Assessing Physical Activity After ACL Injury: Moving Beyond Return to Sport

Christopher Kuenze, PhD, ATC,*†‡ Katherine Collins, MS,† Karin Allor Pfeiffer, PhD,† and Caroline Lisee, PhD, ATC§

Context: Return to sport is widely utilized by sports medicine researchers and clinicians as a primary outcome of interest for successful recovery when working with young patients who have undergone anterior cruciate ligament (ACL) reconstruction (ACLR). While return-to-sport outcomes are effective at tracking progress post-ACLR, they are limited because they do not necessarily capture physical activity (PA) engagement, which is important to maintain knee joint health and reduce the risk of noncommunicable diseases. Therefore, there is a critical need (1) to describe current PA participation and measurement recommendations; (2) to appraise common PA measurement approaches, including patient-reported outcomes and device-based methodologies; and (3) to provide clinical recommendations for future evaluation.

Evidence Acquisition: Reports of patient-reported or device-based PA in patients with ACL injury were acquired and summarized based on a PubMed search (2000 through July 2020). Search terms included *physical activity* OR *activity* AND *anterior cruciate ligament* OR *ACL*.

Study Design: Clinical review.

Level of Evidence: Level 5.

Results: We highlight that (1) individuals with ACLR are 2.36 times less likely to meet the US Department of Health and Human Services PA recommendations even when reporting successful return to sport, (2) common patient-reported PA assessments have significant limitations in the data that can be derived, and (3) alternative patient-reported and device-based assessments may provide improved assessment of PA in this patient population.

Conclusion: Clinicians and researchers have relied on return to sport status or self-reported PA participation via surveys. These approaches are not consistent with current recommendations for PA assessment and do not allow for comparison with contemporary PA recommendations or guidelines. Return to sport, patient-reported outcome measures, and device-based assessment approaches should be used in complementary manners to comprehensively assess PA participation after ACLR. However, appropriate techniques should be used when assessing PA in adult and adolescent populations.

Keywords: moderate-to-vigorous physical activity; ACL reconstruction; device-based physical activity

The US Department of Health and Human Services (USDHHS) physical activity (PA) recommendations were updated in 2018[45,57] to help children and adults clearly understand the frequency, intensity, time, and type of activities (ie, FITT principle) in which they should participate to mitigate the risk of morbidities (ie, coronary artery disease, type 2 diabetes, and certain types of cancer) and premature mortality (Table 1).[46] It is estimated that only 27.1% of high school–aged individuals[29] and 24.3% of adults[24] meet current USDHHS guidelines for aerobic PA.[14,20] The risk of reduced participation in PA is exacerbated in individuals with musculoskeletal injury such as anterior cruciate ligament (ACL) injury and subsequent surgery.[9,26,39] Despite reporting successful return to some level of sport, individuals with ACL reconstruction (ACLR) are 2.36 times less likely to meet USDHHS recommendations for weekly aerobic PA when compared with healthy individuals of similar age and patient-reported activity levels.[34] If patients are unable to reengage in sufficient PA to meet recommendations, they may be at elevated risk for developing chronic, noncommunicable diseases later in life.

From †Department of Kinesiology, Michigan State University, East Lansing, Michigan, ‡Department of Orthopedics, Michigan State University, East Lansing, Michigan, and §Motion Science Institute, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

*Address correspondence to Christopher Kuenze, PhD, ATC, Department of Kinesiology, Michigan State University, 308 West Circle Drive Room 112, East Lansing, MI 48824 (email: kuenzech@msu.edu) (Twitter: @kuenzech, @AIRLabsMSU).

The authors report no potential conflicts of interest in the development and publication of this article.

DOI: 10.1177/19417381211025307

Table 1. Definitions and examples of the components of the FITT (frequency, intensity, time, type) principle for physical activity characterization

	Definitions	Examples
Frequency	The number of times a patient completes a specific activity during a fixed period	Steps per day Sessions per day Days per week Days per month
Intensity	The physiologic demand during a period of activity	Light (<3 METS) Moderate (3 to <6 METS) Vigorous (≥6 METS)
Time	The duration of activity in which a patient is participating	Minutes Minutes per day Minutes per week
Type	The category or classification of activity in which a patient is participating	Jogging Weight training Participation in sport

METS, metabolic equivalents.

