily living in patients with OA. This might potentially contribute to slow down the joint damage and subsequent increase in activity limitations in this group of patients.

Acknowledgements

We would like to thank C. Smolders and A. Mahmoudian for their assistance in gathering the data. This study was funded by the European Commission, through the Erasmus Mundus Joint Doctorate Move-age program (2011-2015). The study sponsor had no involvement in the study.

References

(1) Zhang Y, Jordan JM. Epidemiology of osteoarthritis. Clin Geriatr Med 2010 Aug;26(3):355-69.

(2) World Health Organization. The Global Burden of Disease -2004 Update-. 2008.

(3) Davis MA, Ettinger WH, Neuhaus JM, Mallon KP. Knee osteoarthritis and physical functioning: evidence from the NHANES I Epidemiologic Followup Study. J Rheumatol 1991 Apr;18(4):591-8.

(4) World Health Organization. International classification of functioning, disability and health:ICF. Geneva: WHO; 2001.

(5) Astephen JL, Deluzio KJ. Changes in frontal plane dynamics and the loading response phase of the gait cycle are characteristic of severe knee osteoarthritis application of a multidimensional analysis technique. Clin Biomech (Bristol , Avon) 2005 Feb;20(2):209-17.

(6) Chen CP, Chen MJ, Pei YC, Lew HL, Wong PY, Tang SF. Sagittal plane loading response during gait in different age groups and in people with knee osteoarthritis. Am J Phys Med Rehabil 2003 Apr;82(4):307-12.

(7) Baliunas AJ, Hurwitz DE, Ryals AB, Karrar A, Case JP, Block JA, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. Osteoarthritis Cartilage 2002 Jul;10(7):573-9.

(8) Childs JD, Sparto PJ, Fitzgerald GK, Bizzini M, Irrgang JJ. Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis. Clin Biomech (Bristol , Avon) 2004 Jan;19(1):44-9.

(9) Simic M, Hinman RS, Wrigley TV, Bennell KL, Hunt MA. Gait modification strategies for altering medial knee joint load: a systematic review. Arthritis Care Res (Hoboken) 2011 Mar;63(3):405-26.

(10) Lewek MD, Rudolph KS, Snyder-Mackler L. Control of frontal plane knee laxity during gait in patients with medial compartment knee osteoarthritis. Osteoarthritis Cartilage 2004 Sep;12(9):745-51.

(11) Thorp LE, Sumner DR, Block JA, Moisio KC, Shott S, Wimmer MA. Knee joint loading differs in individuals with mild compared with moderate medial knee osteoarthritis. Arthritis Rheum 2006 Dec;54(12):3842-9.

(12) Schmitt LC, Rudolph KS. Influences on knee movement strategies during walking in persons with medial knee osteoarthritis. Arthritis Rheum 2007 Aug 15;57(6):1018-26.

(13) Heiden TL, Lloyd DG, Ackland TR. Knee joint kinematics, kinetics and muscle co-contraction in knee osteoarthritis patient gait. Clin Biomech (Bristol , Avon) 2009 Dec;24(10):833-41.

(14) Hicks-Little CA, Peindl RD, Fehring TK, Odum SM, Hubbard TJ, Cordova ML. Temporal-spatial gait adaptations during stair ascent and descent in patients with knee osteoarthritis. J Arthroplasty 2012 Jun;27(6):1183-9.

(15) Luyten FP, Denti M, Filardo G, Kon E, Engebretsen L. Definition and classification of early osteoarthritis of the knee. Knee Surg Sports Traumatol Arthrosc 2012 Mar;20(3):401-6.

(16) van der Esch M, Knoop J, van der Leeden M, Voorneman R, Gerritsen M, Reiding D, et al. Self-reported knee instability and activity limitations in patients with knee osteoarthritis: results of the Amsterdam osteoarthritis cohort. Clin Rheumatol 2012 Oct;31(10):1505-10.

