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Quadriceps-Strength–Testing Practices and Barriers During Return to Sport After ACL Reconstruction: A Survey of College Athletic Trainers

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Context: Quadriceps strength is a key outcome for guiding rehabilitation and return to sport-specific activities after anterior cruciate ligament reconstruction (ACLR) surgery.

Objective: (1) Describe the quadriceps-strength–testing practices and barriers college athletic trainers (ATs) are using and experiencing when returning patients to sport-specific activities after ACLR. (2) Compare testing methods between college ATs working in the National Collegiate Athletic Association (NCAA) Division I setting and other college settings.

Design: Cross-sectional study.

Setting: Online survey.

Patients or Other Participants: Two hundred forty-three full-time collegiate ATs who had primarily overseen/directed an ACLR rehabilitation in the past 5 years (age = 34.8 ± 10.7 years, length of AT practice = 11.7 ± 9.3 years, NCAA Division I setting = 56%).

Main Outcome Measure(s): Our survey included 4 sections: demographics, general ACLR rehabilitation practices, quadriceps-strength–testing methods and criteria, and quadriceps-strength–testing barriers.

Results: Knee-muscle strength was the most common (98%) outcome collegiate ATs used when determining whether an ACLR patient is ready to progress to sport-specific activities. Manual muscle testing was the most used testing method (57%), followed by isokinetic dynamometry (IKD) (48%), repetition maximum testing (35%) and handheld dynamometry (22%). Most ATs (63%–64%) used greater than 90% side-to-side symmetry as their return to sport-specific activities criterion. Lack of equipment needed (83%), lack of financial means (28%), and lack of training/education (20%) were the barriers that most limited ATs use of IKD testing, the gold standard testing method. Compared with ATs in other settings, a greater proportion of ATs working in the NCAA Division I setting used IKD testing (65% vs 28%) and a smaller proportion used manual muscle testing (47% vs 70%).

Conclusions: Although almost all college ATs considered knee-muscle strength an important outcome to assess when returning patients to sport-specific activities after ACLR, quadriceps-strength–testing practices were highly variable among ATs and may be affected by access to necessary resources.

Key Words: knee extension, isokinetic dynamometer, handheld dynamometer, rehabilitation

Key Points

- Only 48% of college athletic trainers use isokinetic dynamometer testing, the gold standard method for testing quadriceps strength, when returning ACLR patients to sport-specific activities.
- 65% of ATs in the National Collegiate Athletic Association Division I setting used isokinetic dynamometer testing when returning ACLR patients to sport-specific activities, compared with only 28% of ATs in other college settings.
- Lack of equipment, financial means, and education/training were barriers limiting college athletic trainers' use of more objective strength-testing methods such as isokinetic dynamometer and handheld dynamometer testing.

Anterior cruciate ligament reconstruction (ACLR) surgery is considered the preferred treatment option for physically active individuals hoping to return to sport after a complete ACL tear.[1,2] Despite surgery and rehabilitation, only 41% of athletes with a history of ACLR return to preinjury levels of sport within 1 to 2 years postsurgery.[3] Anterior cruciate ligament reconstruction patients are 6 times more likely to experience a second ACL injury within the first 2 years postsurgery.[4] An estimated 48% of ACLR patients will develop knee osteoarthritis within the first 2 decades postsurgery.[5]

Quadriceps-strength deficits are a common and persistent clinical problem after ACLR.[6] These deficits have been linked to negative clinical outcomes, such as poorer physiological readiness when returning to sport after ACLR,[7] a greater incidence of secondary knee injuries,[8] and a greater risk for knee osteoarthritis.[9] Fortunately, rehabilitation clinicians such as athletic trainers (ATs) and physical therapists (PTs) can identify and treat deficits in quadriceps strength using objective strength-testing methods and appropriate therapeutic exercises, respectively. There are several testing methods clinicians may use to assess

quadriceps strength during ACLR rehabilitation, including but not limited to manual muscle testing (MMT), isokinetic dynamometer (IKD), handheld dynamometer (HHD), and repetition maximum (RM) testing.[10]

