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Postural orientation in subjects with anterior cruciate ligament injury: development and first evaluation of a new observational test battery

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ABSTRACT

Anterior cruciate ligament injury (ACL) is associated with mechanical instability and defective neuromuscular function, and can lead to further injury, increased joint loading and osteoarthritis. Patients with ACL injury demonstrate altered postural orientation, manifested as observable "substitution patterns" (SPs) but no one has applied a clinically useful method to systematically study postural orientation in these patients. Here, we investigated the presence of such patterns in 24 adults with ACL injury and in 49 controls, in parallel with the development and a first evaluation of a new test battery, test for SPs. The rationale behind the Test for SPs was to characterize postural orientation as the ability to maintain appropriate relationships between body segments and environment during weight-bearing movements. In this first study, patients displayed SPs more frequently and/or more clearly on their injured, but also their uninjured side than did controls. Inter-rater and intra-rater reproducibility was good at a group level. Future studies of validity, responsiveness and including other subgroups of patients with ACL injury will have to prove if the Test for SPs can be used in the diagnostics of defective neuromuscular function following knee injury, when planning and carrying out training and rehabilitation and when deciding appropriate time to return to activity and sports after ACL injury.

KEY WORDS: Anterior cruciate ligament; Postural balance; Weight-bearing; Task performance, Analysis; Motor skills; Reproducibility of findings

INTRODUCTION

Anterior cruciate ligament (ACL) injury is associated with mechanical instability and defective neuromuscular function [1, 29]. In the long term, there is an increased risk of further injury, increased joint loading [37] and osteoarthritis (OA) [23, 30]. Clinically, patients with ACL injury demonstrate altered postural orientation, but to the best of our knowledge no one has applied a clinically useful method to systematically study postural orientation in these patients.

Postural orientation is defined as "the ability to maintain an appropriate relationship between the body segments, and between the body and the environment when performing a task" [34]. Postural muscular responses stabilize the joints and act against gravity, through both anticipatory postural muscular activity preceding the onset of the intended movement (feed forward control), and postural muscular activity accompanying and following the intended movement and/or unexpected perturbations (feedback control) [19, 34]. This dynamic multijoint stabilization [4, 18, 28, 35] is of crucial importance in postural orientation.

It appears likely that postural orientation can be affected if any part of the sensorimotor system does not function adequately. This would be not only due to the loss of mechanical stability, but also due to ensuing changes in proprioceptive input from the joints, muscles and ligaments [1, 22, 35], which may lead to altered information processing in central nervous sensorimotor circuits [15, 22, 35]. In an individual with ACL injury, the defective joint stability can lead to an altered position of the knee in relation to hip and foot, with increased risk of sudden knee pivoting and additional lower extremity injury [12, 17, 21, 25]. Disturbances in the activation of the gluteus maximus in patients with recurrent ankle ligament injuries indicate that inappropriate control of the muscles acting on joints adjacent to the affected one can also arise [7, 8].

In addition to altered ankle-knee-hip-joint position after ACL injury [17, 21, 24, 25], alterations in movement patterns during different tasks, such as forward lunge, step, and one-legged hopping have been described [3, 33, 38]. In this study, we have called the clinical observation of altered postural orientation a “substitution pattern” (SP) [28], and assume the SP to be the result of an impaired ability to stabilise the body segments in relation to each other and to the ground/environment when performing a weight-bearing movement. It is likely that when no measures are taken to correct these patterns, problems can arise manifested by joint swelling, pain, continuous giving-way episodes and/or defective neuromuscular function [12, 17, 21, 25]. To be able to systematically and reproducibly study the presence of SPs in the clinical setting, an instrument is needed that without much equipment allows an assessment of the ability to stabilize body segments in relation to each other and to the environment, fundamental qualifications for any movement. In this study, we therefore started the development and made a first evaluation of a new test battery, where the focus is on the ability to maintain appropriate relationships between body segments, and between the body and the environment when performing different weight-bearing movements. We have named this test battery test for substitution patterns (TSP).