(17) Felson DT, Niu J, McClennan C, Sack B, Aliabadi P, Hunter DJ, et al. Knee buckling: prevalence, risk factors, and associated limitations in function. Ann Intern Med 2007 Oct 16;147(8):534-40.

(18) Knoop J, van der Leeden M, van der Esch M, Thorstensson CA, Gerritsen M, Voorneman RE, et al. Association of lower muscle strength with self-reported knee instability in osteoarthritis of the knee: Results from the Amsterdam Osteoarthritis Cohort. Arthritis Care Res (Hoboken) 2012 Jan;64(1):38-45.

(19) Fisher NM, Pendergast DR. Reduced muscle function in patients with osteoarthritis. Scand J Rehabil Med 1997 Dec;29(4):213-21.

(20) Sharma L, Lou C, Felson DT, Dunlop DD, Kirwan-Mellis G, Hayes KW, et al. Laxity in healthy and osteoarthritic knees. Arthritis Rheum 1999 May;42(5):861-70.

(21) Wada M, Imura S, Baba H, Shimada S. Knee laxity in patients with osteoarthritis and rheumatoid arthritis. Br J Rheumatol 1996 Jun;35(6):560-3.

(22) Lewek MD, Ramsey DK, Snyder-Mackler L, Rudolph KS. Knee stabilization in patients with medial compartment knee osteoarthritis. Arthritis Rheum 2005 Sep;52(9):2845-53.

(23) Hortobagyi T, DeVita P. Altered movement strategy increases lower extremity stiffness during stepping down in the aged. J Gerontol A Biol Sci Med Sci 1999 Feb;54(2):B63-B70.

(24) Houck J, Yack HJ. Giving way event during a combined stepping and crossover cutting task in an individual with anterior cruciate ligament deficiency. J Orthop Sports Phys Ther 2001 Sep;31(9):481-9.

(25) Altman R, Asch E, Bloch D, Bole G, Borenstein D, Brandt K, et al. Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. Diagnostic and Therapeutic Criteria Committee of the American Rheumatism Association. Arthritis Rheum 1986 Aug;29(8):1039-49.

(26) Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957;(16):494-502.

(27) Felson DT, Niu J, Guermazi A, Sack B, Aliabadi P. Defining radiographic incidence and progression of knee osteoarthritis: suggested modifications of the Kellgren and Lawrence scale. Ann Rheum Dis 2011 Nov;70(11):1884-6.

(28) Carpenter MR, Carpenter RL, Peel J, Zukley LM, Angelopoulou KM, Fischer I, et al. The reliability of isokinetic and isometric leg strength measures among individuals with symptoms of mild osteoarthritis. J Sports Med Phys Fitness 2006 Dec;46(4):585-9.

(29) Baert IA, Mahmoudian A, Nieuwenhuys A, Jonkers I, Staes F, Luyten FP, et al. Proprioceptive accuracy in women with early and established knee osteoarthritis and its relation to functional ability, postural control, and muscle strength. Clin Rheumatol 2013 Sep;32(9):1365-74.

(30) Kean CO, Birmingham TB, Garland SJ, Bryant DM, Giffin JR. Minimal detectable change in quadriceps strength and voluntary muscle activation in patients with knee osteoarthritis. Arch Phys Med Rehabil 2010 Sep;91(9):1447-51.

(31) Baert IA, Staes F, Truijen S, Mahmoudian A, Noppe N, Vanderschueren G, et al. Weak associations between structural changes on MRI and symptoms, function and muscle strength in relation to knee osteoarthritis. Knee Surg Sports Traumatol Arthrosc 2013 Feb. [Epub ahead of print].

(32) Cooke TD, Sled EA, Scudamore RA. Frontal plane knee alignment: a call for standardized measurement. J Rheumatol 2007 Sep;34(9):1796-801.

(33) de Groot IB, Favejee MM, Reijman M, Verhaar JA, Terwee CB. The Dutch version of the Knee Injury and Osteoarthritis Outcome Score: a validation study. Health Qual Life Outcomes 2008;6:16.