Manual muscle testing is a quick, easy, and commonly used assessment technique to screen for gross deficits in strength during orthopaedic and neurologic examinations. Previous authors have suggested that MMT is widely used in clinical practice to assess quadriceps strength during rehabilitation[10]; however, MMT is a highly subjective assessment method that can be biased by the strength of the clinician[11] and may not be sensitive to detect clinically relevant deficits in quadriceps strength during ACLR rehabilitation.[12]

Isokinetic dynamometer testing is well accepted as the gold standard method to perform valid and reliable measures of quadriceps strength.[13–15] Isokinetic dynamometers are large, computerized machines designed for assessing multiple aspects of muscle strength but are expensive (approximately $50 000), require a large space footprint within a clinic, and may not be accessible to many clinicians.[14]

Handheld dynamometers are small, portable, and cost-effective (<$1500) devices for assessing forces produced during muscle contractions. Although some clinicians and researchers use the term *HHD* to exclusively describe traditional push-type (compression) dynamometers, the term can be used more broadly to describe the wide range of small ("handheld") dynamometers that can measure either push or pull (tension) forces for clinical strength assessment, including pull-type load cells, strain gauges, and hanging/crane scales.[16] Evidence suggests that push- and pull-type HHDs can perform reliable and valid measures of quadriceps strength after ACLR compared with IKD testing when used with an external fixation testing setup.[16,17]

Repetition maximum testing involves using traditional resistance training equipment, such as knee-extension or leg-press machines, to assess quadriceps strength based on the weight a patient can "lift" during the exercise.[14] This assessment method is clinically feasible for clinicians with access to resistance training equipment, and RM testing has demonstrated excellent test-retest and interrater/intrarater reliability.[18,19] However, there is limited evidence evaluating RM testing as a clinical assessment of quadriceps strength in ACLR patients.[20]

Clinical guidelines recommend that rehabilitation clinicians use objective measures of quadriceps strength as an indicator of patient recovery after ACLR and meniscus surgeries.[21] Previous authors have surveyed PTs to understand their current practices for assessing quadriceps strength when returning patients to sport-specific activities after ACLR; however, none have examined quadriceps-strength–testing practices among ATs.[10] Therefore, the primary objectives of our study were (1) to describe the quadriceps-strength–testing methods collegiate ATs use during ACLR rehabilitation, (2) to describe the quadriceps-strength criteria (eg, % side-to-side symmetry) ATs use to determine readiness to return to sports activities, and 3) to describe the barriers that limit ATs' use of each strength-testing method. The secondary objective of our study was to examine whether testing methods were different between ATs working in the National Collegiate Athletic Association (NCAA) Division I setting and ATs working in other college settings. We focused our study on collegiate ATs (rather than ATs in all clinical settings) because ATs are more frequently the clinicians who directly oversee ACLR patients' rehabilitation, including the return to sport-specific activities, in the collegiate setting.

METHODS

Design and Participants

We used a descriptive cross-sectional design, and all data were collected through an online survey. Our target population was college ATs who managed the rehabilitation and return to sport-specific activities for patients after ACLR. We used 3 primary methods to recruit participants during November 2023 and December 2023: (1) we used the National Athletic Trainers' Association (NATA) Research Survey Service to email 2000 randomly selected NATA members employed in collegiate settings, (2) we emailed the survey to members of the Collegiate Athletic Trainers' Society (CATS) email listserve, and (3) we posted the survey on AT-related social media pages. We included participants if they were certified ATs, were employed full-time in a collegiate setting, and had primarily overseen or directed an ACLR rehabilitation in the past 5 years (Supplemental Table, Block 2, available online at http://dx.doi.org/10.4085/1062-6050-0378.24.S1). Our study was approved by the James Madison University Institutional Review Board, and all participants provided informed consent.

