Test Batteries After Primary Anterior Cruciate Ligament Reconstruction: A Systematic Review

Chelsey Roe, PhD, ATC,*† Cale Jacobs, PhD, ATC,‡ Johanna Hoch, PhD, ATC,§ Darren L. Johnson, MD,‡ and Brian Noehren, PT, PhD†

Context: There is a lack of consensus regarding test batteries for return to sport (RTS) after anterior cruciate ligament reconstruction (ACLR).

Objective: To report the RTS test batteries for individuals after ACLR and to examine alignment with the American Academy of Orthopaedic Surgeons (AAOS) Appropriate Use Criteria (AUC). Finally, to examine how published RTS batteries prior to the AAOS AUC (2010-2015) compared with those after publication of the AUC (2016-2020).

Data Source: A systematic search of PubMed (2010-2020).

Study Selection: Studies were included if they were published from 2010 to 2020, patients underwent primary ACLR and were tested between 6 months and 2 years postoperatively and included a minimum of 2 assessments. Studies were excluded if patients were tested outside the designated time; had undergone a revision, contralateral, or multiligament injury; included healthy participants; were level 5 evidence or the study was a systematic review. A total of 1012 articles were reviewed and 63 met the criteria.

Study Design: Systematic review.

Level of Evidence: Level 4.

Data Extraction: Information regarding the RTS batteries and patient demographics were extracted from the included articles.

Results: A total of 63 studies met the inclusion and exclusion criteria (22 from 2010-2015 and 41 from 2016-2020). The most common RTS batteries included the hop test, quadriceps strength test, and patient-reported outcome measures. No study met all 7 AUC; the most common criteria met were functional skills (98.4%), followed by confidence (22.2%), then range of motion and knee stability (20.6%).

Conclusion: The test batteries in the current literature show high variability and a lack of essential components necessary for RTS. No study met the AUC guidelines, suggesting a disconnect between recommended guidelines and clinical practice. Test battery research has expanded over the past decade; however, standardized, clinically applicable batteries that encompass all criteria are needed.

Keywords: anterior cruciate ligament; return to sport; test batteries; appropriate use criteria

Decreased quadriceps strength, functional limitations, and poor patient-reported function often persist after anterior cruciate ligament (ACL) surgery, and can contribute to secondary injuries.[8-10,55,62,84] Secondary ACL injuries have devastating long-term health outcomes, including meniscal loss, articular cartilage damage, and onset of osteoarthritis.[85] In light of the high incidence of second ACL injuries,[79,99] athletes may be returning to sport prematurely without adequate evaluation.

To decrease the rate of reinjury, subjective evaluation, knee examination, and functional test batteries should be assessed at the time of return to sport (RTS).[1,4,8,13,14,42,74] A recent review

From †Department of Physical Therapy, University of Kentucky, Lexington, Kentucky, ‡Department of Orthopedic Surgery & Sports Medicine, University of Kentucky, Lexington, Kentucky, and §Department of Athletic Training and Clinical Nutrition, University of Kentucky, Lexington, Kentucky

*Address correspondence to Chelsey Roe, PhD, ATC, Physical Therapy Department, College of Health Sciences, University of Kentucky, 900 South Limestone, Wethington Building, Room 204J, Lexington, KY 40526 (email: c.roe@uky.edu).

The following author declared potential conflicts of interest: C.J. is a consultant for Flexion Therapeutics and has grants pending from Flexion Therapeutics and Smith & Nephew.

DOI: 10.1177/19417381211009473

reported that only 13% of studies included objective criteria at RTS for post–ACL reconstruction (post-ACLR) patients.[13] Among the studies that included objective criteria, the most common assessments were strength testing, performance-based functional testing, and self-reported knee function.[13] There is a great deal of variability regarding the optimal battery of criteria to implement and which tests are the most applicable in the clinical setting at the time of RTS.[4,13,14,43,102] In 2015, the American Academy of Orthopaedic Surgeons (AAOS) created the Appropriate Use Criteria (AUC) that includes a checklist of 7 objective measures (Table 1).[83] These 7 criteria include assessments of knee stability, range of motion (ROM), strength, balance, functional ability, and confidence. RTS criteria have expanded over the past decade to include additional factors from the previous objective criteria because of the growing volume of ACLR outcome studies. The need for further criteria demonstrates the multifaceted nature of ACL injuries and the requirements needed to be prepared for the demands of sports. The AAOS recommendations state that patients who pass 6 of the 7 criteria on the checklist are permitted to return to unrestricted activity, suggesting the implementation of these criteria will decrease the incidence of subsequent knee injury after RTS.[83] While these criteria have been developed to create a consensus among clinicians, it is not known how current evidence-based test batteries align with the AAOS AUC recommendations. The purpose of this review was to systematically search and synthesize the existing literature to examine similarities and differences in RTS test batteries after primary ACLR. Second, we examined how these criteria compared with the AAOS AUC recommendations. Finally, we determined the differences between articles published from 2010-2015 and 2016-2020 compared with the AAOS AUC guidelines.

Table 1. American Academy of Orthopaedic Surgeons appropriate use criteria[83]

Patient Return to Play Checklist
1. Patient's graft incorporation and graft strength has been considered
2. Patient's functional range of motion is restored
3. Patient has a stable knee with no pivot
4. Functional return of patient's core, hip, quadriceps, and hamstring strength has occurred, as determined by clinician discretion (can be measured by a variety of methods)
5. Patient's functional balance restored
6. Patient attests or surgeon observes functional skills are performed adequately
7. Patient is confident that he/she is ready to return to sport of interest

METHODS

Search Strategy

A literature search was performed to retrieve articles that included test batteries utilized to evaluate RTS after primary ACLR (Table 2). An electronic database search was conducted in PubMed that was limited to results in English over the past 10 years (January 2010–July 2020). A copy of the search strategy can be found in Table 2. The reference lists of included articles were searched for additional articles relevant to the topic and all duplicates were removed.

Criteria for Selecting Studies

Studies were included based on the following criteria:

- Studies that included patients who had undergone primary ACLR with any graft type.
- Studies that included a minimum of 2 tests in the RTS test battery and examined test batteries or used them for RTS evaluation.
- Studies that examined the test batteries from approximately 6 months and up to 2 years after ACLR.
- Studies that were published from 2010 to 2020 and were published in English.
- Studies that had participants complete ROM and knee stability prior to the actual RTS battery, as a part of the diagnostic examination/inclusionary criteria.

Studies were excluded based on the following:

- Studies that reported RTS evaluation prior to 6 months or 2 years after ACLR.
- Studies that included revision ACLR patients, ACL-deficient patients, or patients with multiligament knee injuries. However, patients with meniscal involvement or medial collateral ligament injuries were included.
- Studies that were considered level 5 evidence or literature reviews (narrative, systematic review, etc).
- Studies that were non-English language, were systematic reviews, or included meta-analyses.
- Studies with only healthy participants and articles that reviewed 1 test.