The aims were to conduct a first investigation of the presence of SPs in patients with ACL injury and in uninjured controls, using the TSP. Inter-rater and intra-rater reproducibility of the scoring were evaluated. We hypothesized that ACL injury is associated with altered postural orientation that can be observed by the TSP as SPs in the injured and/or in adjacent joints, and that these patterns are infrequent in uninjured individuals.

MATERIAL & METHODS

The study was approved by the Research Ethics Committee at Lund University, Sweden. All subjects gave their written informed consent to participate. The subjects had no prior knowledge of the test concept.

A total of 73 subjects were included in the study. Twenty-four (12 women) patients (mean age 28, range 18 – 42 years) with a total, unilateral, nonreconstructed ACL injury, mean duration 2.8 years, SD 2.4, were included. The diagnosis was verified by clinical examination, arthroscopy and/or magnetic resonance imaging (MRI) at the Department of Orthopaedics at Lund University Hospital, Sweden. All patients had increased sagittal laxity with a positive Lachman test and a positive pivot shift test. Sixteen of the patients had associated meniscal afflictions, two had an associated collateral ligament injury and one had a compressive trauma to the lateral femur condyle cartilage. Fourteen of the patients had injured their right knee and ten their left knee. All patients were at a given date on a waiting list, scheduled for ligament reconstruction because of knee instability or expectations of a higher activity level. None had a history of complaints or injury to the contralateral extremity. The number of sudden "giving-way episodes" since injury varied from 0 to 10 times (mean 5, SD 4.2). The patients' mean perceived instability on a Visual Analog Scale (VAS) was 55 mm (range 20 - 100 mm). Self-reported knee function was assessed by Lysholm knee-scoring scale (min 0, max 100 points, 100 indicating no knee problems), where mean was 69 points (range 49 – 90) for the patients [36]. Before injury, all patients engaged in recreational sports, but not on a competitive level, and had a pre-injury activity level similar to that of the 49 uninjured controls. All patients had undergone training supervised by physiotherapists but not at the clinic where the assessments took place. Four of the 24 patients perceived mild pain during or after a test occasion. Five of the patients reported knee-pain or a swollen knee before one of the test occasions, but not at the other.

Forty-nine (26 women) subjects (mean age 27, range 17 – 44 years) with no reported neuromuscular or skeletal dysfunction in the lower extremities, back or neck, participated as controls. The uninjured controls regularly engaged in recreational sports, such as aerobics, jogging, cycling or ball games, but none of them engaged in competitive sports. Their mean Lysholm knee score was 98 points (range, 80 – 100) and their mean perceived knee instability on the VAS was 0.9 mm (range, 0 to 16 mm). None of the 49 controls experienced any pain during the test procedure.

Each subject was tested twice with 7 – 14 days between the two test occasions. A staff member not participating as an examiner contacted all 73 subjects in the study. Two examiners, referred to as "Examiner A" and "Examiner B" demonstrated the test-movements, observed and scored the subjects separately but simultaneously on each test occasion, which lasted about 35 minutes. The examiners were experienced physiotherapists, specializing in knee injury rehabilitation and very familiar with the TSP. The examiners were blinded to whether or not subjects had an ACL injury (Tubi-grip® stockings covered both knee joints to disguise possible scars from knee arthroscopy), or to any knowledge of the subjects' Lysholm- or VAS score. The subjects received no information about what the examiners were observing and scoring during the tests. All subjects were dressed in shorts and T-shirt, without shoes or socks, except when performing test G, when all subjects wore trainers.

The TSP, based on clinical observations originally made by Dr. Rose Zätterström (personal communication), consisted in this study of 9 test-movements referred to as A to J, as illustrated and described in the Appendix.

Test-movements A-J were performed in a random order. Tests A, C, D and E were performed five times first on the right leg, then five times on the left leg. Tests B and G were performed five times alternating between the right and the left leg. Test F was performed for about 20 seconds on each side, and test H for approximately two minutes (see below). Test J was performed on both legs at the same time. The subjects were not allowed to practice the demonstrated movements before the testing was performed.