Survey Development and Validation

Our survey was developed based on a previously published survey that examined which outcome measures and return-to-sport-activity criteria US PTs used during ACLR rehabilitation.[10] We modified some questions from the PT study to better align with the college AT clinical setting and removed some questions that were outside the scope of this project. We also added questions to capture outcomes/methods not included in the PT survey. Once a draft of the survey was completed, the survey was reviewed by 2 members of the research team (C.M.K., J.W.G.) with expertise in ACLR rehabilitation and quadriceps-strength outcomes to refine and assess the face validity of the survey. We then piloted the survey with a small sample of 10 collegiate ATs. We used feedback to improve survey clarity for our target population and to fix spelling/grammatical errors. Once the revisions and changes were completed, the survey was distributed.

Survey Instrument

Our survey was deployed using the QualtricsXM online survey tool (Qualtrics LLC). After consent and eligibility criteria, the survey consisted of 4 sections, including demographics, general ACLR rehabilitation practices, quadriceps-strength–testing methods and criteria, and quadriceps-strength–testing barriers. For the survey questions, *sport-specific activities* were defined as "sport-specific skills/drills including agility, cutting, jumping landing, change-or-direction, etc." The following subheadings will describe each survey section. For specific question language and response options for each question, refer to the Supplemental Table.

Demographics. In this section, we collected participants' age, gender, race, ethnicity, years of clinical practice, professional AT education degree (bachelor's or master's), highest

level of education, collegiate division/setting, and NATA district (Supplemental Table, Block 3).

General ACLR Rehabilitation Practices. In this section, we asked about the number of patients whose ACLR rehabilitation program participants had directed in the past 5 years, how many months post-ACLR their patients typically returned to sport-specific activities, and who determined when patients are ready to return. Lastly, we asked what assessments/outcomes they used when determining whether an ACLR patient was ready to progress to sport-specific activities (Supplemental Table, Block 4). If *knee strength* was selected as one of the assessments/outcomes, participants were guided to the quadriceps-strength–testing methods and criteria section of the survey. If *knee strength* was not selected, then the survey was terminated.

Quadriceps-Strength–Testing Methods and Criteria. The first question of this section asked what quadriceps-strength–testing methods participants used when deciding whether an ACLR patient is ready to progress to sport-specific activities (Supplemental Table, Block 5). For each testing method selected, participants were then directed to additional questions regarding how they performed that testing method and what strength criteria they used when deciding whether an ACLR patient is ready to progress to sport-specific activities (Supplemental Table, Block 6a through d).

Quadriceps-Strength–Testing Barriers. In this section, participants were asked about each of the strength-testing methods they indicated they did not use to assess quadriceps strength and what barriers prohibited their use of each testing method (Supplemental Table, Block 7).

Analyses

For our primary objectives, all survey data were summarized using frequencies and proportions (percentage) and means ± SD. For our secondary objective, we used χ^2 tests to compare the proportion of participants who did and did not use MMT, IKD, RM, and HHD between ATs working in the NCAA Division I setting and ATs working in other college settings. Chi-square tests were considered statistically significant at an α level of $P < .05$.

RESULTS

Our final sample included completed survey responses from 243 participants. A total of 327 potential participants initiated the survey, but 50 surveys were not completed (85% completion rate). We excluded 34 respondents who did not meet eligibility criteria (not an AT = 3, not working as a full-time AT in the college/university setting = 24, not directed an ACLR rehabilitation in the past 5 years = 7). Of the remaining 243 participants, 110 (45%) received the survey from the NATA Research Survey Service emails, 71 (29%) from our emails to the CATS membership, 44 (18%) from social media posts, and 18 (7%) from a colleague/friend. See Table 1 for participant demographics.