Data Extraction and Statistical Analysis

Once it was determined the articles met the inclusion criteria, the articles were carefully reviewed and the following data were extracted: participant demographic information, graft type, participant activity level (Tegner activity level/level of sport), time of follow-up, and the criteria used to determine RTS. Categorical data were reported as frequencies with percentages.

Table 2. PubMed search[a]

Step	Search Terms	Boolean Operator	PubMed
1	Anterior cruciate ligament Anterior cruciate ligament reconstruction ACL ACLR	OR	15,458
2	Return to sport Return to play Sport re-entry Return to competition Return to activity Preinjury level	OR	27,928
3	Knee		86,030
4	Functional test Functional test battery Assessment Outcome measure Outcome Outcomes Criteria Reported Function	OR	7,964,523
5	1 + 2 + 3 + 4	AND	1012
References			6
Hand search			2
Total identified			63
	((((((anterior cruciate ligament) OR anterior cruciate ligament reconstruction) OR acl) OR aclr)) AND ((((((return to sport) OR return to play) OR sport re-entry) OR return to competition) OR return to activity) OR pre-injury level)) AND knee) AND ((((((((((functional test) OR functional test battery) OR assessment) OR outcome measure) OR outcome) OR outcomes) OR criteria))) OR reported) OR function)		

[a]ACL, anterior cruciate ligament; ACLR, ACL reconstruction.

RESULTS

Literature Search

The search resulted in 63 studies meeting the inclusion and exclusion criteria. A total of 9439 patients (61.3% men) were included in the review. The mean age of the participants was 23.6 ± 5.2 years. The average time from surgery to RTS testing was 10.0 ± 3.9 months. The most common graft utilized was the hamstring autograft (71.7%) followed by bone–patellar tendon–bone autograft (18.3%), while the allograft and others accounted for 10.6%. The articles included in the current review offered a variety of activity level information, all studies included participants with a minimum Tegner score of 5, and participants played in level 1 or 2 sports or the article did not identify activity level.

Similarities and Differences in RTS Test Batteries

There was no consistent test battery utilized among the literature; however, the batteries contained variations of similar

Table 3. Most common assessments out of the 63 included studies

Most Common Criteria	No. of Studies (%)
Single-leg hop for distance[a]	55 (87.3)
Triple hop[b]	39 (61.9)
IKDC[c]	34 (54.0)
Crossover hop[d]	30 (47.6)
6-m timed hop[e]	25 (39.7)
Isokinetic strength at 60 deg/s[f]	21 (33.3)
Isokinetic strength at 180 deg/s[g]	16 (30.2)
KOOS[h]	15 (25.4)
Isometric at 90°[i]	15 (25.4)
Knee stability[j]	13 (20.6)
Range of motion[k]	13 (20.6)
Tegner[l]	13 (20.6)

IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score.
[a]12,15,18,19,22,24-27,29-33,35-37,39-41,44,50,52,53,55-57,61,65-72,75,76,78,81,82,84,86-88,91,92,95,96,97,100-102,107.
[b]12,17-19,24-27,29,30,32,33,35,36,39,50,57,61,65-68,70-72,78,82,84,86-88,92,95,99-102,107.
[c]5,19,22,27,30,31,35,37,40,52,53,56,57,59-61,65,67,72,75,76,78,82,84,86,87,92,95,96,97,100,101,107.
[d]18,19,25-27,29,30,32,36,39,44,50,61,65-68,70-72,76,78,82,84,86,88,92,102,107.
[e]12,19,25-27,29,30,32,36,39,57,61,68,70-72,76,78,82,84,86,88,92,102.
[f]17,19,21,22,35,39,44,52,53,55,56,59-61,66,73,75,82,87,100,101.
[g]19,26,35,37,50,55,65,66,78,87,88,92,100,101,107.
[h]12,15,27,41,44,50,57,65,69,78,81,82,84,86.
[i]12,19,22,26,32,36,44,61,65,67,70,72,86,102.
[j]5,27,37,52,53,56,57,60,64,78,95-97.
[k]19,27,59,60,64,70,71,75,82,86,95-97.
[l]5,16,21,27,41,50,53,56,57,59,60,87,107.

Table 4. Most common functional tests for each study

Functional Skills	No. of Studies (%)
Single-leg hop for distance[a]	55 (87.3)
Triple hop[b]	39 (61.9)
Crossover hop[c]	30 (47.6)
6-m timed hop[d]	25 (39.7)
Side hop[e]	11 (17.5)
Single-leg vertical jump[15,41,56,81,87,91]	6 (9.5)
Single-leg squat test[24,33,34,40,96]	5 (7.9)
Landing Error Scoring System[26,35,100,101]	4 (6.3)
Shuttle run[53,56,68]	3 (4.7)
Single-leg landing[18,24,75]	3 (4.7)
Double-leg CMJ[21,28,55]	3 (4.7)
Drop vertical jump[31,66,73]	3 (4.7)
Agility program[59,60,75]	3 (4.7)
Double-leg vertical jump[69,76]	2 (3.2)
Lateral bounding[33,34]	2 (3.2)
Broad jump[37,68]	2 (3.2)
Forward/backward jogging[33,34]	2 (3.2)
Single-leg CMJ[21,28]	2 (3.2)
Plyometric jump test[21,28]	2 (3.2)
Speedy jump test[21,28]	2 (3.2)
Quick feet test[21,28]	2 (3.2)
Modified Illinois[17,18]	2 (3.2)
Co-contraction test[53,56]	2 (3.2)
Carioca test[53,56]	2 (3.2)
Tuck jump[31]	1 (1.6)
Modified agility T test[68]	1 (1.6)
Functional movement screen[64]	1 (1.6)
5-jump test[31]	1 (1.6)
Square hop[67]	1 (1.6)
Sprint braking test[17]	1 (1.6)
Quality movement assessment[37]	1 (1.6)

(continued)

criteria for RTS. In total, there were 32 different functional tests among the 63 articles, 13 methods for measuring strength, and 21 different patient-reported outcomes (PROs). The test batteries most commonly consisted of traditional hop testing, strength assessments, and PROs, including Knee injury and Osteoarthritis Outcome Score (KOOS) and International Knee Documentation Committee (IKDC) (Table 3). A majority (98.4%) of the articles implemented hop testing, with the most common test being the single-leg hop for distance (87.3%, Table 4), followed by the triple hop (61.9%), crossover hop (47.6%), and 6-m timed hop (39.7%). Strength was assessed in 52 studies (82.5%). Isokinetic strength at 60°/s was the most commonly (33.3%) utilized

Table 4. (continued)

Functional Skills	No. of Studies (%)
Side-step cut test[17]	1 (1.6)
Normal running and landing/4 weeks of unrestricted training[96]	1 (1.6)

CMJ, countermovement jump.
[a]12,15,18,19,22,24-27,29-33,35-37,39-41,44,50,52,53,55-57,61,65-72,75,76,78,81,82,84,86-88,91,92,95,96,97,100-102,107.
[b]12,17-19,24-27,29,30,32,33,35,36,39,50,57,61,65-68,70-72,78,82,84,86-88,92,95,99-102,107.
[c]18,19,25-27,29,30,32,36,39,44,50,61,65-68,70-72,76,78,82,84,86,88,92,102,107.
[d]12,19,25-27,29,30,32,36,39,57,61,68,70-72,76,78,82,84,86,88,92,102.
[e]16,18,31,35,41,57,69,81,91,100,101.

strength assessment, followed by isokinetic strength at 180 deg/s (25.4%), and isometric strength at 90° of knee flexion (23.8%) (Table 5, Figure 1). A total of 49 studies (77.8%) implemented PROs (Table 6). The IKDC was the most frequently utilized outcome measure (54.0%); KOOS (23.8%) was second, followed by the Tegner activity level scale (20.6%), ACL-Return to Sport after Injury Scale (ACL-RSI) (17.5%), and Knee Outcome Survey Activities of Daily Living (15.9%).