For each of the nine test-movements, 1 – 7 SPs were defined (in accordance with our clinical experience on what had been observed on the injured side in several patients) giving a total of 36 SPs (see Appendix). Two examiners scored each subject at the same time, using a four-point, 0 to 3, ordinal scale: "0": no SP present; "1": SP possibly present (an experienced examiner could see the pattern); "2": SP clearly present (an inexperienced person could see the SP); and "3": subject performed very poorly (i.e., when a subject could not perform the test the predefined number of times or when the subject performed so poorly that there was no similarity to the task). In order to be scored as non-"0", an SP should be observed in the majority of the repetitions, i.e., at least three of the five times (test F; 15 times in 20 seconds and test H; 15 times in 2 minutes).

All calculations and statistical analyses were carried out using SPSS (Statistical Package for the Social Sciences) 15.0. Eight total scores (2 legs x 2 occasions x 2 examiners) were calculated for each of the 73 subjects (a total score is the sum of points on a given occasion and by a given examiner). The total scores could range from a minimum of 0 point and a theoretical maximum of 108 points (3 points x 36 patterns). The average of the right and the left leg was used for statistical analysis in the controls since there were no differences between the legs. In all total scores-comparisons, mean values (of four pooled total scores for each of patients' legs, and eight pooled total scores for controls) were used. In the within group comparisons, the Wilcoxon Signed Rank test was used, and in the between group comparisons the Mann-Whitney U-test was used. P-values less than or equal to 0.05 were considered statistically significant.

Three aspects of inter-rater and intra-rater reproducibility were analysed. To address instrument accuracy, the number of observations with "agreement" and "no agreement" was calculated [10]. "Agreement" means that a given examiner gave the exact same points on occasions 1 and 2 or that the two examiners gave the exact same points on a given occasion. To address instrument-bias, the Wilcoxon Signed Ranks test was used. The "95% limits of agreement" (LOA) was used for assessing within subject variation (absolute reproducibility for subjects, mean difference ±1.96 SD of the difference).

RESULTS

The range of the pooled total scores (see Material and methods) measured by the TSP in this study was 0 – 47 points. Patients displayed more SPs on their injured side (pooled median total score 8 points, range 0 to 47) compared to controls (pooled median total score 1 point, range 0 to 7) ($p<0.001$). Patients also displayed more SPs on their uninjured side (pooled median total score 2 points, range 0 to 8) compared to controls ($p=0.025$). There was a significant difference between pooled total scores of the patients' injured as compared to their uninjured side ($p<0.001$). The patients' number of sudden "giving-way episodes," the perceived instability on VAS and the Lysholm score did not correlate with the patients' scores on the TSP.

A breakdown of the pooled total scores across occasions 1 and 2 and across Examiners A and B is shown in Table 1, while a breakdown of scores across individual test-movements is given in Table 2. Except for test-movements A and H, differences between the scores for the patients' injured side compared to controls were significant for all test-movements ($p=0.043$ for test-movement B, $p<0.001$ for the remaining). Differences between patients' uninjured side and controls in individual test-movements were not significant ($p\geq0.3$ for all comparisons).

The score "2" was given 75 times and the score "3" was given 34 times for a patients' injured leg. In the controls, the score "2" was given three times. None of the controls was ever scored a "3".

The inter-rater (between Examiners A and B) and intra-rater (between occasions 1 and 2) reproducibility for all subjects is shown in Table 3. Notably, of ca. 21 000 observations made in total in this study (n = subjects x legs x SPs x examiners x occasions), only 6% were classified as "no agreement." Of these, a majority (87%) differed by one step on the scoring scale (0 – 1, 1 – 2 or 2 – 3), 6% differed by two steps (0 – 2, 1 – 3), and 6% differed by three steps (0 – 3). All three-step differences were between occasions 1 and 2 and were only observed in the patients.

Small but statistically significant differences were found in total scores between occasions 1 and 2 in controls but not in patients, and between Examiners A and B at occasion 2 in the patients. However, all these total score differences were maximum 1 point (Table 1).