Table 1. Respondent Demographics

Characteristic	Value
Age, mean ± SD, y	34.8 ± 10.7
Years of AT practice, mean ± SD	11.7 ± 9.3
Gender, No. (%)	
Woman	153 (63.0)
Man	90 (37.0)
Race, No. (%)	
American Indian/Alaska Native	1 (0.4)
Asian	7 (2.9)
Black/African American	17 (7.0)
Hispanic/Latinx/Spanish origin	18 (7.4)
White/Caucasian	211 (86.8)
Unknown/prefer not to say	2 (0.8)
Professional AT education, No. (%)	
Bachelor's	181 (74.5)
Master's	62 (25.5)
Highest education level, No. (%)	
Bachelor's	10 (4.1)
Master's	213 (87.7)
Clinical doctorate	12 (4.9)
Academic doctorate	5 (2.1)
Other	3 (1.2)
Collegiate setting, No. (%)	
NCAA Division I athletics	136 (56.0)
NCAA Division II athletics	31 (12.7)
NCAA Division III athletics	42 (17.3)
NAIA athletics	16 (6.6)
Junior/community college athletics	16 (6.6)
Student recreation/club	2 (0.8)
NATA district, No. (%)[a]	
1 (CT, ME, MA, NH, RI, VT)	11 (4.5)
2 (DE, NY, NJ, PA)	27 (11.1)
3 (DC, MD, NC, SC, VA, WV)	53 (21.8)
4 (IN, MI, OH)	26 (10.7)
5 (IA, KA, MO, NE, ND, OK, SD)	23 (9.5)
6 (AK, TX)	10 (4.1)
7 (AZ, CO, NM, UT, WY)	11 (4.5)
8 (CA, HI, NV)	22 (9.1)
9 (AL, FL, GA, KY, LA, MS, TN)	32 (13.2)
10 (AL, ID, MT, OR, WA)	7 (2.9)
11 (IL, MN, WI)	21 (8.6)

Abbreviations: AT, athletic trainer; NAIA, National Association of Intercollegiate Athletics; NATA, National Athletic Trainers' Association; NCAA, National Collegiate Athletic Association.
[a] NATA district abbreviations represent US state abbreviations.

ACL Reconstruction Rehabilitation Practices

College ATs reported directing an average of 6 ACLR patient rehabilitation programs and progression to sport-specific activities over the past 5 years (Table 2). Half of ATs reported that their typical ACLR patient progressed to sport-specific activities between 6 and 7 months postsurgery (50%) (Table 2). A large proportion of ATs (77%) reported that progressing a patient to sport-specific activities was a collaborative decision between ATs and orthopaedic surgeons (Table 2). Knee-muscle strength (98%) was the most frequent assessment/factor college ATs evaluated when progressing patients to sport-specific activities, followed by lower extremity functional testing (93%), knee range of motion (87%), time postsurgery (85%), balance assessments (54%), and knee effusion (50%).

Quadriceps-Strength–Testing Methods

Among the 98% of ATs who reported assessing knee-muscle strength, MMT was the method most ATs (56%) used for testing quadriceps strength, followed by IKD

Table 2. Anterior Cruciate Ligament Reconstruction (ACLR) Rehabilitation Practices and Assessments/Outcomes Used for Returning to Sport-Specific Activities[a]

Characteristic	Value
No. of ACLR rehabilitation programs directed in past 5 years, mean ± SD	6.0 ± 10.7
Months postsurgery until ACLR patients progress to sport-specific activities, No. (%)	
<3	5 (2.1)
4–5	54 (22.2)
6–7	122 (50.2)
8–9	48 (19.8)
10–11	12 (4.9)
>12	2 (0.8)
Who decides when patient progresses to sport-specific activities, No. (%)	
AT	15 (6.2)
Orthopaedic surgeon	20 (8.2)
AT and orthopaedic surgeon	188 (77.4)
Other	20 (8.2)
Assessments/outcomes used for deciding when patient progresses to sport-specific activities, No. (%)	
Knee-muscle strength	238 (97.9)
Lower extremity functional testing	225 (92.6)
Knee range of motion	212 (87.2)
Time postsurgery	206 (84.8)
Balance assessments	130 (53.5)
Knee effusion	122 (50.2)
Psychological readiness questionnaires	88 (36.2)
Knee symptom/function questionnaires	75 (30.9)
ACL laxity special tests	72 (29.6)
Other	22 (9.1)
None—do not use specific assessments/outcomes	0 (0.0)