How the Reported Test Batteries Align With the AAOS AUC

None of the included studies met all 7 recommended AUC (Figure 2). All studies assessed functional skills but 1 (98.4%).[5] Three studies included measures of hip strength,[40,78] and no study included an assessment of core strength. Although 82.5% of studies did report a measure of strength, none of the studies assessed all suggested strength assessments (quadriceps, hamstring, hip, and core strength) in 1 battery. Fourteen studies (21%) included PROs, and most often utilized more than 1, which resulted in an overwhelming total of 116 PROs. Fourteen of the 63 (22.2%) studies included an assessment of confidence with the ACL-RSI, Tampa Scale of Kinesiophobia (TSK-11), or a single question from the KOOS–Quality of Life questionnaire. Thirteen studies (20.6%) measured knee stability using the KT-1000/2000, Com-puKT, Lachman or pivot-shift test. Only 13 of 63 of studies (20.6%) included ROM and 8 studies (12.7%) included measures of balance. Graft strength was not assessed.

Differences Between the 2010-2015 and 2016-2020 Test Batteries With the AAOS AUC Guidelines

The AAOS guidelines were created in 2015. From 2010 to 2015, 22 articles fit the inclusion criteria for RTS batteries in the current study. The most common assessments were functional skills (95.5%) and a measure of strength (86.4%). Knee stability and ROM were included in 5 studies (22.7%). From 2016 to 2020, 41 articles fit the inclusion criteria for the current study. Functional skills were included in 100% of the articles and 33 articles (80.5%) included a strength assessment. In the more recent articles, 11 (26.8%) included an assessment of confidence

Table 5. Strength assessments

Strength Measures	No. of Studies (%)
Isokinetic strength at 60 deg/s[a]	21 (33.3)
Isokinetic strength at 180 deg/s[b]	16 (25.4)
Isometric at 90°[c]	15 (23.8)
Other[d]	11 (17.5)
Isokinetic strength at 300 deg/s[e]	9 (14.3)
Isokinetic strength at 90 deg/s[15,27,29,30,65,72]	6 (9.5)
Isometric strength at 60°[15,25,78,84]	4 (6.3)
Hip strength[40,78]	2 (3.2)
Isometric hamstring at 90°[19,65]	2 (3.2)
Isokinetic strength at 120 deg/s[107]	1 (1.6)
Isometric strength at 30°[15]	1 (1.6)
Core strength	0 (0)

[a]17,19,21,22,35,39,44,52,53,55,56,59-61,66,73,75,82,87,100,101.
[b]19,26,35,37,50,55,65,66,78,87,88,92,100,101,107.
[c]12,19,22,26,32,36,44,61,65,67,70,72,86,102.
[d]5,17,22,41,55,57,71,75,82,91,96.
[e]35,50,78,88,100,101,107.

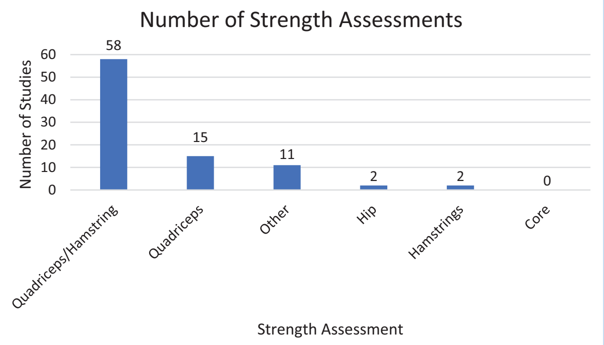

Figure 1. Most common strength assessments of all the included studies.

Table 6. Patient-reported outcomes

Patient-Reported Outcomes	No. of Studies (%)
IKDC[a]	34 (54.0)
KOOS[b]	15 (23.8)
Tegner[c]	13 (20.6)
ACL-RSI[d]	11 (17.5)
KOS-ADL[e]	10 (15.9)
Lysholm[f]	9 (14.3)
GRS[25,32,36,39,61,70]	6 (9.5)
Global Rating of Perceived Function[12,71,86]	3 (4.7)
TSK-11[59,60,67]	3 (4.8)
Physical Activity Scale[41,55]	2 (3.2)
Return to sport status[55,60]	2 (3.2)
NSARS[27,30]	2 (3.2)
SANE[97]	1 (1.6)
K-SES[41]	1 (1.6)
NRS[59]	1 (1.6)
Knee pain intensity[60]	1 (1.6)
Episode of instability[60]	1 (1.6)
VAS[21]	1 (1.6)
WOMAC[57]	1 (1.6)
Marx Activity[37]	1 (1.6)

ACL-RSI, Anterior Cruciate Ligament–Return to Sport after Injury Scale; GRS, Global Rating Scale; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; KOS-ADL, Knee Outcome Survey Activities of Daily Living Scale; K-SES, Knee Self-Efficacy Scale; NRS, Numeric Rating Scale; NSARS, Noyes Sports Activity Rating Scale; SANE, Single Assessment Numeric Evaluation Score; SF-8, Short Form 8; TSK-11, Tampa Scale of Kinesiophobia; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[a]5,19,22,27,30,31,35,37,40,52,53,56,57,59-61,65,67,72,75,76,78,82,84,86,87,92,95-97,100,101,107.
[b]12,15,27,41,44,50,57,65,69,78,81,82,84,86.
[c]5,16,21,27,41,50,53,56,57,59,60,87,107.
[d]18,19,26,35,52,56,67,81,82,100,101.
[e]12,25,27,32,36,39,61,70,71.
[f]12,22,37,53,55-57,76,82.