Currently, sports medicine researchers and clinicians utilize return to sport (RTS) as a primary outcome of interest when working with patients who have undergone ACLR[4,5,61] because many individuals undergoing ACLR describe successful recovery as a full RTS after surgery.[61] RTS is a valuable indicator of clinical success, as it considers the physical, psychological, and social well-being of a patient as well as a patient's motivation to make a return to preinjury patterns of PA participation.[6,61] Consequently, approximately 81% of individuals return to any level of sport, 65% of individuals return to preinjury level of sport, and only 55% of individuals return to competitive levels of sport.[5] While RTS is helpful when assessing clinical success and achievement of patient goals, it is limited in its ability to assess (1) the frequency, time, and intensity of PA; (2) whether patients with ACLR meet PA recommendations; and (3) if patients opted out of sport due to life transitions or lack of access to organized sport.

Historically, patient-reported PA assessments have dominated the sports medicine literature due to the ease of implementation in clinical and research settings.[36,51] However, technological advances and commercial availability of wearable technology have made the incorporation of device-based assessments (ie, pedometers and smart watches) into the evaluation of PA outcomes increasingly feasible.[8,9,32,34] Sports medicine clinicians are uniquely positioned to guide PA assessment and promotion for patients during rehabilitation due to their education in exercise science principles and consistent contact with patients throughout recovery. Therefore, the purposes of this review are (1) to appraise common PA measurement approaches, including patient-reported outcomes and device-based methodologies after ACLR and (2) to provide clinical recommendations for PA evaluation.

EVIDENCE ACQUISITION

Reports of patient-reported or device-based PA in patients with ACL injury were acquired and summarized based on a PubMed search (January 2000 to July 2020). Search terms included *physical activity* OR *activity* AND *anterior cruciate ligament* OR *ACL*. Based on the review of included studies, measurement properties and technical details for specific approaches to measurement or outcome measures were summarized by reviewing the reference lists from the included papers and follow-up literature search by the authors.

PATIENT-REPORTED PHYSICAL ACTIVITY

There are several patient-reported outcome measures that have been used to assess PA characteristics among individuals with ACLR.[15] These outcomes are selected for several reasons including surveillance of PA participation and reengagement in sport after surgery as well as assessment of the effectiveness or efficacy of surgical or rehabilitation interventions among this patient population. This section will highlight 2 outcome measures commonly utilized in the orthopaedic literature, the Tegner Activity Scale (TAS) and the Marx Activity Rating Scale (MARS),[15] and the International Physical Activity Questionnaire (IPAQ), which is commonly utilized in the PA surveillance literature.

Tegner Activity Scale

The TAS is an easy to administer 2-item patient-reported outcome measure that has been validated in healthy and knee-injured individuals (eg, acute patellar dislocations, meniscal injury, ACLR).[12] The survey asks patients to characterize their preinjury and current peak level of PA participation ranging from sick leave or disability (level 0) to competitive sports such

Table 2. Comparison of commonly utilized device-based and patient-reported assessments relative to the components of the FITT (frequency, intensity, time type) principle of physical activity measurement

	Frequency	Intensity	Time	Type
Device-Based Assessments				
Pedometer	Device dependent	Device dependent	Device dependent	No
Commercially available accelerometer	Device dependent	Device dependent	Device dependent	No
Research-grade accelerometer	Yes	Yes	Yes	No[a]
Patient-reported outcomes				
Return to sport	No	No	No	Yes
Tegner Activity Score	No	No	No	Yes
Marx Activity Rating Scale	Yes	No	No	Yes
IPAQ long or short form	Yes	Yes	Yes	No[b]
Godin Leisure-Time Physical Activity Questionnaire	Yes	Yes	No	No
UCLA Activity Score	No	No	No	Yes
PAQ-C and PAQ-A	Yes	Yes	No	Yes
HSS Pedi-FABS	Yes	No	No	Yes

HSS Pedi-FABS, Hospital for Special Surgery Pediatric Functional Activity Brief Scale; IPAQ, International Physical Activity Questionnaires; PAQ-A, Physical Activity Questionnaire for Adolescents; PAQ-C, Physical Activity Questionnaire for Children; UCLA, University of California Los Angeles.
[a]With advanced data processing techniques, such as machine learning models, activity type could be detected by individuals with proper expertise.
[b]One item on the IPAQ measures time and frequency spent in walking throughout the week but does not assess other types of activities.

