Assessment of Functional Tests After Anterior Cruciate Ligament Surgery

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Functional tests are often used to assess knee function after knee ligament injuries. However, the reliability and validity of these tests have not been sufficiently studied. The main purpose of this study was to examine six functional knee tests in order to establish the tests according to functional demands. The functional tests (vertical jump, figure-of-eight, stairs-running, triple jump, stairs hopple, and side jump tests) were evaluated on 35 patients after anterior cruciate ligament reconstruction ($\bar{X}$ = 18 months postoperative). Evaluative variables were the Lysholm functional score, thigh atrophy, and knee instability. Factor analysis was used to identify knee tests based on the same basic variables in order to employ the most representative tests. The factor analysis disclosed two factors that reflected diverse functions. The first factor had significant correlation to the Lysholm score (daily life function) and was best represented by the figure-of-eight and stairs-running tests. The second factor was best correlated to the strength/stability function and was best represented by the triple jump test and the new stairs hopple test. Thus, the tests were categorized according to functional demands—daily life function and strength/stability function. The Lysholm functional score was inaccurate in identifying functional problems during strenuous activities.

Key Words: anterior cruciate ligament, functional tests, rehabilitation

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The anterior cruciate ligament (ACL) acts as one of the primary passive restraints of the knee joint (12). Functional stability of the knee joint is, however, provided by passive restraints of all the ligaments, by active restraints generated by the muscles, and by joint geometry (12). All these structures are working interdependently during *in vivo* joint function. Functional rehabilitation of the ACL-deficient knee is, therefore, recommended in the literature (10,17,21). However, evaluation of the results after the rehabilitation program has mostly been limited to clinical laxity tests and subjective functional scoring systems. These tests are not in accordance with the therapeutic interventions. Some authors have reported no relationship between clinical laxity tests and the patients' own perceptions of their knee function (6,18).

Functional testing is an attempt to evaluate the functional stability of the knee joint, and it may also contribute to finding a better relationship between the results of clinical examinations and the patient's knee function. Several functional knee tests are described in the literature: the shuttle run test (1,4), the stairs-running test (20), the figure-of-eight test (20), the vertical jump test (1,3), four types of one-legged hop tests (3,11,20), the cocontraction test (8), and the carioca test (8). Many of these tests have been poorly evaluated and therefore do not provide reliable results. In addition, previous literature does not explain the validity of each test. Given the paucity of research on functional tests, the purpose of this study was to study six functional tests in order to establish the tests according to functional demands and to validate the Lysholm score according to the patient's knee function.

MATERIAL AND METHODS

Subjects

Between November 1987 and June 1989, 40 patients were treated for acute (0–14 days old) ACL injuries. Twenty-two men and 18 women, mean age of 26 years (± 8.2), volunteered to participate in this study. Eighteen were treated with simple suturing of the ACL and 22 with an additional augmentation using the medial third of the patellar tendon. The patients were followed up after the operation ($\bar{X}$ = 18 ± 3.9 months).

Ninety-four percent of the patients had been injured in sports activities: 11 soccer players (29%), eight alpine skiers (21%), seven handball players (20%), six cross country skiers (16%), and three others (8%).

Two patients could not be followed up and were excluded from the study. One patient was operated on bilaterally during the period, and, additionally, one patient was reinjured the day before the follow-up examination. Another patient sustained a fracture in the contralateral leg. These three patients were also excluded from the study.

Procedure

Data for each subject were recorded by one physician and one physiotherapist. The variables measured included the Lysholm score (19), the Tegner activity score (19), thigh atrophy, laxity test, and six functional tests. Two of the functional tests were designed exclusively for this study.

Lysholm Score, Tegner Score, Thigh Atrophy, and Laxity Tests

Subjects filled in a questionnaire, the Lysholm score (20), in order to record their patient self-assessment. They graded their knee problems according to eight different variables: limping, weight bearing, stair climbing, squatting, instability, pain, swelling, and locking. Maximum score was 100. Scores below 68 were considered poor, from 68 to 77 fair, from 77 to 90 good, and above 90 excellent (16).

The patients' pre- and postoperative activity levels were registered by the Tegner activity score (19). This scoring system ranges from 0 to 10. Activities are graded according to performance difficulty—zero denoting sick leave or disability pension because of knee problems and 10 denoting the most strenuous activities of the knee, like competitive soccer and handball.

Muscle atrophy was recorded by measuring the circumference of the thigh, 15 cm proximal to the superior pole of the patella. A KT-1000 knee arthrometer (2) (MEDmetric Corp., San Diego, CA) was used to record the anterior displacement of the tibia relative to the femur. More than 3 mm of difference between the involved and uninvolved knees at the 89 N force test was defined as instability and used in the statistical analysis (2).