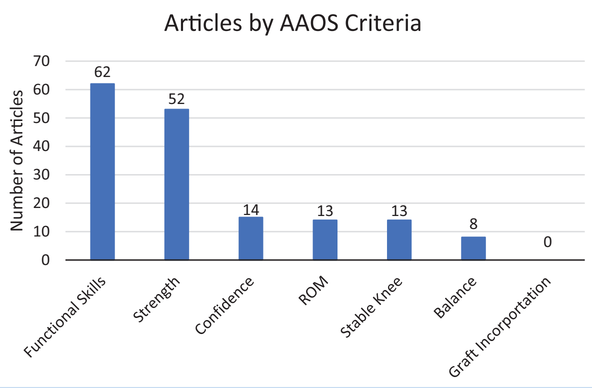

Figure 2. Number of articles that met each American Academy of Orthopaedic Surgeons (AAOS) appropriate use criterion. ROM, range of motion.

with either the ACL-RSI, TSK-11, or a question from the KOOS–Quality of Life. Table 7 represents the number of studies that met each AAOS AUC guideline before (2010-2015) and after (2016-2020) its creation in 2015.

DISCUSSION

The primary purpose of the review was to determine the existing RTS test batteries for post-ACLR patients in the literature. A secondary goal was to determine how the RTS test batteries align with the AAOS AUC guidelines. The last purpose was to examine how published RTS batteries prior to the AAOS AUC guidelines (2010-2015) compared with those published after the AAOS AUC guidelines (2016-2020). Although subjective and objective criteria have been included in the RTS decisions across all included studies, there remains a variety of tests that comprise these batteries and none of the test batteries reported all necessary criteria recommended by the AAOS AUC. Furthermore, high variability persists between test batteries with a lack of standardized measures.[13,14] However, objective criteria have been used more frequently than previously reported.[13] The articles included in this review rarely included measurement strategies other than hop testing, quadriceps strength, and PRO measures. The AAOS AUC recommendation includes an extensive multifaceted approach for a successful RTS[13,54,63]; however, the current literature published either before or after the AAOS AUC has not incorporated this approach in RTS testing.

Similarities and Differences in RTS Test Batteries

In total, 33 different functional tests were reported in the 63 studies included in this review (Table 4). The Noyes hop tests,[74] specifically the single-leg hop for distance, were the most common tests of function. The limb symmetry index (LSI) uses average measures of the uninvolved limb for comparison with the involved limb to determine readiness to RTS.[74] Symmetry is traditionally defined using a cutoff of 90% or greater, meaning limb to limb asymmetries are reduced to 10% or less.[3] Recently, hop testing and LSI have been called into question.[43,102] The literature suggests hop tests have failed to correlate with RTS[102]; however, with more stringent limb symmetry requirements, they

Table 7. Studies meeting American Academy of Orthopaedic Surgeons appropriate use criteria

	No. of Studies		
Criteria	2010-2020	2010-2015	2016-2020
Functional skills	62	21	41
Strength	52	19	33
Confidence	15	4	11
Range of motion	14	5	9
Stable knee	14	5	9
Balance[a]	8	1	7
Graft incorporation	0	0	0
Total articles	63	22	41

[a]21,26,28,31,64,69,73,78.

may be a better representative measure of RTS readiness.[78,92] Although single-limb testing may reveal deficits not identified during double-limb testing,[68] asymmetrical loading of both limbs after ACLR is a risk factor for ipsilateral and contralateral injury.[37,47] Hop testing does not appear to capture all the essential components necessary for a safe RTS at this time.[3,106] However, it does appear to be the most common data element used across studies examining RTS criteria for patients after primary ACLR.

Quadriceps weakness correlates with greater movement asymmetries,[75] lower self-reported and performance-based measures,[84,104] and is predictive of failing RTS criteria.[25] While there is agreement that adequate quadriceps strength remains a key variable prior to RTS,[63] the current literature lacks standard guidelines of assessment.[93] The most common measurement of strength was isokinetic angular velocity of 60 deg/s followed by 180 deg/s. However, there was no justification in the studies as to why these velocities were selected. Furthermore, cutoff scores of 10% to 15% have been suggested for the LSI,[54,62,63,92] yet the most acceptable deficits remain unknown. Additionally, studies that reported quadriceps strength utilized an isokinetic dynamometer that may not be available in all settings. Cost-effective and clinically feasible approaches are necessary to determine if these methods are indicative of quadriceps function prior to unrestricted RTS.

Psychological factors have become increasingly reported as measures of patient perspective and have been shown to heavily influence RTS.[10,13,23] Additionally, knee impairments have been associated with psychological variables, highlighting the link between subjective and objective function.[58] The most common self-reported measure in this review was the IKDC. The IKDC is used to assess knee symptoms, function, and sports activities.[49] However, the IKDC does not address measures of confidence or fear of reinjury, which was cited as the most common reason for reduction or cessation of preinjury level of sport.[7] There are additional measures that have been used to assess confidence,[98] fear of movement/reinjury,[105] or self-efficacy in post-ACLR patients.[89,90] Although a lack of consensus remains, psychological variables must be addressed prior to RTS.[63] Future work should determine how to address these impairments throughout rehabilitation, as psychological variables are modifiable.[6,20]

Included Studies' RTS Test Batteries Alignment With the AAOS AUC

None of the studies presented in this review met the criteria recommended by the AAOS AUC guidelines. A disconnect exists between the current evidence-based literature, the proposed AUC guidelines, and clinical practice. From the review, 98% of articles met the functional skills criteria and 82.5% met at least 1 strength criterion. However, no study included all strength measures suggested by the AAOS including assessments of quadriceps, hamstring, hip, and core strength. Furthermore, less than 30% of the studies included any assessment of confidence, ROM, knee stability, or balance. The first item on the AUC guidelines is "graft incorporation and strength." This item may need further explanation as item 3 refers to knee stability that can be simply assessed in the clinic. For this reason, we did not assess any studies for "graft incorporation and strength." Furthermore, this battery recommended by the AAOS guidelines may not be assessed by 1 clinician. The AAOS AUC guidelines do not provide specific methods of assessment for clinicians and investigators to follow since consensus does not exist.

The AUC recommend a battery of strength assessments that include hip and core strength, along with confidence. Only 2 articles measured hip strength[40,78] and included a handheld dynamometer (HHD) and a Biodex, respectively. Isokinetic dynamometers and HHDs may not be available in all clinical settings. None of the studies assessed core strength of any kind. Hip weakness and poor trunk control have been implicated as risk factors in lower extremity injury[2,46,48,109] and associated with biomechanical deficits that are linked to second injury risk.[51,80] Clinically applicable assessments of hip and core strength are necessary to reach athletes in all settings. Furthermore, the AUC guidelines specifically indicate confidence as a measure of RTS rather than a generalized patient-reported function questionnaire. Fear of movement/reinjury is the most common reason for not returning to preinjury level.[11] Increased fear and poor confidence have been related to greater asymmetries on single-leg hop testing and quadriceps strength deficits.[18,19,77] All athletes should be assessed for confidence and fear of movement/reinjury to identify those at a greater risk of future injury.