DISCUSSION

The most important finding of the present study was that SPs could be detected with the TSP in a subgroup of patients with ACL injury, as more frequent and/or more clearly present SPs on patients' injured and uninjured sides as compared to uninjured controls. These findings support our hypothesis that ACL injury is associated with altered postural orientation, which may be measured as SPs associated not only with the injured joint but also with adjacent joints, and that these are infrequent in uninjured subjects. Inter-rater and intra-rater reproducibility of the TSP scoring was good at a group level.

When a new instrument is introduced, validity, reliability and generalizability have to be considered. In this study, we started this investigation by addressing reproducibility, but several issues remain. Concurrent validity could not be obtained since no test-instrument similar to the TSP exists for golden-standard-comparison. To evaluate validity of the TSP, SPs should be documented and characterized by, for instance, a computerized motion capture system and compared to visual assessment, as carried out here. The TSP also needs to be compared with several well-known and commonly used tests of, for example, muscle strength, reflex contraction latency of the muscles measured with electromyography, and hop tests, as well as with patient-relevant outcomes.

Another limitation is the generalizability of the TSP. The present sample was recruited on a specific date from a waiting list for surgical reconstruction and thus constituted a mixture of patients with severe and moderate instability-problems, but with high demands of function.

However, although all patients had knee instability, we cannot disregard the issue of selection bias. To be able to use the TSP in the clinic, it needs to be investigated in other subgroups of the ACL-population, e.g., in newly injured, during and after completed rehabilitation.

Alterations in movement and joint loading after ACL injury have been investigated previously [14]. In specific, altered muscle activation patterns [20], muscle timing and recruitment order [39], movement patterns [38], joint loading [17] and walking patterns [2] have been described. While focus in these studies was on quantitative aspects of movement and joint loading, this study evaluates the quality of performance with respect to postural orientation. Few visual observation-based test instruments with focus on qualitative aspects have been used in studies of patients with knee injury. Oberg et al. [26] developed an assessment system for lower extremity joint impairments, but the test was developed for and tested on older patients with OA, scheduled for total joint replacement arthroplasty, and may thus not be relevant for younger patients with ACL injury. Björklund et al. [5] carried out a study of visual observation in ACL-insufficient subjects, evaluating functional performance in strength, stability, springiness and endurance. However, their test is best suited for athletes in a well-rehabilitated stage, since subjects have to be able to perform strenuous activity tests, such as various hop tests and fast running. To meet the demands of a test method evaluating qualitative aspects of function for both athletes and non-athletes before, during and after rehabilitation, the test-movements in the TSP do not require running or jumping. Instead, postural orientation, a fundamental condition for any movement, is evaluated.

In patients with ACL injury, a knee position medial to the foot is assumed to be an injury mechanism for ACL injury (named “knee valgus” or “valgus collapse”) [14, 27], and has also been reported to cause unfavourable complications by increasing the risk of new injuries through “giving-way episodes” [12, 17, 21]. In accordance with its clinical significance in ACL injury, the SP “knee medial to the foot on supported side” was detected in most TSP test-movements in the patients. In specific, patients got high points on test-movements C, F, G, J and to a somewhat lesser extent also on test-movements D and E. The fact that a patient could perform one test-movement with no SP, but scored high points in another, is in line with our prior clinical experience. It suggests that different starting positions stress different muscular synergies and activation patterns.

To develop a test lacking unnecessary items, Gustavsson et al. [16] choose three of five original hop tests, since they were the most sensitive to discriminate between the injured and the uninjured sides. In that perspective, test-movements A, B and H could be reconsidered as part of the TSP since they yielded low scores. However, it should be emphasized that the TSP is not intended as a diagnostic test for ACL injury. Its main purpose is to provide information on the patients’ current postural abilities in different weight-bearing positions resembling conditions in daily life and more strenuous activities. Therefore, a variety of weight-bearing positions can be an advantage and it has to be finally decided in future studies which test-movements should be excluded from the TSP. The result that a substantial proportion of the patients had total scores that overlapped with the controls is consistent with other authors who found that patients with ACL-injury can perform similarly to uninjured subjects in functional tests [9, 13, 31, 32]. Fitzgerald [13], for instance, found that 42% of patients with ACL injury in their study had such a good knee stability (measured by a screening tool of clinical functional tests), that they were appropriate rehabilitation candidates with no need for surgical stabilization.