as national elite soccer, football, or rugby (level 10).[12] However, the TAS does not assess the frequency or time of PA at either time point (Table 2). While the purpose of the TAS is not to replace more comprehensive PA assessments, it has been widely adopted in the sports medicine literature as an indicator of whether or not patients with ACL injury are physically active.[15] For example, a patient may respond that he or she has participated in national elite soccer; but based on the structure of the TAS, the frequency, duration, and intensity of their soccer participation are not assessed. In addition to this limitation, it is important to note that previous attempts to establish construct validity of this scale were limited to comparison with patient-reported measures of knee function (eg, Lysholm score) or quality of life (eg, the 36- or 12-Item Short Form Health Survey) instead of device-assessed or directly observed PA, which is a more typical approach for validation of patient-reported measures of PA.[12] In 2 recent studies of individuals with ACLR, TAS was weakly to moderately correlated with weekly minutes of moderate-to-vigorous PA (MVPA) (r = −0.02 and rho [ρ] = 0.31) or average daily step count (r = 0.36).[9,34] The TAS is an indicator of peak activity type and competition level, not a broader indicator of PA, and it should be utilized as such to maximize its benefit as a component of a comprehensive PA assessment.

Marx Activity Scale

The MARS is a valid[37] and reliable[15] 4-item patient-reported outcome measure that asks patients to categorize their frequency of participation in running, cutting, deceleration, and pivoting over the course of the prior month (Table 2).[37] Patients can select from 5 frequency categories ranging from less than 1 time in a month (0 points) to 4 or more times in a week (4 points), which allows for a maximum score of 16.[37] Overall, the MARS is a clinically feasible assessment that can identify the frequency of sport-related behaviors; however, limitations in the MARS should be considered when describing patients as physically active or not based on their MARS score. Importantly, several authors have reported strong convergent validity with the TAS and the Cincinnati Knee Scale, but criterion validity has not been established relative to device-based assessments, direct activity observation, or indirect calorimetry as recommended in the PA literature.[50] Among individuals with ACLR, the MARS demonstrates a moderate relationship with the TAS (r = 0.66),[37] but a poor relationship (ρ = 0.15) with MVPA assessed using triaxial accelerometry.[32] Based on these findings, it appears that the MARS may be effective for identifying the frequency of participation in sport-specific activity types but not in characterizing activity intensity or time. For example, individuals who are recreationally active, jog, and strength train 3 times per week to meet aerobic PA guidelines may only achieve 3 of 16 total points on the MARS. Conversely, someone who plays in a single recreational soccer match with no other source of MVPA throughout the week would report a total score of 16 out of 16 regardless of the duration or intensity of his or her soccer match.[17] Similarly, if patients choose not to RTS due to lack of access to organized sports or natural life changes (eg, graduating from school), utilizing the TAS or MARS may underestimate an their PA and do not provide an opportunity for the patient to explain their underlying rationale.

International Physical Activity Questionnaire

The IPAQ Short Form (IPAQ-SF) is a 9-item questionnaire assessing the amount of time spent in vigorous activity, moderate activity, walking, and sitting over the course of 1 week (Table 2).[35] The IPAQ demonstrates good test-retest reliability in adults[58] and poor to moderate reliability in adolescents, which is understandable as the IPAQ-SF was not developed for use with adolescent or pediatric populations.[47] Because the IPAQ-SF is self-reported, it is subject to recall bias and often overestimates activity (metabolic equivalents (MET)–min/wk) by 36% to 173% when compared with accelerometers.[35] Consistent with these findings, the IPAQ-SF has demonstrated negligible to weak relationships with total PA assessed via triaxial accelerometers and moderate relationships when assessing the distance (ρ = 0.16) and duration of walking (ρ = 0.08-0.57).[35] Recent studies[9,34] have included the IPAQ-SF to help better define the frequency, time, and intensity of activity in individuals with ACLR because, unlike the TAS and MARS, it can also be used to determine if individuals are meeting the recommended national PA guidelines.[27,45,52] The IPAQ-SF is a promising self-reported measure of PA because it quantifies at least 3 of the 4 FITT components and can be considered to assess all 4 components if a clinician is primarily interested in a patient's volume or frequency of walking for exercise; however, the limitations in self-reported outcome measures should be acknowledged, especially when applied to pediatric patients.