Functional Tests

Six functional tests simulating various functional activities were used. All tests were performed without a brace. Three of the tests were two-leg tests; the other three were one-leg tests. All patients were tested by the same physiotherapist. Each subject underwent an 8-minute warm-up period of low-resistance ergometer cycling before performing the functional tests. All functional tests were performed in the same order following each other immediately after instructions: vertical jump test, figure-of-eight test, triple jump test, stairs hopple test, and side jump test.

Some authors have reported no relationship between clinical laxity tests and the patients' own perceptions of their knee function.

Vertical Jump Test The injured leg was positioned closest to the wall. The patients were standing on both feet, one foot length away from the wall. After bending down to a knee flexion of 80–90°, they jumped vertically and made a mark on the wall with a pen. This test was performed three times and the best trial was used for data analysis. The distance from the floor to the pen marking was measured in cm.

Figure-of-Eight Test Patients ran a figure-of-eight (each circle 4 m in diameter) three times. The time was recorded in seconds (Figure 1).

Stairs-Running Test The patients ran up and down a staircase, with two 180° turns and 55 steps in total. Each step was 17.5 cm high. The time was measured in seconds.

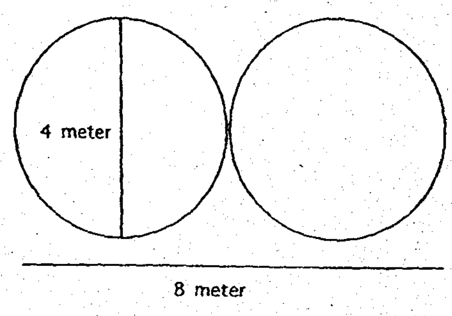

FIGURE 1. *The figure-of-eight test.*

Triple Jump Test Standing on one leg [first the uninjured (uninvolved) and subsequently the injured (involved) one], patients jumped three times along a straight line. The difference between the two legs' performances was recorded in cm (Figure 2).

Stairs Hopple Test This is a new test in which the patients jumped on the uninvolved leg up and down 22 steps (each step 17.5 cm high) on a

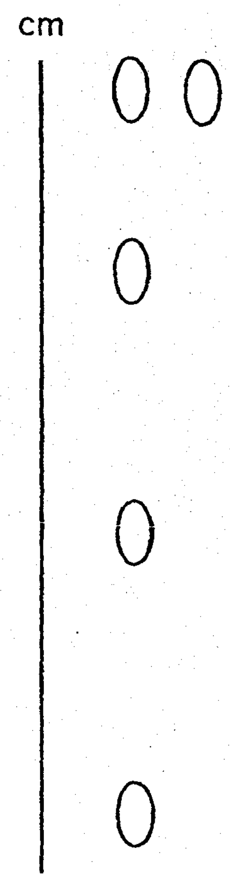

FIGURE 2. *The triple jump test.*

staircase, followed by the corresponding procedure with the involved leg. The time was measured in seconds and the difference between the uninvolved and involved legs was recorded (Figure 3).

Side Jump Test Two straight parallel lines were drawn, each 6 m long and 30 cm apart. Ten marks were made on the outside of one line at 60-cm intervals. Corresponding markings were made on the other line starting 30 cm from the base line. The patients first jumped on the uninvolved leg from mark to mark and then repeated the procedure on the involved leg. The time was measured in seconds, and the difference between the two legs was recorded (Figure 4).

Statistical Analysis

Factor analysis (5) is a multivariate statistical method. The purpose of factor analytic techniques is to summarize information contained in a number of original variables into a smaller set of composite dimensions (factors) with a minimum loss of information. The method was used to analyze the relationship among variables, functional tests, and to explain these variables in terms of their common dimensions or factors. A factor loading was determined for each functional test for each factor. A factor loading represents the correlation between the functional test and its factor. When the factors were used in subsequent analyses (regression and correlation analyses), a factor score was included to represent the newly derived variables. This factor score is a composite of all the original variables that were important in determining the new factor.

FIGURE 3. The stairs hopple test.

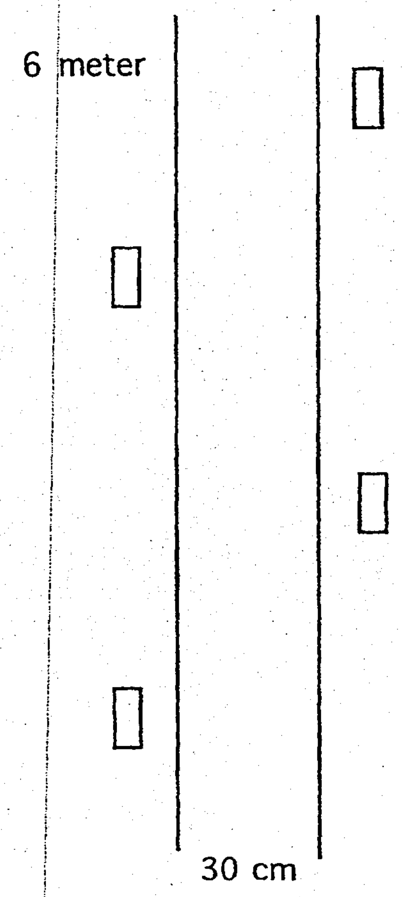

FIGURE 4. The side jump test.