(34) Malfait B, Sankey S, Azidin RM, Deschamps K, Vanrenterghem J, Robinson MA, et al. How Reliable Are Lower Limb Kinematics and Kinetics during a Drop Vertical Jump? Med Sci Sports Exerc 2013 Oct. [Epub ahead of print].

(35) Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000 Oct;10(5):361-74.

(36) Kendall F.P., Kendall McCreary E., Provance P.G. Muscle-testing and function. 4th ed. ed. Baltimore: Williams and Wilkins; 1993.

(37) Winter DA, Fuglevand AJ, Archer SE. Crosstalk in surface electromyography: Theoretical and practical estimates. J Electromyogr Kinesiol 1994;4(1):15-26.

(38) Besier TF, Sturnieks DL, Alderson JA, Lloyd DG. Repeatability of gait data using a functional hip joint centre and a mean helical knee axis. J Biomech 2003 Aug;36(8):1159-68.

(39) Cappozzo A, Catani F, Croce UD, Leardini A. Position and orientation in space of bones during movement: anatomical frame definition and determination. Clin Biomech (Bristol , Avon) 1995 Jun;10(4):171-8.

(40) Schwartz MH, Rozumalski A. A new method for estimating joint parameters from motion data. J Biomech 2005 Jan;38(1):107-16.

(41) Bisseling RW, Hof AL. Handling of impact forces in inverse dynamics. J Biomech 2006;39(13):2438-44.

(42) Robertson DG, Dowling JJ. Design and responses of Butterworth and critically damped digital filters. J Electromyogr Kinesiol 2003 Dec;13(6):569-73.

(43) Yang JF, Winter DA. Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. Arch Phys Med Rehabil 1984 Sep;65(9):517-21.

(44) Saywell N, Taylor D, Boocock M. During step descent, older adults exhibit decreased knee range of motion and increased vastus lateralis muscle activity. Gait Posture 2012 Jul;36(3):490-4.

(45) Rudolph KS, Axe MJ, Snyder-Mackler L. Dynamic stability after ACL injury: who can hop? Knee Surg Sports Traumatol Arthrosc 2000;8(5):262-9.

(46) Palmieri-Smith RM, McLean SG, Ashton-Miller JA, Wojtys EM. Association of quadriceps and hamstrings cocontraction patterns with knee joint loading. J Athl Train 2009 May;44(3):256-63.

(47) Schmitt LC, Fitzgerald GK, Reisman AS, Rudolph KS. Instability, laxity, and physical function in patients with medial knee osteoarthritis. Phys Ther 2008 Dec;88(12):1506-16.

(48) Messier SP, DeVita P, Cowan RE, Seay J, Young HC, Marsh AP. Do older adults with knee osteoarthritis place greater loads on the knee during gait? A preliminary study. Arch Phys Med Rehabil 2005 Apr;86(4):703-9.

(49) Fitzgerald GK, Childs JD, Ridge TM, Irrgang JJ. Agility and perturbation training for a physically active individual with knee osteoarthritis. Phys Ther 2002 Apr;82(4):372-82.

(50) Chmielewski TL, Hurd WJ, Rudolph KS, Axe MJ, Snyder-Mackler L. Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral anterior cruciate ligament rupture. Phys Ther 2005 Aug;85(8):740-9.

(51) Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. Phys Ther 2000 Feb;80(2):128-40.

(52) Patsika G, Kellis E, Amiridis IG. Neuromuscular efficiency during sit to stand movement in women with knee osteoarthritis. J Electromyogr Kinesiol 2011 Oct;21(5):689-94.

(53) Steultjens M, Dekker J. The pros and cons of muscle co-contraction in osteoarthritis of the knee: comment on the article by Lewek et al. Arthritis Rheum 2006 Apr;54(4):1354-5.

(54) Livingston LA, Stevenson JM, Olney SJ. Stairclimbing kinematics on stairs of differing dimensions. Arch Phys Med Rehabil 1991 May;72(6):398-402.