Other Patient-Reported Physical Activity Measures

In addition to the patient-reported PA measures described in this section, the Godin Leisure Time Exercise Questionnaire (Godin)[11,33,41,53] and the University of California Los Angeles (UCLA) Activity Score[16] have also been used to describe activity patterns among individuals with ACLR in a limited number of studies. The Godin is a 3-item survey[23] that asks patients to describe the weekly frequency of bouts of at least 15 minutes of mild, moderate, and strenuous exercise (Table 2). It has been validated in an number of populations with chronic and acute disease; however, it has not been validated specifically for use in patients with ACLR or, more broadly, acute knee injury; and therefore, it should be used with caution when assessing PA in patients with ACLR.[3,40] Alternatively, the UCLA Activity Score asks patients to rate their current activity level from 1 (ie, wholly inactive, dependent on others, and cannot leave residence) to 10 (ie, regularly participates in impact sports). The UCLA Activity Score was originally validated to describe activity limitations in older patients with joint arthroplasty[28,60,63] and has since been used for the same assessment in patients older than 55 years who have had ACLR.[16] Therefore, this outcome may be limited in its ability to capture characteristics on PA among younger individuals with ACLR in a manner consistent with the FITT principle.

Considerations for Pediatric and Adolescent Patients

Adolescents and children tend to participate in MVPA in a less organized and intentional manner compared with adults,[7] which results in overestimation of vigorous activities and underestimation of moderate activities assessed via indirect calorimetry and device-assessed PA.[7] Therefore, the appropriateness of a given patient-reported PA outcome measure can vary based on the age of the patient.[64] To address this concern, the Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS Pedi-FABS) has been recently adapted from the MARS with the goal of better meeting the needs of pediatric patients.[18,19] Accordingly, the Pedi-FABS has been validated in a similar manner to the MARS, which, while providing confidence as a measure of activity frequency, has significant limitations as a surrogate measure of PA (Table 2).[59] Alternatively, the Physical Activity Questionnaires for Children (PAQ-C) or Adolescents (PAQ-A) may provide feasible options that allow for the assessment of activity frequency, intensity, and type in a valid, responsive, and reliable manner.[62] These surveys include more items but compartmentalize activity questions so that adolescents and children can report activity at specific times rather than across the entire day. However, the PAQ-C and PAQ-A do not provide estimates of time spent in discrete PA intensities, which limits the ability to categorize individuals relative to current PA guidelines. Regardless, clinicians working with pediatric populations should consider incorporating age-appropriate questionnaires to assess PA in a manner that is consistent with the FITT principle.

DEVICE-ASSESSED PHYSICAL ACTIVITY

Pedometers, triaxial accelerometers, and commercially available devices such as Fitbit Inc. monitors have been used to evaluate PA in individuals with lower extremity injury.[8,9,26,32,34] These monitor types have been used and validated across age groups and assessment settings.[21,25,31,43,49,54] These devices provide detailed information regarding PA while eliminating the influence of recall error and bias.[13,48] In this section, we have highlighted several common device-based PA assessment tools.

Research Grade Pedometers

Pedometers provide information about frequency of PA in the form of step counts, commonly reported as steps per day

(Table 1). Baez et al[8] utilized the Digi-Walker SW-200 pedometer worn at the hip for 7 days in patients with history of ACLR. These individuals took an average of 8657 ± 2467 steps per day, with step counts of individuals who reported that they had returned to sport (7754 ± 2399 steps/day) being similar to those individuals who had not returned to sport (9198 ± 2385 steps/day).[8] However, there are limitations to the use of pedometers that should be considered prior to their integration into practice. First, most pedometers do not describe the type, intensity, or duration of PA engagement, which significantly limits the interpretative data obtained from these devices. Additionally, pedometers tend to underestimate step count, especially at slow walking speeds (<2 mph)[44] and may not agree with step count data obtained from research grade or commercially available accelerometers (eg, Fitbit devices), which are increasingly common in the realm of PA assessment.[56] Despite these potential challenges, pedometers may provide a reliable and inexpensive alternative to patient-reported assessments of PA that allow for real-time capture of PA under free-living conditions. Pedometers provide an inexpensive and practical means of assessing PA that does not require extensive expertise in data processing techniques, but limitations in the data obtained should be acknowledged.