The agreement between occasions and examiners in this study was good at a group level. A contributing factor could be that the examiners in our study were familiar with the test method since they used the tests in their clinical work and had undergone a training session prior to the assessments. The importance of experience and standardization has also been pointed out by others [6, 11]. Notably, there was a lower agreement between occasions 1 and 2 than between Examiners A and B, especially on patients' injured side (Table 3). Five of the injured patients had knee-pain or a swollen knee in one of the test sessions only. This minority of patients (5 out of 24) affected the agreement between occasions by having more knee-complaints at one of the test occasions, indicating that the TSP can be sensitive to changes in function/symptoms.

In the uninjured controls, the median total score was statistically significantly lower on occasion 2 than occasion 1 (Table 1), indicating a learning effect. Although the difference was small (one point) and its clinical relevance can be questioned, it may suggest that the TSP is an instrument well suited for patients with ACL injury but less so for uninjured individuals. No learning effect was seen in the patients.

The results of this study indicate that detecting, describing and measuring postural orientation may be important in patients with ACL injury. Since no easily accessible method to study SPs existed prior to this study, our findings can form the basis for the development of a clinically useful instrument to be used in the diagnostics of impaired neuromuscular function following knee injury, when planning and carrying out training and rehabilitation and when deciding appropriate time to return to activity and sports after ACL injury.

CONCLUSIONS

Patients with ACL injury exhibited altered postural orientation, measured with the TSP as more frequent and/or more clearly present SPs not only on their injured, but also their uninjured side, than did uninjured controls. SPs could be detected not only in the injured knee joint but also in adjacent joints. Intra- and inter-rater reproducibility of the TSP was good at a group level. These results encourage us to study other subgroups of patients with ACL injury and to further clarify the validity and responsiveness of the TSP.

Conflict of interest statement

The authors report no conflict of interest for this manuscript.

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Table Title

Table 1. Median total score (range), p-value and 95% limits of agreement (LOA) for Examiners A and B and occasions 1 and 2 for patients' injured and uninjured side and for controls' right and left side.

Table 2. Median points (range) for each specific test-movement A to J for patients' injured and uninjured sides and for controls.

Table 3. Percent agreement in assessment between Examiners A and B and occasions 1 and 2 for patients' injured and uninjured sides and controls' right and left sides.

TABLES 1-3

Table 1 Median total score (range), p-value and 95% limits of agreement (LOA) for Examiners A and B and occasions 1 and 2 for patients' injured and uninjured side and for controls' right and left side.

	Examiner A versus Examiner B Occasion 1				**Examiner A versus Examiner B Occasion 2**			
	Total score Examiner A Median (range)	**Total score Examiner B Median (range)**	**p-value**	**95% LOA**	**Total score Examiner A Median (range)**	**Total score Examiner B Median (range)**	**p-value**	**95% LOA**
Patient, injured side n=24	6 (0 – 51)	7 (0 – 51)	0.793	-4.8 – 5.2	10 (0 – 64)	9 (0 – 62)	0.856	-5.2 – 5.8
Patient, uninjured side n=24	2 (0 – 9)	2 (0 – 9)	0.292	-1.6 – 2.0	1 (0 – 7)	2 (0 – 12)	0.042	-4.4 – 6.9
Control, right side n=49	1 (0 – 8)	1 (0 – 8)	0.414	-2.7 – 3.2	1 (0 – 7)	0 (0 – 7)	0.967	-1.9 – 2.0
Control, left side n=49	1 (0 – 7)	0 (0 – 11)	0.858	-4.5 – 5.1	0 (0 – 6)	0 (0 – 5)	0.792	-1.8 – 1.9
	Occasion 1 versus Occasion 2 Examiner A				**Occasion 1 versus Occasion 2 Examiner B**			
	Total score Occasion 1 Median (range)	**Total score Occasion 2 Median (range)**	**p-value**	**95% LOA**	**Total score Occasion 1 Median (range)**	**Total score Occasion 2 Median (range)**	**p-value**	**95% LOA**
Patient, injured side n=24	6 (0 – 51)	10 (0 – 64)	0.823	-23.5 – 24.5	7 (0 – 51)	9 (0 – 62)	0.828	-21.7 – 22.4
Patient, uninjured side n=24	2 (0 – 9)	1 (0 – 7)	0.065	-3.3 – 4.9	2 (0 – 9)	2 (0 – 12)	0.819	-5.7 – 6.1
Control, right side n=49	1 (0 – 8)	1 (0 – 7)	0.011	-2.1 – 3.0	1 (0 – 8)	0 (0 – 7)	0.014	-3.3 – 4.7
Control, left side n=49	1 (0 – 7)	0 (0 – 6)	0.020	-0.7 – 1.4	0 (0 – 11)	0 (0 – 5)	0.010	-3.3 – 4.8

