



Functional assessments for anterior cruciate ligament reconstruction return to sport

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Abstract: Despite technical advancements in anterior cruciate ligament (ACL) surgery, the high re-rupture and contralateral ACL injury rates following ACL reconstruction remain a clinically and economically relevant problem. ACL re-ruptures are multi-factorial, however premature return to sport and functional deficits are important causes for graft failure and contralateral ACL injuries. While various prevention programs exist, little is known about functional assessment following ACL reconstruction. Most of the functional tests are for research purposes only because of the associated high costs, time and personnel consumption. In order to integrate functional testing into the rehabilitation process and to subsequently improve patient care, test batteries must be clinically applicable. Many tests have been introduced and evaluated, but many of them reflect only limited aspects of the knee and lower limb function. Therefore, test batteries evaluating muscle strength, speed and agility, as well as neuromuscular control have been introduced. In order to properly interpret the test results however, comparison to normative data or longitudinal data are necessary to properly determine the return to sport.

Keywords: Anterior cruciate ligament (ACL); knee; functional assessment; return to sport; rehabilitation; muscle strength; neuromuscular control; balance; agility

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Introduction

Re-ruptures of a reconstructed anterior cruciate ligament (ACL) are frequently observed with an incidence of 5% to 18%, or more, depending on the follow-up (1-3). Half of these re-ruptures can be observed within the first twelve postoperative months (1,3). Of note, many studies found an even higher incidence of contralateral ACL injuries, with a reported extraordinarily high incidence of 16% or higher (1-3). Even the implementation of various prevention

programs has not substantially reduced this risk (4). Factors associated with graft failure or contralateral ACL injuries are younger age (1,3), male gender (1,2), technical errors (i.e., poor bone tunnel placement) and graft choice (i.e., allografts, hamstring tendons) (5), the biomechanical properties of the graft during the ligamentization process (6), as well as return to pivoting activities (1). Further, it has been shown that muscular and proprioceptive deficits may be observed for more than one year following ACL reconstruction (7,8). Therefore, many surgeons prefer to postpone the return

to sport until six months or later. However, most sports medicine specialists do not utilize functional tests that may provide more accurate feedback regarding the optimal timing for “safe” return to sport. Reasons for this could be that the athlete is under pressure to return to competition as soon as possible, the high time commitment associated with performing many functional tests, or unawareness of functional tests and lack of evidence especially regarding normative values. Currently, patients usually return to sports within 6 to 12 months following ACL reconstruction (9,10) and most of the surgeons rely solely on physical exams, although some surgeons also utilize more objective measures such as Lysholm and International Knee Documentation Committee scores.

When applying functional performance tests (11), many of the sports medicine specialists perform isolated tests. Hop tests are the most commonly used performance tests (12-14). However, these tests have been criticized for not being sufficient to properly evaluate the patients’ functional capability following ACL reconstruction (15). Even commonly available isokinetic muscle strength tests do not necessarily correlate with knee function, suggesting that they should not be used in isolation (16-18). Based on these facts, functional assessment following ACL reconstruction should consist of multiple tests to properly evaluate the functional abilities of the patient to determine a safe return to sport.

Different test batteries do exist (19-21). However, the utility of these tests to adequately predict readiness for return to sport is limited (15). Further, the test batteries do not compare the obtained data with normative values and were generally performed not before one year after surgery. However, functional assessment following ACL reconstruction should not only be used as a tool to determine the readiness to return to sport, but also to evaluate the progress over time during the rehabilitation in order to properly address possible functional and sports specific deficits.

Demands on functional assessment

Functional assessment to determine return to sport following ACL reconstruction requires time, personnel, infrastructure, equipment and finally money. The ideal functional assessment includes movement analyses (either two dimensional or three dimensional) to detect abnormal motion patterns (i.e., dynamic valgus landing), strength tests, agility tests, proprioception and postural tests. The

ideal test battery including all of these tests would have low cost, time, and personnel efficiency. Therefore, such a test battery with the highest quality standards is clinically not practicable.

To date, little evidence regarding normative values for different tests exists (22,23), with most of the sports medicine specialists relying on limb symmetry indices (LSI). However, it has been shown, that the clinically acceptable LSI of >90% does not necessarily detect sufficiently functional deficits, since both limbs are negatively affected by an ACL reconstruction (24). Further, studies evaluating the LSI often do not take into account limb-dominance when interpreting the results. A recently published study on healthy subjects by Hildebrandt *et al.* (23) has shown that clinically relevant side-to-side differences between the dominant and non-dominant leg exist, especially for the single-legged counter movement jump. In that study the LSI was found to be up to 124%, on average, for the counter movement jump, indicating a 24% better performance in the dominant leg. Therefore, it is questionable whether a LSI >90% for such a test is clinically acceptable.