Abbreviation: AT, athletic trainer.
[a] Percentages calculated as proportion of total respondents (N = 243).

testing (47%), RM testing (35%), and then HHD testing (22%) (Table 3). Among ATs who assessed knee-muscle strength, 18% (44 of 238) reported MMT was the only strength-testing method they used when returning patients to sport-specific activity.

Isokinetic dynamometer testing was the method most used by ATs working in the NCAA Division I setting (65%), whereas MMT was the method most used by ATs working in other college settings (70%). We observed that a significantly greater proportion of ATs in other college settings used MMT compared with ATs in the NCAA Division I setting, and a significantly greater proportion of ATs in the NCAA Division I setting used IKD and HHD testing compared with ATs in other settings (Table 3). There was no difference in the proportion of ATs who used RM testing or "other" between settings (Table 3).

MMT Methods and Criteria

Among those who used MMT (n = 135) to assess quadriceps strength, most tested at 90° of knee flexion (65%), followed by full knee range of motion (62%) (Table 4). Sixty-six percent used a self-assessed 5/5 and 32% used 4/5 on the patient's ACLR knee as their criterion for progression to sport-specific activity. Ninety-eight percent also used a side-to-side MMT comparison as part of their assessment (Table 4).

IKD Methods and Criteria

Among those who used IKD testing (n = 115) to assess quadriceps strength, most (91%) tested isokinetic concentric contractions, and just over half (55%) tested isokinetic eccentric contractions, with 60°/s (61%) and 180°/s (55%) being the most common isokinetic testing speeds (Table 5). Of the 42% who used isometric contractions on the IKD, most (94%) tested at 90° of knee flexion (Table 5). The majority (50%) of IKD tests were performed by a clinician on staff, followed by a local researcher or lab (31%). The majority (52%) used greater than 90% side-to-side symmetry as their criterion for progression to sport-specific activity (Table 5).

HHD Methods and Criteria

Among those who used HHD testing (n = 52) to assess quadriceps strength, most used a push/compression dynamometer (65%), used external fixation/resistance (65%), and tested at 90° of knee flexion (94%) (Table 6). The largest proportion (44%) used greater than 90% side-to-side symmetry as their criterion for progression to sport-specific activity (Table 6).

RM Methods and Criteria

Among those who used RM testing (n = 82) to assess quadriceps strength, most used a leg-press exercise (76%) and used 3 RM for testing (56%) (Table 7). The majority (54%) used greater than 90% side-to-side symmetry as their criterion for progression to sport-specific activity (Table 7).

Testing Method Barriers

Feeling that MMTs were not a valid/reliable measure of quadriceps strength (67%) and/or preferring other methods (46%) were the most-reported barriers for college ATs not using MMT (Table 8). Lack of equipment (83%) and/or lack of financial means (28%) were the most-reported

Table 3. Quadriceps-Strength–Testing Methods Used by College Athletic Trainers and Comparisons of Testing Methods Between Those Working in the National Collegiate Athletic Association (NCAA) Division I Setting and Other College Settings

	No. (%)			
	Total Sample (N = 238)	NCAA Division I (N = 133)	Other College Settings (N = 105)	*P* Value[a]
Manual muscle testing	135 (56.7)	62 (46.6)	73 (69.5)	<.001[b]
Isokinetic dynamometer	115 (48.3)	86 (64.7)	29 (27.6)	<.001[b]
Handheld dynamometer	52 (21.8)	37 (27.8)	15 (14.3)	.012[b]
Repetition maximum	82 (34.5)	42 (31.6)	40 (38.1)	.29
Other	20 (8.4)	10 (7.5)	10 (9.5)	.58

[a] *P* value = χ^2 test between participants working in NCAA Division I and other college settings.
[b] $P < .05$.