The Pearson correlation coefficient was used to assess the relationship between the Lysholm score, the thigh atrophy, the laxity test, and the two factor scores (factor 1, factor 2) derived from the factor analysis.

A paired *t*-test was used to compare data between the two limbs, and two sample *t*-tests were used to evaluate gender differences. Differences were considered significant when $p < 0.05$.

RESULTS

Lysholm Score, Tegner Activity Score, Thigh Atrophy, and Instability Tests

Eighty-one percent of the patients showed good or excellent results as evaluated by the Lysholm score. The mean score was 89.1 (± 10.4). All patients scored maximum on walking with full weight bearing, and only one patient stated problems with periodical limping. This patient was tested 8 months postoperatively and had limited flexion and extension. Eighty-nine percent of the patients scored maximum on stair climbing. Regarding the pain, instability, and swelling variables, 25.8% had no symptoms. Fifty-five percent experienced problems during strenuous activities, and 16.1% of these also had problems during daily activities.

The results from the one-leg tests showed a significant difference between involved and uninvolved limb for the triple jump test and the stairs hopple test.

Mean values of the Tegner activity score were 7.6 preoperatively and 6.1 postoperatively. This reduction in activity level was significant ($p < .05$). The circumference of the thigh showed a mean value of 14.3 cm (± 8.8 cm).

The KT-1000 knee arthrometer showed that six patients revealed an increased anterior displacement of the tibia relative to the femur. Only one of the six patients complained about instability problems in the Lysholm score during athletic activity or daily life.

Functional Tests

The results from the one-leg tests showed a significant difference between the involved and uninvolved limb for the triple jump test and the stairs hopple test, but not for the side jump test (Table 1). For the side jump test, no difference was recorded by 37% of the patients, whereas 55% performed equally or better on the operated leg. Five recordings were excluded because the patients were not accurate in jumping on each mark. This test was, therefore, excluded in the factor analysis.

One of the first steps in the application of factor analysis involves the calculation of the correlation matrix of the variables (5). Correlations for the five remaining tests are shown in Table 2. Relatively high correlations were found between the figure-of-eight test and the stairs-running test (0.74), between the triple jump test and the figure-of-eight test (0.64), and between the triple jump test and the stairs hopple test (0.61).

The second step in the factor analysis is to identify a set of dimensions latent in the functional tests (5). Each of the tests is considered as a dependent variable that is a function of an underlying and hypothetical set of factors. The factor analysis summarized the information contained in the five tests into two factors (factor 1 and factor 2) that reflected diverse functions.

The third step is considering and interpreting the factor loadings (Table 3). The vertical jump test, the figure-of-eight test, and the stairs-running test showed the highest factor loading on factor 1. The triple jump test and the stairs hopple test disclosed the highest factor loading on factor 2. Thus, the two-leg tests represent a common function, and the one-leg tests represent another function.

The last step in the analysis was to establish an entirely new and smaller set of variables to replace the original variables for inclusion in subsequent correlation analysis. Each patient was then represented by two factor scores calculated according to the factor loading given in Table 3. These scores were used in the correlation analysis (Table 4). The correlation between the Lysholm score and factor 1 was higher (0.62) than the correlation between the Lysholm score and factor 2 (0.43). Therefore, the figure-of-eight test, the stairs-running test, and the vertical jump test were more related to the Lysholm score than the other tests. Instability was highly correlated to factor 2. Thus, the triple jump test and the stairs hopple test were correlated to the degree of instability produced from the KT-1000 knee arthrometer. Also, atrophy was better re-

	Factor Loading	
	Factor 1	Factor 2
Vertical jump test	−0.79	0.02
Figure-of-eight test	0.83	0.37
Stairs-running test	0.86	0.22
Triple jump test	0.33	0.86
Stairs hopple test	0.03	0.88

TABLE 3. *Factor loading for the two factors (factor 1, factor 2) derived from the factor analysis of functional knee tests: The correlation between the observed value on each functional test and the factors.*