Underrepresented guidelines within the AAOS AUC included the knee stability tests, ROM, and balance. Less than a quarter of the studies reported a Lachman, pivot-shift, or KT-1000 test to determine knee stability. These measures are designed to assess anterior and rotational stability of the knee joint allowing patients to return to higher levels of activity.[108] Poor postoperative results have been linked to knee ROM deficits[103]; however, few studies reported ROM at RTS. Balance assessments were only included in 8 studies, with 7 different methods for assessment, including dynamic postural control and static balance. Dynamic postural control involves a level of expected movement around a base of support, which may better replicate the demands of physical activity.[38] Though some articles included dynamic postural control assessments such as the Y-balance test or Star Excursion Balance Test, others included a static balance assessment on a hard or unstable surface. These criteria have not improved from a systematic review conducted in 2011.[13] It is imperative that clinicians and researchers incorporate a multifaceted assessment in future RTS testing protocols for patients and research participants.

Comparison of Published RTS Criteria in 2010-2015 and 2016-2020 With the AAOS AUC

The number of articles published between 2016 and 2020 (41 articles) nearly doubled from the previous 5-year period of 2010-2015 (22 articles). Hop testing continues to be the number 1 method of RTS assessment across all time points. The most noticeable changes were increases in the assessment of confidence and balance. However, confidence, balance, ROM, and knee stability remain underrepresented through all 10 years.

From the most recent publications (2016-2020), few changes have been implemented to create a test battery that encompasses the AAOS AUC guidelines. However, the surge in the number of articles suggests the increased interest on this critical issue and the need for an acceptable test battery. Research that has been conducted on PROs, specifically confidence, may have successfully driven investigators to include an assessment of confidence/fear of reinjury. Although this increase was minimal (8.6%), it should be recognized as an important step for RTS test batteries. Furthermore, balance assessments increased the most dramatically from 1 to 7 studies through the past 10 years. Multiple assessment methods were clinically applicable in any setting apart from a Biodex stability test.[78] Finally, there was an increase in ROM and knee stability tests included in the most recent publications (2016-2020). While there was an increase in the number of studies published between 2016 and 2020, the items included in the published RTS batteries do not appear to be significantly different from 2010 to 2015 or in line with the AAOS AUC guidelines.

Finally, an eighth criteria was included in the AAOS guidelines, that patients be advised to participate in an ongoing ACL prevention/movement retraining program. This final criterion is included in the new guidelines; however, it is difficult to assess as it is a recommendation by the AAOS. Salem et al[83] required 6 of the 7 criteria be met to RTS; however, there was no mention of a prevention program. None of the included studies described any education or health promotion strategies for the included participants. However, the inclusion of health promotion strategies at the time of RTS may be important for many reasons, as prevention programs have been shown to reduce the risk of secondary injury and are warranted for individuals after ACLR.[45]

According to the current literature and AUC recommendation, the RTS battery should include the single-leg hop for distance, measures of both quadriceps and hamstring strength, the PRO (IKDC) and confidence (ACL-RSI), knee stability (KT-1000), knee ROM assessment, and a functional balance (dynamic single-leg balance) test (Table 8). Previous studies and reviews have recommended similar criteria to the AAOS[1,3,6,54,63,94,103]; however, no study has implemented all factors into 1 battery aimed at RTS. No gold standard exists, and many questions remain around the current test batteries, leaving many areas to be explored further. Additionally, the recommended battery is time-consuming and limited evidence exists to justify the inclusion of all 8 features.

This review is not without limitations. First, we did not include recommendations, commentaries, healthy individuals, or patients after revision ACLR. This potentially minimized the number of batteries included in our assessment. It is possible that some studies were not captured; however, with a large database and reference search we believe this to be minimal. Additionally, we did not assess the results of these test batteries, only the content of the batteries themselves. Last, we recognize that the studies were conducted in the years prior to submission and acceptance, and some prior to the AAOS AUC guidelines. However, we did further explore publication time frame and report our results according to publication date.

CONCLUSION

This systematic search of the literature reviewed all RTS test batteries after primary ACLR since 2010. Reporting has improved

Table 8. Return-to-play checklist and recommendations based on results of the current study[a]

Patient Return-to-Play Checklist	Recommendation
1. Patient's graft incorporation and graft strength has been considered	Not applicable
2. Patient's functional range of motion is restored	Knee flexion and extension range of motion
3. Patient has a stable knee with no pivot	KT-1000
4. Functional return of patient's core, hip, quadriceps, and hamstring strength has occurred, as determined by clinician discretion (can be measured by a variety of methods)	Quadriceps and hamstring strength
5. Patient's functional balance restored	Dynamic balance assessment
6. Patient attests or surgeon observes functional skills are performed adequately	Single-leg hop for distance
7. Patient is confident that he/she is ready to return to sport of interest	ACL-RSI and IKDC
8. Patient has been advised to participate in an ongoing ACL prevention/movement retraining program	Not applicable

[a]ACL, anterior cruciate ligament; ACL-RSI, ACL–Return to Sport after Injury Scale; IKDC, International Knee Documentation Committee.

to include more than time postoperatively for RTS testing; however, there is still lack of standardized measures across studies. A variety of hop tests, quadriceps strength assessments, and PROs have been included within the published RTS test batteries. Additionally, no study meets all recommended AAOS AUC guidelines. Finally, test battery research has expanded over the previous 10 years; however, standardized, clinically applicable batteries that encompass all components recommended by the AAOS AUC are missing.