Research-Grade Triaxial Accelerometers

Research-grade triaxial accelerometers (eg, ActiGraph Link, ActiGraph wGT3X-BT, activPAL) are valid[10] and reliable[1,38,43] tools that provide an assessment of free-living PA frequency, intensity, and time; however, these devices are costly and require technical expertise for effective implementation. Research-grade triaxial accelerometers assess PA by capturing the magnitude and frequency of accelerations about 3 axes of motion.[2,30,42,49] Activity counts reflect intensity of the movement via the vertical axis or the vector magnitude of acceleration data derived from all 3 axes of the triaxial accelerometer, and the rate of activity counts (ie, counts per minute) can be used to assess the intensities of activities captured while wearing the accelerometer. Triaxial accelerometers also provide information about frequency or volume of PA in the form of step counts and the duration of PA commonly reported in minutes per day. Application of triaxial accelerometer–assessed PA has been limited in the ACLR population but in the largest study to date, researchers utilized ActiGraph wGT3X-BT triaxial accelerometers to monitor the time and intensity of PA in a young, active group of individuals with and without history of ACLR.[9] In this study, individuals with ACLR spent less time in MVPA (ACLR = 79.37 ± 23.95 min/d; control = 93.12 ± 23.94 min/d; $P < 0.02$) than those without history of ACLR.[9] Bell et al[9] also reported that individuals 6 to 60 months post-ACLR took 1611 fewer steps per day as compared with healthy matched control subjects. However, these evaluations are not necessarily exhaustive, as the type of PA may not be captured without patient self-report of activity type. Research-grade triaxial accelerometers may provide a better understanding of PA behavior and characteristics after ACLR, but these devices should be used in conjunction with patient-reported PA to provide a more comprehensive evaluation that reflects all components of the FITT principle.

Commercially Available Accelerometers

Commercially available devices are user-friendly and do not require expertise to implement and interpret the PA outcomes. Smart watches, such as Fitbit devices or the Apple Watch, provide information about the frequency of PA in the form of step counts, which can be tracked in real-time. These devices serve as a more clinically feasible alternative for PA assessment since patients may already own these devices. Depending on the model, these devices may also provide information about the intensity of activity in the form of active minutes, METS, or real-time heart rate data. A recent systematic review of commercially available PA monitors found that Apple Inc and Samsung Inc devices demonstrated the best validity for step counts when compared with other devices (45.2% of included devices were within ±3% measurement error), but no single device consistently demonstrated acceptable measurement error for energy expenditure (only 9.2% of devices included were within ±3% measurement error).[22] Duration (active and sedentary minutes) and type (ie, sport, running, walking, cycling) of activity can be derived from these devices as movement identification algorithms continue to improve. However, the proprietary algorithms implemented to define PA intensities or types remain largely unavailable for public use, which may be a limitation to data interpretation. While application of commercially available devices for PA assessment has been limited in the ACLR population, these monitors and smartwatches may provide a more clinically feasible alternative for monitoring and evaluating PA behavior, especially within the same patient over time.

Considerations for Pediatric and Adolescent Patients

It is essential to collect device-based PA using best practices and to compare findings with age-appropriate guidelines for PA (Table 3). Cut points for determining activity intensity based on activity counts derived from research-grade accelerometers are different for children and adolescents when compared with adults.[55] Accordingly, age-specific recommendations should be followed if research-grade accelerometers are integrated into clinical or research assessment of PA in pediatric or adolescent populations. Last, smart watches often cannot be worn during organized sports, which may lead to a misrepresentation of true PA engagement since organized sport is the primary source of PA for many children and adolescents. This is further complicated by the fact that some devices are not waterproof, which can prevent assessment of PA during water-based activities such as swimming or water polo.

CLINICAL ASSESSMENT RECOMMENDATIONS

RTS and the meeting of PA guidelines are important goals for individuals after ACLR, but these outcomes are not

Table 3. Summary of key 2018 USDHHS physical activity recommendations for adults, adolescents, and children

	Adults (≥18 years old)	Children and Adolescents (6-17 years old)	Activity Types
Aerobic activity[a]	≥150-300 min/wk of moderate PA, or ≥75-150 min/wk of vigorous PA, or an equivalent of MVPA	≥60 min/d of predominantly MVPA including ≥3 d/wk with vigorous PA	Brisk walking Running Bicycling Swimming
Muscle strengthening	≥2 d/wk including all major muscle groups	≥3 d/wk as a part of the ≥60 min/d of predominantly MVPA	Weight lifting Elastic band or body weight resistance exercise
Bone strengthening	No specific recommendation	≥3 d/wk as a part of the ≥60 min/d of predominantly MVPA	Weight lifting Running Jumping

MVPA, moderate-to-vigorous physical activity; PA, physical activity; USDHHS, United States Department of Health and Human Services.
[a]The 2018 guidelines consider all forms of PA and are no longer assessed relative to 10-minute bouts of activity, which was a characteristic of the 2008 version of the guidelines.