	One-Leg Tests				
	Uninvolved Leg		Involved Leg		p value†
	X*	(SD)	X*	(SD)	
Triple jump test	490.0	(91.7)	463.1	(109.0)	0.002
Stairs hopple test	22.7	(10.5)	25.2	(11.3)	0.001
Side jump test	13.4	(5.1)	13.9	(5.2)	ns

* *Mean and SD are given in cm for the triple jump test and in seconds for the stairs hopple test and the side jump test.*
† *Paired t-test.*

TABLE 1. *The performance data of the three one-leg hop tests are provided for the uninvolved and the involved leg. The significant differences between the two legs are indicated.*

	Functional Tests			
	Correlation Among Variables			
	Vertical Jump	Triple Jump	Figure-of-Eight	Stairs Running
Triple jump test	−0.15			
Figure-of-eight test	−0.51*	0.64*		
Stairs-running test	−0.52*	0.47*	0.74*	
Stairs hopple test	−0.21	0.61*	0.24	0.19

* $P<.01$.

TABLE 2. *Correlations among five functional tests.*

	Factor 1	Factor 2
Lysholm	−0.62 (0.001)	−0.43 (0.03)
Instability	0.94 (ns)	0.97 (0.03)
Atrophy	0.24 (ns)	0.41 (0.05)

TABLE 4. *Pearson correlation coefficients (and, in parentheses, p values) between factor scores and the Lysholm score, instability, and atrophy in patients with anterior cruciate ligament repair. Two factor scores (one for factor 1 and one for factor 2) are calculated for each patient based on the rotated factor loading given in Table 3. Significance level = $p < 0.05$.*

flected by the triple jump test and the stairs hopple test than the other three tests (Table 4).

No gender difference was found in the performance of the figure-of-eight test, the stairs-running test, the triple jump test, or in the stairs hopple test. However, a significant gender difference was evident on the vertical jump test.

DISCUSSION

Strenuous activities do impose other types of stress on ligaments than those imposed by clinical laxity tests (13). Noyes et al showed that strenuous activities may easily exert five times greater forces than laxity testing (13). Noyes et al also reported increase in frequency of pain, swelling, and "giving away" as the activity level increased (14,15). The functional tests should be sensitive to the functional demands of an athlete. Therefore, running, jumping, and twisting activities must be included in the clinical examinations of the patients to enable true assessment of the knee function. Functional tests may, however, be influenced by motivation and learning factors, and the tests require space.

The Lysholm score showed high functional performance, even though 55% had problems during strenuous activities. This was also emphasized by the significant reduction in strenuous knee activities recorded by the Tegner score. If the aim of rehabilitation is to enable patients to resume strenuous activities at their preinjured level, the Lysholm score did not seem to meet these requirements. The Lysholm score should, therefore, preferably be used in the early period of rehabilitation, not as an assessment of knee function after the patients have resumed sports activities.

The correlations between thigh atrophy and the different tests were low, but measuring the circumference of the thigh may be an inaccurate measure for muscle strength. According to Lopresti et al (9), thigh circumference is inaccurate as a tentative measuring method for muscle strength. On the other hand, Kannus et al (7) found a significant correlation between thigh circumference deficit and strength score recorded by an isokinetic dynamometer.

The results showed that the functional tests could be categorized into two different functions, referring to the two dimensions or factors derived from the analysis. One function could be labeled "daily life" function (factor 1) and the other could be labeled "strength/stability" function (factor 2). It is valuable to apply tests that quantitatively assess functional disabilities both in the early and late postoperative phases. The aim of the early phase of rehabilitation is to bring the patient back to "daily life" function. After 3 months, the figure-of-eight test and the stairs-running test would provide a quantitative assessment of "daily life" function. The next step in the rehabilitation program is to reestablish preinjury sports-related functions. Six months after the operation, the patient should be able to perform the triple jump test and the stairs hopple test, which provide an assessment of functional stability of the involved leg (strength/stability function).

The factor analysis also seemed to discriminate between one-leg and two-leg tests. One-leg tests are impractical early in the rehabilitation program. The correlation between two-leg tests and the Lysholm score emphasized the tests' usefulness in evaluating daily-life activities. Further studies are necessary to establish which functional test in each category shows the highest reliability and validity.

In the present study, the figure-of-eight and the stairs-running tests were not influenced by gender. In contrast, the vertical jump test showed a significant gender difference. According to Barber (3) et al, neither dominant side, activity level, nor gender affected the results of their functional tests. Some of their tests were similar to those included in this study (three one-leg tests and two two-leg tests).

SUMMARY

Functional tests should be categorized according to functional demands during the rehabilitation program. The two-leg tests, figure-of-eight test, and the stairs-running test were correlated to the daily life function. The one-leg tests, the triple jump test, and the new stairs hopple test were highly correlated to knee instability. The Lysholm functional score results were not associated with performance problems during strenuous activities. JOSPT

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