REFERENCES

1. Abrams GD, Harris JD, Gupta AK, et al. Functional performance testing after anterior cruciate ligament reconstruction: a systematic review. *Orthop J Sports Med*. 2014;2:2325967113518305.
2. Abt JP, Smoliga JM, Brick MJ, Jolly JT, Lephart SM, Fu FH. Relationship between cycling mechanics and core stability. *J Strength Cond Res*. 2007;21:1300-1304.
3. Adams D, Logerstedt DS, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: a criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42:601-614.
4. Anderson MJ, Browning WM 3rd, Urband CE, Kluczynski MA, Bisson LJ. A systematic summary of systematic reviews on the topic of the anterior cruciate ligament. *Orthop J Sports Med*. 2016;4:2325967116634074.
5. Angelozzi M, Madama M, Corsica C, et al. Rate of force development as an adjunctive outcome measure for return-to-sport decisions after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2012;42:772-780.
6. Ardern CL. Anterior cruciate ligament reconstruction—not exactly a one-way ticket back to the preinjury level: a review of contextual factors affecting return to sport after surgery. *Sports Health*. 2015;7:224-230.
7. Ardern CL, Österberg A, Tagesson S, Gauffin H, Webster KE, Kvist J. The impact of psychological readiness to return to sport and recreational activities after anterior cruciate ligament reconstruction. *Br J Sports Med*. 2014;48:1613-1619.
8. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. 2014;48:1543-1552.
9. Ardern CL, Taylor NF, Feller JA, Webster KE. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2012;40:41-48.
10. Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE. Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. *Am J Sports Med*. 2013;41:1549-1558.
11. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med*. 2011;45:596-606.
12. Arundale AJH, Capin JJ, Zarzycki R, Smith A, Snyder-Mackler L. Functional and patient-reported outcomes improve over the course of rehabilitation: a secondary analysis of the ACL-SPORTS trial. *Sports Health*. 2018;10:441-452.
13. Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27:1697-1705.
14. Barber-Westin SD, Noyes FR. Objective criteria for return to athletics after anterior cruciate ligament reconstruction and subsequent reinjury rates: a systematic review. *Phys Sportsmed*. 2011;39:100-110.
15. Beischer S, Senorski EH, Thomeé C, Samuelsson K, Thomeé R. Young athletes return too early to knee-strenuous sport, without acceptable knee function after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1966-1974.
16. Besier TF, Lloyd DG, Ackland TR. Muscle activation strategies at the knee during running and cutting maneuvers. *Med Sci Sports Exerc*. 2003;35:119-127.
17. Bisciotti GN, Quaglia A, Belli A, Carimati G, Volpi P. Return to sports after ACL reconstruction: a new functional test protocol. *Muscles Ligaments Tendons J*. 2016;6:499-509.
18. Blakeney WG, Ouanezar H, Rogowski I, et al. Validation of a composite test for assessment of readiness for return to sports after anterior cruciate ligament reconstruction: the K-STARTS test. *Sports Health*. 2018;10:515-522.
19. Burland JP, Kostyun RO, Kostyun KJ, Solomito M, Nissen C, Milewski MD. Clinical outcome measures and return-to-sport timing in adolescent athletes after anterior cruciate ligament reconstruction. *J Athl Train*. 2018;53:442-451.
20. Chmielewski TL, Zeppieri G Jr, Lentz TA, et al. Longitudinal changes in psychosocial factors and their association with knee pain and function after anterior cruciate ligament reconstruction. *Phys Ther*. 2011;91:1355-1366.
21. Csapo R, Hoser C, Gföller P, Raschner C, Fink C. Fitness, knee function and competition performance in professional alpine skiers after ACL injury. *J Sci Med Sport*. 2019;22(suppl 1):S39-S43.
22. Curran MT, Lepley LK, Palmieri-Smith RM. Continued improvements in quadriceps strength and biomechanical symmetry of the knee after postoperative anterior cruciate ligament reconstruction rehabilitation: is it time to reconsider the 6-month return-to-activity criteria? *J Athl Train*. 2018;53:535-544.
23. Czuppon S, Racette BA, Klein SE, Harris-Hayes M. Variables associated with return to sport following anterior cruciate ligament reconstruction: a systematic review. *Br J Sports Med*. 2014;48:356-364.