interchangeable. Health care providers should develop a plan to help patients reengage with PA after ACLR that takes into account whether or not a patient is planning to RTS.[61] Ultimately, a combination of patient-reported outcomes and device-based activity assessment are likely the best approach that mirror the FITT principle and can evolve over the clinical course for a given patient. Patient-reported outcomes are the most clinician-friendly assessments due to the ease of administration and processing. The TAS and MARS are helpful for patients with goals of returning to sport and can quickly establish the level of sport and frequency of sport-related activities. However, these assessments should not be used to assess duration and intensity of PA. Instead, clinicians should consider incorporating instruments like the IPAQ-SF to allow for comparison with established PA guidelines, particularly for adults without goals of RTS. Furthermore, pedometers and consumer-grade technology allow for feasible and accessible PA assessment. Clinicians should consider integrating PA tracking to enhance monitoring of patient progress and promote patient-oriented goal setting. Clinicians can provide patients with cost-effective device-based assessment tools (eg, pedometers) or have patients utilize personal accelerometers (eg, Fitbit or smart phones). Typically, consumer-grade monitors can track frequency of steps and are increasingly capable of assessing PA intensity and duration. Ultimately, device-based assessment and validated patient-report can be complementary in providing a comprehensive description of PA in this patient population. Clinicians should also be aware that the USDHHS also provides PA recommendations for muscle and bone strengthening (Table 3). The current literature is limited in its assessment of meeting these guidelines after ACLR despite the strong evidence of muscle strength loss and development of poor knee joint health in this population. Muscle and bone strengthening recommendations should be incorporated into return to PA plans by clinicians.

CONCLUSION

Many individuals do not return to preinjury level of sport or meet PA guidelines after ACL injury and ACLR. Measuring RTS serves as a starting point for activity measurement after ACLR. A comprehensive activity measurement strategy that includes all FITT components should be incorporated into clinical practice when possible. Patient-reported outcomes and device-based assessments are only weakly or moderately correlated because they measure different FITT components indicating that they are best used together.

REFERENCES

1. Aadland E, Ylvisaker E. Reliability of the Actigraph GT3X+ accelerometer in adults under free-living conditions. *PloS One*. 2015;10:e0134606.
2. Adolph AL, Puyau MR, Vohra FA, Nicklas TA, Zakeri IF, Butte NF. Validation of uniaxial and triaxial accelerometers for the assessment of physical activity in preschool children. *J Phys Act Health*. 2012;9:944-953.
3. Amireault S, Godin G, Lacombe J, Sabiston CM. Validation of the Godin-Shephard Leisure-Time Physical Activity Questionnaire classification coding system using accelerometer assessment among breast cancer survivors. *J Cancer Surviv*. 2015;9:532-540.
4. 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.
5. 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.
6. 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.