In summary, functional assessment following ACL reconstruction should cover the status of the knee, as well as motoric skills in a clinically applicable setting. Further, data analysis must be efficient and the results should be compared to normative values to allow for proper interpretation. Ideally, functional assessment should be performed more than once following ACL reconstruction to address functional deficits during the rehabilitation.

What do we need to assess?

Physical examination

Before any functional assessment is begun, a standard physical exam to evaluate ligament laxity, range of motion and effusion needs to be performed. Normal laxity and an inflammation-free knee are prerequisites for any return to sport. Especially, quantitative laxity measures could help to detect even subtle side-to-side differences (25).

Muscle strength

Muscle strength can be evaluated with either isokinetic strength measurements or jumping tasks, such as plyometric jumps, counter movement jumps or different hop tests.

Muscle strength testing with an isokinetic dynamometer

(i.e., Contrex® MJ; CMV AG, Zurich, Switzerland) for the flexor and extensor apparatus can be a useful tool to evaluate the rehabilitation progress and to determine return to sport. Usually, peak extensor and flexor torque (Nm) are obtained at different angular velocities. Since it has been shown that muscle strength deficits continue to persist for more than one year postoperatively (18,26-28), it is recommended to perform muscle strength tests more than once during rehabilitation. Data can be interpreted based on the pre-injury state (longitudinally), or more commonly using the LSI. As mentioned above, a LSI >90% is a commonly accepted threshold for return to play. However, it has been shown that the hamstring to quadriceps ratio might be a more important predictor for muscular imbalances around the knee than the maximum isokinetic torque (29). A decreased hamstring to quadriceps ratio was also found to be a risk factor for further knee injuries (30). Kyritsis *et al.* reported a hazard ratio of 10.6 for subsequent ACL re-ruptures per 10% difference in the hamstring to quadriceps ratio (31). Thus, restoration and evaluation of both extensor and flexor muscle strength is of high importance following ACL reconstruction and the hamstring to quadriceps ratio might represent a good parameter for decision-making regarding return to sport. Ideally, the hamstring to quadriceps ratio should be around 80% (29,30). In addition to knee extension and flexion strength, hip and trunk muscle strength should be considered in either screening programs or functional assessments following ACL reconstruction, as they are associated with an increased ACL injury risk and inferior performance during functional tasks (i.e., single leg step-down test) (32,33).

Hop tests are commonly used as functional outcome measures following ACL reconstruction, since they indicate muscle strength and dynamic muscle co-activation. Clinically, single-leg hop performance correlates with self-reported knee function return to play (13,17). Amongst the different available jump tests, the vertical jump, jump for distance and the side hop have been shown to have the highest sensitivity in detecting functional deficits following ACL reconstruction (34). The tests should be performed with one and two legs, since it has been shown that deficits might not be evident during bipedal tasks (21). Besides height and distance, the power (W/kg) as well as ground contact time can be obtained with an acceleration sensor (i.e., Myotest SA, Sion, Switzerland). However, care should be taken when interpreting the hop test results. It has been shown that hop test performance correlates strongly with fatigue (12). Therefore, the tests should be performed

under non-fatigued and fatigued test conditions. Also, the time point of testing during the rehabilitation is of high importance. In the early phases, subjects might not be able to perform any jumping tests, whereas in very late phases the sensitivity to detect functional deficits might be decreased. However, it has been shown that hop test performance is significantly decreased up to 9 months following ACL reconstruction (35). Video analyses or visual feedback from a supervisor can be added to screen for abnormal motion patterns during the jumping task such as functional knee valgus as a secondary ACL injury prevention (36).

Even though, hop test performance does correlate moderately with isokinetic quadriceps strength (37), such tests cannot replace muscle strength testing.

Speed and agility

Speed (i.e., running speed, ground contact time during plyometric jumps) and agility (i.e., ability to perform cutting maneuvers) are prerequisites for many competitive sports and should therefore be included in any functional assessment following ACL reconstruction. Such movements (cutting/pivoting maneuvers, deceleration) are commonly related to non-contact ACL injuries and proper intervention with motion modification can decrease the injury risk (38). Therefore, various prevention programs are designed to screen for deficits regarding speed and agility.

Speed and agility can be assessed in different ways, such as with a speedy test, quick feet test, shuttle run, the agility T-test (21) or different consecutive jump patterns (39). Of note, the assessment should include single leg as well as bipedal tests to properly screen for potential deficits (21). All of these tests have in common, that the subjects need to perform the task as fast as possible without losing control over the trunk. Thus, besides agility and speed, also coordination, balance, and concentration are required and tested.