24. Dan MJ, Lun KK, Dan L, et al. Wearable inertial sensors and pressure MAT detect risk factors associated with ACL graft failure that are not possible with traditional return to sport assessments. *BMJ Open Sport Exerc Med*. 2019;5:e000557.
25. Di Stasi SL, Logerstedt D, Gardinier ES, Snyder-Mackler L. Gait patterns differ between ACL-reconstructed athletes who pass return-to-sport criteria and those who fail. *Am J Sports Med*. 2013;41:1310-1318.
26. DiFabio M, Slater LV, Norte GE, Goetschius J, Hart JM, Hertel J. Relationships of functional tests following ACL reconstruction: exploratory factor analyses of the lower extremity assessment protocol. *J Sport Rehabil*. 2018;27:144-150.
27. Ebert JR, Annear PT. ACL reconstruction using autologous hamstrings augmented with the ligament augmentation and reconstruction system provides good clinical scores, high levels of satisfaction and return to sport, and a low retear rate at 2 years. *Orthop J Sports Med*. 2019;7:2325967119879079.
28. Ebert JR, Edwards P, Currie J, et al. Comparison of the "Back in Action" test battery to standard hop tests and isokinetic knee dynamometry in patients following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2018;13:389-400.
29. Ebert JR, Edwards P, Yi L, et al. Strength and functional symmetry is associated with post-operative rehabilitation in patients following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:2353-2361.
30. Edwards PK, Ebert JR, Joss B, et al. Patient characteristics and predictors of return to sport at 12 months after anterior cruciate ligament reconstruction: the importance of patient age and postoperative rehabilitation. *Orthop J Sports Med*. 2018;6:2325967118797575.
31. Fältström A, Hägglund M, Kvist J. Functional performance among active female soccer players after unilateral primary anterior cruciate ligament reconstruction compared with knee-healthy controls. *Am J Sports Med*. 2017;45:377-385.
32. Gardinier ES, Di Stasi S, Manal K, Buchanan TS, Snyder-Mackler L. Knee contact force asymmetries in patients who failed return-to-sport readiness criteria 6 months after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;42:2917-2925.
33. Garrison JC, Bothwell JM, Wolf G, Aryal S, Thigpen CA. Y balance test anterior reach symmetry at three months is related to single leg functional performance at time of return to sports following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2015;10:602-611.
34. Garrison JC, Shanley E, Thigpen C, Geary R, Osler M, Delgiorno J. The reliability of the Vail Sport Test™ as a measure of physical performance following anterior cruciate ligament reconstruction. *Int J Sports Phys Ther*. 2012;7:20-30.
35. Gokeler A, Welling W, Zaffagnini S, Seil R, Padua D. Development of a test battery to enhance safe return to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2017;25:192-199.
36. Goodstadt NM, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Functional testing to determine readiness to discontinue brace use, one year after ACL reconstruction. *Int J Sports Phys Ther*. 2013;8:91-96.
37. Graziano J, Chiaia T, de Mille P, Nawabi DH, Green DW, Cordasco FA. Return to sport for skeletally immature athletes after ACL reconstruction: preventing a second injury using a quality of movement assessment and quantitative measures to address modifiable risk factors. *Orthop J Sports Med*. 2017;5:2325967117700599.
38. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47:339-357.
39. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50:804-808.
40. Hall MP, Paik RS, Ware AJ, Mohr KJ, Limpisvasti O. Neuromuscular evaluation with single-leg squat test at 6 months after anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2015;3:2325967115575900.
41. Hamrin Senorski E, Samuelsson K, Thomeé C, Beischer S, Karlsson J, Thomeé R. Return to knee-strenuous sport after anterior cruciate ligament reconstruction: a report from a rehabilitation outcome registry of patient characteristics. *Knee Surg Sports Traumatol Arthrosc*. 2017;25:1364-1374.
42. Harris JD, Abrams GD, Bach BR, et al. Return to sport after ACL reconstruction. *Orthopedics*. 2014;37:e103-e108.
43. Hegedus EJ, McDonough S, Bleakley C, Cook CE, Baxter GD. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med*. 2015;49:642-648.
44. Herrington L, Ghulam H, Comfort P. Quadriceps strength and functional performance after anterior cruciate ligament reconstruction in professional soccer players at time of return to sport. *J Strength Cond Res*. 2021;35:769-775.
45. Hewett TE, Di Stasi SL, Myer GD. Current concepts for injury prevention in athletes after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2013;41:216-224.
46. Hewett TE, Myer GD. The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury. *Exerc Sport Sci Rev*. 2011;39:161-166.
47. Hewett TE, Myer GD, Ford KR, Paterno MV, Quatman CE. The 2012 ABJS Nicolas Andry Award. The sequence of prevention: a systematic approach to prevent anterior cruciate ligament injury. *Clin Orthop Relat Res*. 2012;470:2930-2940.
48. Hickey Lucas KC, Kline PW, Ireland ML, Noehren B. Hip and trunk muscle dysfunction: implications for anterior cruciate ligament injury prevention. *Ann Joint*. 2017;2(5).
49. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the International Knee Documentation Committee Subjective Knee Form. *Am J Sports Med*. 2001;29:600-613.
50. Ithurburn MP, Longfellow MA, Thomas S, Paterno MV, Schmitt LC. Knee function, strength, and resumption of preinjury sports participation in young athletes following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2019;49:145-153.
51. Jamison ST, McNally MP, Schmitt LC, Chaudhari AM. The effects of core muscle activation on dynamic trunk position and knee abduction moments: implications for ACL injury. *J Biomech*. 2013;46:2236-2241.
52. Kitaguchi T, Tanaka Y, Takeshita S, et al. Importance of functional performance and psychological readiness for return to preinjury level of sports 1 year after ACL reconstruction in competitive athletes. *Knee Surg Sports Traumatol Arthrosc*. 2020;28:2203-2212.
53. Kong DH, Yang SJ, Ha JK, Jang SH, Seo JG, Kim JG. Validation of functional performance tests after anterior cruciate ligament reconstruction. *Knee Surg Relat Res*. 2012;24:40-45.
54. Kvist J. Rehabilitation following anterior cruciate ligament injury: current recommendations for sports participation. *Sports Med*. 2004;34:269-280.
55. Larsen JB, Farup J, Lind M, Dalgas U. Muscle strength and functional performance is markedly impaired at the recommended time point for sport return after anterior cruciate ligament reconstruction in recreational athletes. *Hum Mov Sci*. 2015;39:73-87.
56. Lee DW, Yang SJ, Cho SI, Lee JH, Kim JG. Single-leg vertical jump test as a functional test after anterior cruciate ligament reconstruction. *Knee*. 2018;25:1016-1026.
57. Leister I, Kulnik ST, Kindermann H, et al. Functional performance testing and return to sport criteria in patients after anterior cruciate ligament injury 12-18 months after index surgery: a cross-sectional observational study. *Phys Ther Sport*. 2019;37:1-9.
58. Lentz TA, Tillman SM, Indelicato PA, Moser MW, George SZ. Factors associated with function after anterior cruciate ligament reconstruction. *Sports Health*. 2009;1:47-53.
59. Lentz TA, Zeppieri G Jr, George SZ, et al. Comparison of physical impairment, functional, and psychosocial measures based on fear of reinjury/lack of confidence and return-to-sport status after ACL reconstruction. *Am J Sports Med*. 2015;43:345-353.
60. Lentz TA, Zeppieri G Jr, Tillman SM, et al. Return to preinjury sports participation following anterior cruciate ligament reconstruction: contributions of demographic, knee impairment, and self-report measures. *J Orthop Sports Phys Ther*. 2012;42:893-901.
61. Logerstedt D, Di Stasi S, Grindem H, et al. Self-reported knee function can identify athletes who fail return-to-activity criteria up to 1 year after anterior cruciate ligament reconstruction: a Delaware-Oslo ACL cohort study. *J Orthop Sports Phys Ther*. 2014;44:914-923.
62. Logerstedt D, Lynch A, Axe MJ, Snyder-Mackler L. Symmetry restoration and functional recovery before and after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:859-868.
63. Lynch AD, Logerstedt DS, Grindem H, et al. Consensus criteria for defining 'successful outcome' after ACL injury and reconstruction: a Delaware-Oslo ACL cohort investigation. *Br J Sports Med*. 2015;49:335-342.
64. Mayer SW, Queen RM, Taylor D, et al. Functional testing differences in anterior cruciate ligament reconstruction patients released versus not released to return to sport. *Am J Sports Med*. 2015;43:1648-1655.
65. Menzer H, Slater LV, Diduch D, et al. The utility of objective strength and functional performance to predict subjective outcomes after anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2017;5:2325967117744758.
66. Mohammadi F, Salavati M, Akhbari B, Mazaheri M, Mohsen Mir S, Etemadi Y. Comparison of functional outcome measures after ACL reconstruction in competitive soccer players: a randomized trial. *J Bone Joint Surg Am*. 2013;95:1271-1277.
67. Müller U, Krüger-Franke M, Schmidt M, Rosemeyer B. Predictive parameters for return to pre-injury level of sport 6 months following anterior cruciate ligament reconstruction surgery. *Knee Surg Sports Traumatol Arthrosc*. 2015;23:3623-3631.
68. Myer GD, Schmitt LC, Brent JL, et al. Utilization of modified NFL combine testing to identify functional deficits in athletes following ACL reconstruction. *J Orthop Sports Phys Ther*. 2011;41:377-387.
69. Nae J, Creaby MW, Ageberg E. Extended version of a test battery for visual assessment of postural orientation errors: face validity, internal consistency, and reliability. *Phys Ther*. 2020;100:1542-1556.