Table 4. Manual Muscle Testing (MMT) Methods Used by College Athletic Trainers When Assessing Quadriceps Strength for Return to Sport-Specific Activities

Testing Characteristic	No. (%)[a]
MMT knee position	
90° knee flexion	88 (65.2)
60° knee flexion	31 (23.0)
45° knee flexion	52 (38.5)
Full knee range of motion	83 (61.5)
Other	3 (2.2)
MMT criterion for progression to sport-specific activities	
5/5 on ACLR knee	89 (66.0)
4/5 on ACLR knee	43 (31.9)
3/5 on ACLR knee	2 (1.5)
None—do not use specific criteria	1 (0.7)
Use side-to-side MMT comparison for progression to sport-specific activities	
Yes	132 (97.8)
No	3 (2.2)

Abbreviation: ACLR, anterior cruciate ligament reconstruction.
[a] Percentages calculated from the proportion of respondents who reported using manual muscle testing (n = 135).

Table 5. Isokinetic Dynamometer (IKD) Testing Methods Used by College Athletic Trainers When Assessing Quadriceps Strength for Return to Sport-Specific Activities

Testing Characteristic	No. (%)[a]
IKD testing mode	
Isokinetic concentric	105 (91.3)
Isokinetic eccentric	63 (54.8)
Isometric	48 (41.7)
IKD isometric testing position	
90° knee flexion	45 (93.8)
60° knee flexion	21 (43.8)
45° knee flexion	21 (43.8)
Other	2 (4.2)
IKD isokinetic speeds, °/s	
60	66 (61.1)
90	34 (31.5)
120	31 (28.7)
180	59 (54.6)
240	14 (13.0)
300	33 (30.6)
Other	8 (7.4)
Who performs IKD testing	
Myself or other clinician on staff	58 (50.4)
Local researcher/lab	36 (31.3)
Other	21 (18.3)
IKD criterion for progression to sport-specific activities	
>95% side-to-side symmetry	13 (11.3)
>90% side-to-side symmetry	60 (52.2)
>85% side-to-side symmetry	20 (17.4)
>80% side-to-side symmetry	14 (12.2)
>75% side-to-side symmetry	4 (3.5)
Other	3 (2.6)
None—do not use specific criteria	1 (0.9)

[a] Percentages based on the proportion of respondents who reported using isokinetic dynamometer testing (n = 115).

barriers to using IKD testing (Table 8). Lack of equipment (69%) and/or lack of training/education (29%) were the most-reported barriers to using HHD testing (Table 8). Preferring other methods (51%) and/or lack of training/education (28%) were the most-reported barriers to using RM testing (Table 8).

DISCUSSION

Our findings provide a detailed description of the testing methods and criteria college ATs use and the barriers they experience when assessing quadriceps strength during the late phases of ACLR rehabilitation. We observed that knee-muscle strength was the most common assessment/outcome that collegiate ATs used when determining whether an ACLR patient was ready to progress to sport-specific activities. Manual muscle testing was the most used method for assessing quadriceps strength, followed by IKD testing, RM testing, and then HHD testing. The most-reported barriers that limited ATs' use of IKD testing were lack of equipment needed, lack of financial means, and lack of training/education. Greater than 90% side-to-side symmetry was the most common criterion ATs used for guiding return-to-sports decisions. When comparing ATs working in the NCAA Division I setting vs other college settings, we observed that a greater proportion of NCAA Division I ATs used objective IKD and HHD testing and a smaller proportion used subjective MMT compared with ATs working in other college settings. Greater access to equipment and financial resources at high levels of collegiate athletics may influence the testing methods that college ATs can use in their clinical practice.