Table 2. Median points (range) for each specific test-movement A-J for patients' injured and uninjured sides and for controls.

	Patients injured side (n=24)	**Patients uninjured side (n=24)**	**Controls (n=49)**
Test-movement	**Points median (range)**	**Points median (range)**	**Points median (range)**
A	0 (0 – 0)	0 (0 – 0)	0 (0 – 0)
B	0 (0 – 4)	1 (0 – 2)	0 (0 – 1)
C	21 (17 – 21)	2 (1 – 2)	2 (0 – 3)
D	18 (14 – 22)	3 (2 – 4)	3 (1 – 5)
E	17 (12 – 18)	2 (0 – 4)	2 (0 – 5)
F	10 (7 – 13)	0.5 (0 – 4)	0 (0 – 3)
G	13 (12 – 16)	0 (0 – 10)	1 (0 – 2)
H	1 (0 – 5)	0 (0 – 4)	0 (0 – 2)
J	7	0	0

Table 3. Percent agreement in assessment between Examiners A and B and occasions 1 and 2 for patients' injured and uninjured sides and controls' right and left sides.

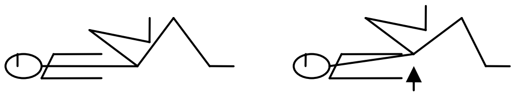
	% Agreement in assessment between Examiners A and B				**% Agreement in assessment between Occasions 1 and 2**			
	Occasion 1		**Occasion 2**		**Examiner A**		**Examiner B**	
Patients (n=24)	**Injured side**	**Un-injured side**	**Injured side**	**Un-injured side**	**Injured side**	**Un-injured side**	**Injured side**	**Un-injured side**
0 [a]	92	96	90	95	80	94	83	95
1 [a]	8	4	10	4	12	5	10	5
2 [a]	0	0	0	0	4	0	3	0
3 [a]	0	0	0	0	4	0	3	0
Controls (n=49)	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
0 [a]	95	96	98	97	97	96	96	95
1 [a]	4	4	2	3	3	4	4	4
2 [a]	0	0	0	0	0	0	0	0
3 [a]	0	0	0	0	0	0	0	0

[a] **0** = % no divergence in assessment, i.e. total agreement, **1**= % no agreement between points 0-1, 1-2 or 2-3, **2** = % no agreement between points 0-2, or 1-3, **3** = % no agreement between points 0-3.