70. Nawasreh Z, Logerstedt D, Cummer K, Axe MJ, Risberg MA, Snyder-Mackler L. Do patients failing return-to-activity criteria at 6 months after anterior cruciate ligament reconstruction continue demonstrating deficits at 2 years? *Am J Sports Med*. 2017;45:1037-1048.
71. Norouzi S, Esfandiarpour F, Mehdizadeh S, Yousefzadeh NK, Parnianpour M. Lower extremity kinematic analysis in male athletes with unilateral anterior cruciate reconstruction in a jump-landing task and its association with return to sport criteria. *BMC Musculoskelet Disord*. 2019;20:492.
72. Norte GE, Goetschius JW, Slater LV, Hart JM. Influence of patient demographics and surgical characteristics on pass rates of return-to-activity tests in anterior cruciate ligament-reconstructed patients before physician clearance. *Clin J Sport Med*. Published online February 17, 2020. doi:10.1097/JSM.0000000000000790
73. Novaretti JV, Franciozi CE, Forgas A, Sasaki PH, Ingham SJM, Abdalla RJ. Quadriceps strength deficit at 6 months after ACL reconstruction does not predict return to preinjury sports level. *Sports Health*. 2018;10:266-271.
74. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med*. 1991;19:513-518.
75. Palmieri-Smith RM, Lepley LK. Quadriceps strength asymmetry after anterior cruciate ligament reconstruction alters knee joint biomechanics and functional performance at time of return to activity. *Am J Sports Med*. 2015;43:1662-1669.
76. Papalia R, Franceschi F, Tecame A, D'Adamio S, Maffulli N, Denaro V. Anterior cruciate ligament reconstruction and return to sport activity: postural control as the key to success. *Int Orthop*. 2015;39:527-534.
77. Paterno MV, Flynn K, Thomas S, Schmitt LC. Self-reported fear predicts functional performance and second ACL injury after ACL reconstruction and return to sport: a pilot study. *Sports Health*. 2018;10:228-233.
78. Paterno MV, Huang B, Thomas S, Hewett TE, Schmitt LC. Clinical factors that predict a second ACL injury after ACL reconstruction and return to sport: preliminary development of a clinical decision algorithm. *Orthop J Sports Med*. 2017;5:2325967117745279.
79. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med*. 2014;42:1567-1573.
80. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med*. 2010;38:1968-1978.
81. Piussi R, Beischer S, Thomeé R, Hamrin Senorski E. Hop tests and psychological PROs provide a demanding and clinician-friendly RTS assessment of patients after ACL reconstruction, a registry study. *BMC Sports Sci Med Rehabil*. 2020;12:32.
82. Raoul T, Klouche S, Guerrier B, et al. Are athletes able to resume sport at six-month mean follow-up after anterior cruciate ligament reconstruction? Prospective functional and psychological assessment from the French Anterior Cruciate Ligament Study (FAST) cohort. *Knee*. 2019;26:155-164.
83. Salem HOM, Wicks E, Dodson C, Hammoud S, Cohen SB, Tjoumakaris FP, Ciccotti MG, Freedman KB. Safer return to play following anterior cruciate ligament reconstruction: development and validation of an evidence-based checklist. *American Academy of Orthopaedic Surgery*. 2018.
84. Schmitt LC, Paterno MV, Hewett TE. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2012;42:750-759.
85. Shelbourne KD, Gray T. Minimum 10-year results after anterior cruciate ligament reconstruction: how the loss of normal knee motion compounds other factors related to the development of osteoarthritis after surgery. *Am J Sports Med*. 2009;37:471-480.
86. Smith AH, Capin JJ, Zarzycki R, Snyder-Mackler L. Athletes with bone-patellar tendon-bone autograft for anterior cruciate ligament reconstruction were slower to meet rehabilitation milestones and return-to-sport criteria than athletes with hamstring tendon autograft or soft tissue allograft: secondary analysis from the ACL-SPORTS trial. *J Orthop Sports Phys Ther*. 2020;50:259-266.
87. Sousa PL, Krych AJ, Cates RA, Levy BA, Stuart MJ, Dahm DL. Return to sport: does excellent 6-month strength and function following ACL reconstruction predict midterm outcomes? *Knee Surg Sports Traumatol Arthrosc*. 2017;25:1356-1363.
88. Sueyoshi T, Nakahata A, Emoto G, Yuasa T. Single-leg hop test performance and isokinetic knee strength after anterior cruciate ligament reconstruction in athletes. *Orthop J Sports Med*. 2017;5:2325967117739811.
89. Thomeé P, Währborg P, Börjesson M, Thomeé R, Eriksson BI, Karlsson J. A new instrument for measuring self-efficacy in patients with an anterior cruciate ligament injury. *Scand J Med Sci Sports*. 2006;16:181-187.
90. Thomeé P, Währborg P, Börjesson M, Thomeé R, Eriksson BI, Karlsson J. Self-efficacy of knee function as a pre-operative predictor of outcome 1 year after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:118-127.
91. Thomeé R, Neeter C, Gustavsson A, et al. Variability in leg muscle power and hop performance after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2012;20:1143-1151.
92. Toole AR, Ithurburn MP, Rauh MJ, Hewett TE, Paterno MV, Schmitt LC. Young athletes cleared for sports participation after anterior cruciate ligament reconstruction: how many actually meet recommended return-to-sport criterion cutoffs? *J Orthop Sports Phys Ther*. 2017;47:825-833.
93. Undheim MB, Cosgrave C, King E, et al. Isokinetic muscle strength and readiness to return to sport following anterior cruciate ligament reconstruction: is there an association? A systematic review and a protocol recommendation. *Br J Sports Med*. 2015;49:1305-1310.
94. van Melick N, van Cingel RE, Brooijmans F, et al. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. *Br J Sports Med*. 2016;50:1506-1515.
95. Webster KE, Feller JA. Clinical tests can be used to screen for second anterior cruciate ligament injury in younger patients who return to sport. *Orthop J Sports Med*. 2019;7:2325967119863003.
96. Webster KE, Feller JA. Return to level I sports after anterior cruciate ligament reconstruction: evaluation of age, sex, and readiness to return criteria. *Orthop J Sports Med*. 2018;6:2325967118788045.
97. Webster KE, Feller JA. Younger patients and men achieve higher outcome scores than older patients and women after anterior cruciate ligament reconstruction. *Clin Orthop Relat Res*. 2017;475:2472-2480.
98. Webster KE, Feller JA, Lambros C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport*. 2008;9:9-15.
99. Webster KE, Feller JA, Leigh WB, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;42:641-647.
100. Welling W, Benjaminse A, Lemmink K, Gokeler A. Passing return to sports tests after ACL reconstruction is associated with greater likelihood for return to sport but fail to identify second injury risk. *Knee*. 2020;27:949-957.
101. Welling W, Benjaminse A, Seil R, Lemmink K, Zaffagnini S, Gokeler A. Low rates of patients meeting return to sport criteria 9 months after anterior cruciate ligament reconstruction: a prospective longitudinal study. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:3636-3644.
102. Wellsandt E, Failla MJ, Snyder-Mackler L. Limb symmetry indexes can overestimate knee function after anterior cruciate ligament injury. *J Orthop Sports Phys Ther*. 2017;47:334-338.
103. Wilk KE, Macrina LC, Cain EL, Dugas JR, Andrews JR. Recent advances in the rehabilitation of anterior cruciate ligament injuries. *J Orthop Sports Phys Ther*. 2012;42:153-171.
104. Wilk KE, Romaniello WT, Soscia SM, Arrigo CA, Andrews JR. The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *J Orthop Sports Phys Ther*. 1994;20:60-73.
105. Woby SR, Roach NK, Urmston M, Watson PJ. Psychometric properties of the TSK-11: a shortened version of the Tampa Scale for Kinesiophobia. *Pain*. 2005;117:137-144.
106. Wren TAL, Mueske NM, Brophy CH, et al. Hop distance symmetry does not indicate normal landing biomechanics in adolescent athletes with recent anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2018;48:622-629.
107. Xergia SA, Pappas E, Zampeli F, Georgiou S, Georgoulis AD. Asymmetries in functional hop tests, lower extremity kinematics, and isokinetic strength persist 6 to 9 months following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2013;43:154-162.
108. Xie X, Liu X, Chen Z, Yu Y, Peng S, Li Q. A meta-analysis of bone–patellar tendon–bone autograft versus four-strand hamstring tendon autograft for anterior cruciate ligament reconstruction. *Knee*. 2015;22:100-110.
109. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35:1123-1130.