To our knowledge, this is the first study to examine how college ATs assess quadriceps strength during ACLR rehabilitation and return to sport-specific activities. Similar to our findings, a previous survey of US PTs observed that knee-muscle strength was the most-used assessment/outcome by PTs when progressing an ACLR patient back to sports activities.[10] The authors of that study also observed that MMT was the method most PTs (75%) used to assess quadriceps strength and that 36% of PTs used MMT as their only method to assess quadriceps strength.[10] Manual muscle testing is quick and easy, requires no equipment, and is widely instructed in AT education programs; however, evidence suggests that MMT can be biased by the strength of the assessor[11,22,23] and is not sensitive enough to detect more subtle but clinically important quadriceps-strength deficits.[12] In alignment with these limitations, feeling that MMT was not a valid/reliable measure of quadriceps strength was the most-reported barrier among college ATs who did not use MMTs.

Although MMT was the most popular method college ATs used to assess quadriceps strength after ACLR in the current study (57% used), this proportion was much lower than the 98% of ATs who reported they used MMT to assess ankle strength when determining a patient's readiness for sport after ankle sprains in a previous study.[24] Additionally, about two-thirds of the ATs who reported they used MMT to assess quadriceps strength did so in combination with other strength-testing methods (IKD, HHD, RM, or other). We observed that only 18% (n = 44) of the college ATs who assessed knee strength used only MMT to assess quadriceps strength. Barriers such as lack of equipment, lack of finances, and lack of training/education that we identified in this study may contribute to some ATs' use of only MMT to assess quadriceps strength after ACLR. These barriers may also explain why more college ATs working in other college settings used MMT compared with ATs working in the NCAA Division I setting.

Almost half (48%) of the college ATs in our study used IKD testing to assess quadriceps strength in their ACLR

Table 6. Handheld Dynamometer (HHD) Testing Methods Used by College Athletic Trainers When Assessing Quadriceps Strength for Return to Sport-Specific Activities

Testing Characteristic	No. (%)[a]
Dynamometer type	
Push/compression	34 (65.4)
Pull/tension	18 (34.6)
Fixation/resistance method	
Manual resistance	18 (34.6)
External fixation/resistance	34 (65.4)
Knee testing position	
90° knee flexion	49 (94.2)
60° knee flexion	20 (38.5)
45° knee flexion	23 (44.2)
Other	1 (1.9)
Criterion for progression to sport-specific activities	
>95% side-to-side symmetry	10 (19.2)
>90% side-to-side symmetry	23 (44.2)
>85% side-to-side symmetry	7 (13.5)
>80% side-to-side symmetry	9 (17.3)
>75% side-to-side symmetry	1 (1.9)
Other	2 (3.9)
None—do not use specific criteria	0 (0.0)

[a] Percentages based on the proportion of respondents who reported using handheld dynamometer testing (n = 52).

Table 7. Repetition Maximum (RM) Testing Methods Used by College Athletic Trainers When Assessing Quadriceps Strength for Return to Sport-Specific Activities

Testing Characteristic	No. (%)
RM testing exercise	
Knee extension	47 (57.3)
Leg press	62 (75.6)
Other	18 (22.0)
RM repetitions	
1	17 (20.7)
3	46 (56.1)
5	14 (17.1)
10	9 (11.0)
Other	10 (12.2)
RM criterion for progression to sport-specific activities	
>95% side-to-side symmetry	8 (9.8)
>90% side-to-side symmetry	44 (53.7)
>85% side-to-side symmetry	18 (22.0)
>80% side-to-side symmetry	8 (9.8)
>75% side-to-side symmetry	1 (1.2)
Other	0 (0.0)
None—do not use specific criteria	3 (3.7)