Appendix:

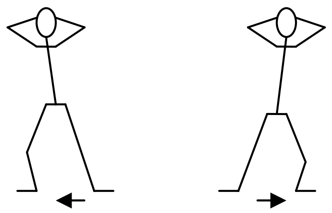
Test for Substitution Patterns (TSP)

<u>A – Pelvic lift with support from one foot</u>



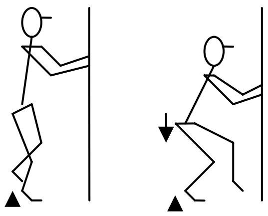
Substitution patterns:
A1 .Knee medial to the foot (knee not in line with hip and foot) on supported side
A2 .Lateral displacement of hip-pelvis-region on the supported side
A3.Difficulty in lifting the seat 5 times/side

<u>B – Body-weight-altering test</u>



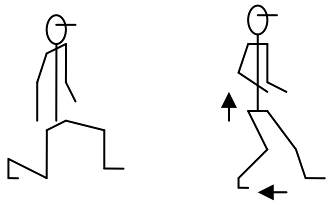
Substitution patterns:
B1 .Increased pronation of supported foot
B2 .Knee medial to the foot (knee not in line with hip and foot) on supported side
B3 .Lateral displacement of hip-pelvis region on the supported side
B4 .Displacement of trunk (for instance bending trunk forward or displacing trunk laterally) on supported side
B5 .Displacement of arms (look at elbows) such as moving arms laterally or forward on supported side

<u>C – Tip-toe standing knee flexion</u>



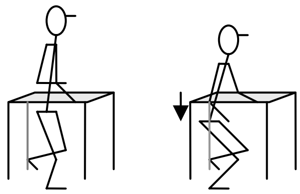
Substitution patterns:
C1 .Knee medial to the foot (knee not in line with hip and foot) on supported side
C2 .Lateral displacement of hip-pelvis region on the supported side
C3 .Displacement of trunk (for instance bending trunk forward or displacing laterally) on supported side

<u>D – Rising up from half-kneeling</u>



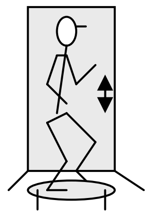
Substitution patterns:
D1 .Body weight displaced to the front leg (despite instructions not to do so)
D2 .Displacement of trunk (for instance bending trunk forward or trying to raise with extra help from arms) on supported side

<u>E – Knee-flexion-extension standing on one leg</u>



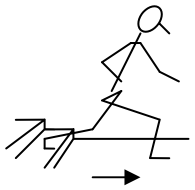
Substitution patterns:
E1 . Increased pronation of supported foot
E2 . Knee medial to the foot
E3 . Lateral displacement of hip-pelvis region on supported side
E4 . Displacement of trunk (for instance bending trunk exaggeratedly forward or displacing trunk laterally) on supported side

<u>F – One-leg-standing bouncing on trampoline</u>



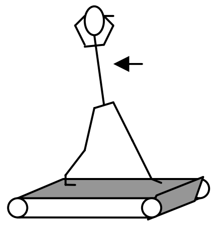
Substitution patterns:
F1 .Increased pronation of supported foot
F2 .Knee medial to the foot (knee not in line with hip and foot) on supported side
F3 .Lateral displacement of hip-pelvis region on supported side
F4 .Displacement of trunk (bending trunk forward or displacing trunk laterally) on supported side
F5 .Difficulty doing the exercise with flexibility in flexion-extension in the knee joint when bouncing (“stiff knee“)
F6 .Head displaced; not in line with trunk

G – Forward lunge from stairs



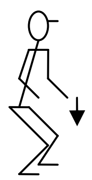
Substitution patterns:
G1 Shorter stride
G2 .Knee medial to the foot (knee not in line with hip and foot) on supported side
G3 .Displacement of trunk (for instance bending trunk forward or displacing laterally) on supported side
G4 .Subject tries to help out with support from hands or takes a more careful stride (sound muffled when foot meets floor)
G5.Avoids weight-bearing on hind leg during return

H – Walking backwards on treadmill



Substitution patterns:
H1 .Limp
H2 . Increased pronation of supported foot
H3 . Circular movement with foot in swing phase
H4 . Knee medial to the foot (knee not in line with hip and foot) on supported side
H5 . Displacement of trunk (for instance bending trunk forward or displaced laterally) on supported side
H6 . Displacement of arms (look at elbows) such as: moving arms laterally or forward on supported side
H7 . "Heel-drop" when either side was weight-bearing (meaning; the whole foot met the treadmill on the supported leg instead of a step starting with support from the big-toe ending with heel-support)