Neuromuscular/postural control

Decreased neuromuscular control of the knee, hip and trunk are associated with a higher ACL (re-) injury risk (40,41). Therefore, many ACL injury prevention programs include different screening tests to detect and correct such deficits. In a meta-analysis by Hewett *et al.*, it has been shown, that such prevention programs can effectively reduce the injury risk (42). Of note, most of the screening tests for neuromuscular deficits are highly demanding



Figure 1 Speedy jump. The participant is introduced to accomplish a jump coordination path, which includes forward, backward and sideways jumps (indicated with the different pole color) as fast as possible.

and include two-dimensional or three-dimensional video analyses to evaluate joint angles during different task (such as step-down test or jumping tests). Therefore, their clinical applicability is questionable and simpler tests have been established to assess for postural control. Balance tests are easy and time efficient and are representative for hip, trunk, knee and ankle neuromuscular control and can therefore be used for functional assessment following ACL reconstruction (43). Different tests and devices exist. The Biodex Stability System (Biodex Medical Systems, Shirley, New York, USA) can assess dynamic postural stability in a closed-chain manner. The foot platform has different resistance levels and the subject is instructed to maintain the level position during a test (8). Another device to assess dynamic balance is the MFT Challenge Disc (TST Trendsport, Grosshöflein, Austria), which is connected to a laptop or personal computer. The disc is free to move and a software provides instant feedback regarding disc position while the subjects tries to maintain the balance on the disc (23). Alternatively to dynamic balance tests, postural control can also be assessed in a static manner, such as the participant is instructed to maintain the balance with open and closed eyes and the motion and excursion of the lower and upper body are registered (8).

Development of a new test battery

A new test battery (Back in Action, CoRehab, Trento, Italy) consisting of seven subtests has been developed and clinically established (22,23). The different subtests provide data on strength, jumping power, speed and agility as well as balance. The test battery can be accomplished within one hour and needs only little equipment and space and can therefore be performed in one room. A software program provides fast evaluation and feedback and compares the subjects' performance with normative data from 434 participants (23). All data are evaluated using the absolute values as well as the limb symmetry index for one-legged tests. The results of the participants are classified from "very weak" to "very good" based on age and gender specific normative values. The test battery should be performed at least twice following ACL reconstruction or once if the participant meets the return to sport criteria (22).

Jump tests

The participants must perform a counter movement jump (one- and two-legged) as well as plyometric jumps. For the counter movement jump, the subjects are instructed to quickly bend their knees followed by an immediate upward jump. The arms have to be placed on the hips. For the plyometric jumps subjects must perform three consecutive bipedal jumps. In contrast to the counter movement jump, the arms can be used to assist with the jump. The outcome variables include maximum height (cm), power (W/kg), ground contact time (ms) and reactivity (mm/ms). All tests are performed using Myotest (Myotest SA, Sion, Switzerland).

Speed and agility

The participants must accomplish a jump coordination path (Speedy jump; one-legged) (*Figure 1*). The path includes forward, backward and sideways jumps and the subjects should be as fast as possible without a rest between the hurdles, touching the hurdles or twisting of the hip. The outcome variable is time in seconds.

For the Quick feet test (*Figure 2*), the same equipment same equipment is used as for the Speedy jump. The participant has to step in and out by alternating the foot without touching the poles or reversing the order of the



Figure 2 Quick feet test. The participant has to step in and out the box as indicated by the poles as fast as possible. The time between the beginning and the point where 15 repetitions are completed is measured.



Figure 3 One-legged stability test. While the participant is balancing on a disc trying to hold the center of the disc, a software provides instant feedback (right).

steps. The time between the beginning and the point where 15 repetitions are completed is measured (seconds). One repetition is considered completed when the starting leg returns to its initial position.

Postural control

The tests are performed on a MFT Challenge Disc (TST Trendsport, Grosshöflein, Austria). A software program provides instant feedback about the disc position while the subject is balancing on the disc (either one- or two-legged). The participant is asked to maintain the balance for 30 seconds and the outcome variable is the level of stability index (*Figure 3*).

In addition to the Back in Action test battery (Back in Action, CoRehab, Trento, Italy), subjects complete isokinetic quadriceps and hamstring muscle strength tests.

Future perspective

The key for any functional testing is the comparison to normative data, or ideally to the pre-injury state (longitudinal design). For our test battery, age and gender specific normative data were obtained from 434 healthy subjects. However, to individualize the rehabilitation and return to sport criteria, sports specific normative data need to be obtained. Further, clinical studies investigating the effectiveness of such functional tests are needed.

Conclusions

Functional assessment following ACL reconstruction should be incorporated in the rehabilitation process. Individual tests are not sensitive enough to detect functional deficits, therefore test batteries including muscle strength, hop/jump tests, agility and neuromuscular control should be established. While prevention programs might reduce the ACL injury risk there is a lack of evidence whether functional assessment following ACL reconstruction can reduce the incidence of graft failures.

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