7. Armstrong N, Welsman JR. The physical activity patterns of European youth with reference to methods of assessment. *Sports Med*. 2006;36:1067-1086.
8. Baez SE, Hoch MC, Hoch JM. Psychological factors are associated with return to pre-injury levels of sport and physical activity after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2020;28:495-501.
9. Bell DR, Pfeiffer KA, Cadmus-Bertram LA, et al. Objectively measured physical activity in patients after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2017;45:1893-1900.
10. Bianchim MS, McNarry MA, Larun L, Mackintosh KA; ActiveYouth SRC group ASSTMRC. Calibration and validation of accelerometry to measure physical activity in adult clinical groups: a systematic review. *Prev Med Rep*. 2019;16:101001.
11. Bodkin S, Goetschius J, Hertel J, Hart J. Relationships of muscle function and subjective knee function in patients after ACL reconstruction. *Orthop J Sports Med*. 2017;5:2325967117719041.
12. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. *Am J Sports Med*. 2009;37:890-897.
13. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. *PLoS One*. 2012;7:e36345.
14. Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Division of Population Health. BRFSS Prevalence & Trends Data 2015. Accessed May 31, 2021. https://www.cdc.gov/brfss/brfssprevalence/
15. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). *Arthritis Care Res (Hoboken)*. 2011;63(suppl 11):S208-S228.
16. Dahm DL, Wulf CA, Dajani KA, Dobbs RE, Levy BA, Stuart MA. Reconstruction of the anterior cruciate ligament in patients over 50 years. *J Bone Joint Surg Br*. 2008;90:1446-1450.
17. Dunn WR, Spindler KP; Consortium M. Predictors of activity level 2 years after anterior cruciate ligament reconstruction (ACLR): a Multicenter Orthopaedic Outcomes Network (MOON) ACLR cohort study. *Am J Sports Med*. 2010;38:2040-2050.
18. Fabricant PD, Robles A, Downey-Zayas T, et al. Development and validation of a pediatric sports activity rating scale: the Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS Pedi-FABS). *Am J Sports Med*. 2013;41:2421-2429.
19. Fabricant PD, Suryavanshi JR, Calcei JG, Marx RG, Widmann RF, Green DW. The Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS Pedi-FABS): normative data. *Am J Sports Med*. 2018;46:1228-1234.
20. Fakhouri TH, Hughes JP, Burt VL, Song M, Fulton JE, Ogden CL. Physical activity in U.S. youth aged 12-15 years, 2012. *NCHS Data Brief*. 2014:1-8.
21. Ferguson T, Rowlands AV, Olds T, Maher C. The validity of consumer-level, activity monitors in healthy adults worn in free-living conditions: a cross-sectional study. *Int J Behav Nutr Phys Act*. 2015;12:42.
22. Fuller D, Colwell E, Low J, et al. Reliability and validity of commercially available wearable devices for measuring steps, energy expenditure, and heart rate: systematic review. *JMIR mHealth and uHealth*. 2020;8:e18694.
23. Godin G, Shephard RJ. A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci*. 1985;10:141-146.
24. HealthyPeople.gov. Healthy People 2020: nutrition, physical activity, and obesity. Accessed February 12, 2019. https://www.healthypeople.gov/2020/leading-health-indicators/2020-lhi-topics/Nutrition-Physical-Activity-and-Obesity/data
25. Hochsmann C, Knaier R, Eymann J, Hintermann J, Infanger D, Schmidt-Trucksass A. Validity of activity trackers, smartphones, and phone applications to measure steps in various walking conditions. *Scand J Med Sci Sports*. 2018;28:1818-1827.
26. Hubbard-Turner T, Turner MJ. Physical activity levels in college students with chronic ankle instability. *J Athl Train*. 2015;50:742-747.
27. Iversen MD, von Heideken J, Farmer E, Rihm J, Heyworth BE, Kocher MS. Validity and comprehensibility of physical activity scales for children with sport injuries. *J Pediatr Orthop*. 2016;36:278-283.
28. Jassim SS, Douglas SL, Haddad FS. Athletic activity after lower limb arthroplasty: a systematic review of current evidence. *Bone Joint J*. 2014;96-B:923-927.
29. Kann L, McManus T, Harris WA, et al. Youth Risk Behavior Surveillance—United States, 2015. *MMWR Surveill Summ*. 2016;65:1-174.
30. Kelly LA, McMillan DG, Anderson A, Fippinger M, Fillerup G, Rider J. Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Med Phys*. 2013;13:5.
31. Kingsley MIC, Nawaratne R, O'Halloran PD, et al. Wrist-specific accelerometry methods for estimating free-living physical activity. *J Sci Med Sport*. 2019;22:677-683.
32. Kuenze C, Cadmus-Bertram L, Pfieffer K, et al. Relationship between physical activity and clinical outcomes after ACL reconstruction. *J Sport Rehabil*. 2019;28:180-187.
33. Kuenze C, Hertel J, Saliba S, Diduch DR, Weltman A, Hart JM. Clinical thresholds for quadriceps assessment after anterior cruciate ligament reconstruction. *J Sport Rehabil*. 2015;24:36-46.
34. Kuenze C, Lisee C, Pfeiffer KA, et al. Sex differences in physical activity engagement after ACL reconstruction. *Phys Ther Sport*. 2019;35:12-17.
35. Lee PH, Macfarlane DJ, Lam TH, Stewart SM. Validity of the International Physical Activity Questionnaire Short Form (IPAQ-SF): a systematic review. *Int J Behav Nutr Phys Act*. 2011;8:115.
36. Lepley LK. Deficits in quadriceps strength and patient-oriented outcomes at return to activity after ACL reconstruction: a review of the current literature. *Sports Health*. 2015;7:231-238.
37. Marx RG, Stump TJ, Jones EC, Wickiewicz TL, Warren RF. Development and evaluation of an activity rating scale for disorders of the knee. *Am J Sports Med*. 2001;29:213-218.
38. Matthews CE, Ainsworth BE, Thompson RW, Bassett DR Jr. Sources of variance in daily physical activity levels as measured by an accelerometer. *Med Sci Sports Exerc*. 2002;34:1376-1381.
39. McPhail SM, Schippers M, Marshall AL, Waite M, Kuipers P. Perceived barriers and facilitators to increasing physical activity among people with musculoskeletal disorders: a qualitative investigation to inform intervention development. *Clin Interv Aging*. 2014;9:2113-2122.
40. Motl RW, Bollaert RE, Sandroff BM. Validation of the Godin Leisure-Time Exercise Questionnaire classification coding system using accelerometry in multiple sclerosis. *Rehabil Psychol*. 2018;63:77-82.
41. Norte GE, Solaas H, Saliba SA, Goetschius J, Slater LV, Hart JM. The relationships between kinesiophobia and clinical outcomes after ACL reconstruction differ by self-reported physical activity engagement. *Phys Ther Sport*. 2019;40:1-9.
42. O'Brien MW, Wojcik WR, Fowles JR. Correction: Medical-grade physical activity monitoring for measuring step count and moderate-to-vigorous physical activity: validity and reliability study. *JMIR mhealth uhealth*. 2019;7:e12576.
43. O'Brien MW, Wojcik WR, Fowles JR. Medical-grade physical activity monitoring for measuring step count and moderate-to-vigorous physical activity: validity and reliability study. *JMIR mhealth uhealth*. 2018;6:e10706.
44. Park W, Lee VJ, Ku B, Tanaka H. Effect of walking speed and placement position interactions in determining the accuracy of various newer pedometers. *J Exer Sci Fitness*. 2014;12:31-37.
45. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320:2020-2028.
46. Powell KE, King AC, Buchner DM, et al. The Scientific Foundation for the Physical Activity Guidelines for Americans, 2nd edition. *J Phys Act Health*. 2018:1-11.
47. Rangul V, Holmen TL, Kurtze N, Cuypers K, Midthjell K. Reliability and validity of two frequently used self-administered physical activity questionnaires in adolescents. *BMC Med Res Methodol*. 2008;8:47.
48. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport*. 2000;71(suppl 2):1-14.
49. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14:411-416.
50. Sylvia LG, Bernstein EE, Hubbard JL, Keating L, Anderson EJ. Practical guide to measuring physical activity. *J Acad Nutr Diet*. 2014;114:199-208.
51. Tan SH, Lau BP, Khin LW, Lingaraj K. The importance of patient sex in the outcomes of anterior cruciate ligament reconstructions: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44:242-254.
52. Tengman E, Brax Olofsson L, Nilsson KG, Tegner Y, Lundgren L, Hager CK. Anterior cruciate ligament injury after more than 20 years: I. Physical activity level and knee function. *Scand J Med Sci Sports*. 2014;24:e491-e500.
53. Toomey CM, Whittaker JL, Nettel-Aguirre A, et al. Higher fat mass is associated with a history of knee injury in youth sport. *J Orthop Sports Phys Ther*. 2017;47:80-87.
54. Toth LP, Park S, Springer CM, Feyerabend MD, Steeves JA, Bassett DR. Video-recorded validation of wearable step counters under free-living conditions. *Med Sci Sports Exerc*. 2018;50:1315-1322.

55. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*. 2011;43:1360-1368.
56. Tudor-Locke C, Ainsworth BE, Thompson RW, Matthews CE. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med Sci Sports Exerc*. 2002;34:2045-2051.
57. United States Department of Health and Human Services. 2018 Physical Activity Guidelines Advisory Committee Scientific Report, 2018. Accessed May 31, 2021. https://health.gov/sites/default/files/2019-09/PAG_Advisory_Committee_Report.pdf
58. van Poppel MN, Chinapaw MJ, Mokkink LB, van Mechelen W, Terwee CB. Physical activity questionnaires for adults: a systematic review of measurement properties. *Sports Med*. 2010;40:565-600.
59. Wagner KJ 3rd, Sabatino MJ, Zynda AJ, et al. Activity measures in pediatric athletes: a comparison of the Hospital for Special Surgery Pediatric Functional Activity Brief Scale and Tegner Activity Level Scale. *Am J Sports Med*. 2020;48:985-990.
60. Waldstein W, Kolbitsch P, Koller U, Boettner F, Windhager R. Sport and physical activity following unicompartmental knee arthroplasty: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2017;25:717-728.
61. Webster KE, Feller JA. Expectations for return to preinjury sport before and after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2019;47:578-583.
62. Yang X, Chen JY, Zhai Y, Zhao WH. A systematic review of evaluation studies on physical activity questionnaires for children and adolescents [in Chinese]. *Zhonghua Yu Fang Yi Xue Za Zhi*. 2019;53:1290-1295.
63. Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement patients. *J Arthroplasty*. 1998;13:890-895.
64. Zebis MK, Warming S, Pedersen MB, et al. Outcome measures after ACL injury in pediatric patients: a scoping review. *Orthop J Sports Med*. 2019;7:2325967119861803.