J – Mini-squat



Substitution pattern:
J1. displacement of bodyweight to either side

Starting positions (*S*) and performance (*P*)

Test A. Supine position: Pelvic-lift with support of one foot

S: Subject lying supine on a bench with pillow under head, one knee bent about 90° and foot placed on bench in line with hip and knee. Other leg pulled towards abdomen through flexion in hip and knee. Arms rested aside body. ***P:*** Instructions: "Push chin down towards chest, press the hollow of your back into the bench, lift seat up and down slowly 5 times." Subject repeats the exercise in the same way with the other leg. Examiner standing at the head of and beside the bench.

Test B. Standing position: Body-weight-altering test

S. Subject standing barefoot with feet a good hip-width apart. Hands placed on head. ***P***. Instructions: "Alternate body weight from right to left leg at the same time as you bend the supporting leg slightly at ankle, knee and hip joints. Do this slowly alternating the right and the left leg; 5 times on each side. Look straight ahead." Examiner standing in front of subject.

Test C. Tiptoe-standing position: Tiptoe-standing knee flexion

S: Subject barefoot, standing tip-toe on one foot facing wall. Slight support from fingertips against wall in front of subject. ***P:*** Instructions: "Bend your knee slowly about this deep (demonstrating approx. 70° of knee flexion) without lowering the heel. Five repetitions." Examiner standing behind and then beside subject.

Test D. Half-kneeling position: Rising up from "half-kneeling"

S: Subject, without shoes on a mat, "half-kneeling" supported by right knee and with toes of right foot bent and on the mat (right hip in full extension, head and trunk vertical). Left foot placed in front of right foot on the mat (left knee and hip at about 90° of flexion). Body weight on right leg. ***P:*** Instructions: "Rise slowly with your body weight on the hind leg until knees are fully extended. Return to initial position. Five times on each leg." To emphasize that the body weight should be placed on the hind leg, Examiner gives this instruction every time subject rises up. Examiner observing subject from behind and from the side.

Test E. Standing on one leg: Knee flexion–extension

S:. Subject standing on right foot beside a bench with left leg slightly raised from the floor, fingertips of left hand providing slight balance support on bench. ***P:*** Instructions: "Bend your right leg (demonstrating approx. 70° of knee flexion) and rise 5 times. Turn around and repeat the procedure on the left leg." Examiner standing in front of and beside subject.

Test F. One-leg-standing: Bouncing on a trampoline

S: Subject one-leg-standing on right foot on a trampoline close to wall, left side turned to wall, slight support from fingertips of left (then right) hand against wall. Left leg slightly elevated in hip and knee flexion. ***P:*** Instructions: "Bounce hard (but without leaving the trampoline with the supporting foot, in other words: do not jump and do no heel-ups) for about 20 seconds. Turn around and repeat on the left leg." Examiner standing in front of and beside subject.

Test G. Forward lunge: Forward lunge from stairs

S: Subject standing with shoes, on first step of a staircase (about 15 cm high). ***P:*** Instructions: "Take a long stride out onto the floor (about 80 cm from the step) with the right leg and land on the right foot with about 90° of flexion in the right knee (called "stride" in protocol), while the left foot remains on the step. Remain in this position for a moment, then return to the step with support mainly on the left leg (called "return" in protocol). Do this slowly, alternating the right and the left legs, 5 times on each side." Examiner standing in front of and beside subject observing both the "stride" and the "return".

Test H. Backwards walking: walking backwards on a treadmill

S: Subject walking backwards on treadmill at a rate of 25 min/km, barefoot with hands placed on top of the head, elbows pointing out sideways. (Practice for about 1 minute before the test was allowed.) ***P:*** Instructions: "Walk backwards for about 2 minutes." Examiner standing in front of, beside and behind subject.

Test J. Mini-squat

S:. Subject standing barefoot with feet a good hip-width apart. ***P:*** Instructions: "Bend your knees as if you were going to squat (minimum 90° of knee flexion), and rise up again 5 times". Examiner standing in front of subject.