[a] Percentages based on the proportion of respondents who reported using isokinetic dynamometer testing (n = 82).

patients. This proportion was more than double the 20% of PTs who reported using IKD testing with their ACLR patients in a previous study.[10] This contrast in findings between PTs and college ATs is likely reflective of these ATs working exclusively with the college-athlete population and that our sample was predominately ATs working in the NCAA Division I setting. We observed that IKD testing was the method most used by ATs in the NCAA Division I setting and that over 2 times as many ATs working in NCAA Division I used IKD testing compared with ATs working in other college settings (65% vs 28%). These findings are likely related to our findings that the greatest reported barriers for ATs not using IKD testing were lack of equipment, lack of financial means, and lack of training/education. Interestingly, it seems that a large proportion of ATs were overcoming these barriers by referring their ACLR patients to local research labs (32%) for IKD testing. Further analyses of the "other" (18%) write-in responses suggest that many ATs also referred ACLR patients to local PT clinics for IKD testing. Referral opportunities for IKD testing may be more accessible at larger institutions with research labs, which may also contribute to the greater use of IKD testing by college ATs working in NCAA Division I vs other college settings.

Repetition maximum testing was the third-most-used method for assessing quadriceps strength. Repetition maximum testing can be a cost-effective and feasible testing option for clinicians, as the weight-machine equipment needed is often available in AT clinics and/or strength and conditioning facilities. In alignment, our findings suggest that RM testing was the only objective strength-testing method for which lack of equipment or financial means were not frequent barriers for ATs. We observed that more college ATs used leg-press exercises for RM testing compared with knee-extension exercises. Leg-press RM testing assesses quadriceps strength in combination with other major lower extremity muscle groups (eg, triceps surae at the ankle, gluteus maximus at the hip) using a closed-chain motion, whereas knee-extension RM testing assesses more-isolated quadriceps strength using an open-chain motion. Authors of one study examining both methods in a sample of participants with a history of knee injuries reported that leg-press RM testing may overestimate limb symmetry compared with knee-extension RM testing.[20] Those authors theorized that the overestimation may have been due to the contributions from other lower extremity muscle groups during the leg-press RM testing and concluded that knee-extension RM testing may be a better option to identify asymmetries in quadriceps strength.[20] Given the higher accessibility to testing resources and the limited barriers reported in this study, there is a need for more evidence examining the use of RM testing as a method for assessing quadriceps strength during return-to-sport activities after ACLR patients.

Only 22% of college ATs used HHD testing when returning ACLR patients to sport-specific activities. The barriers that most limited college ATs' use of HHD were lack of equipment and lack of training/education. Given the low costs (<$1500) and versatility of HHDs, it was surprising that fewer college ATs report having access to an HHD in their clinics. Additionally, it seems that professional and/or continuing education regarding HHD strength testing could benefit ATs, given that lack of training/education was a frequently cited barrier. Growing evidence supports the use of push and pull HHDs for performing reliable, valid, and diagnostically accurate measures of quadriceps strength in individuals with a history of ACLR.[16,17,25] Traditionally, the market for HHDs has been relatively small and dominated by traditional push/compression dynamometers, which likely explains why more ATs reported they used push/compression dynamometers. However, with recent growth in pull/tension dynamometer availability, we may see a shift in future clinical use. Given evidence suggesting that quadriceps-strength testing using an HHD with manual resistance may be biased by the clinician's strength, it was promising to observe that more ATs are using these dynamometers in combination with an external fixation/resistance rather than the traditional manually resisted testing methods.[22]

Table 8. Barriers Prohibiting College Athletic Trainers' Use of Each Quadriceps-Strength–Testing Method

Barriers	Testing Method, No. (%)[a]			
	Manual Muscle Testing	Isokinetic Dynamometer	Handheld Dynamometer	Repetition Maximum
Lack of training/education	2 (1.9)	25 (20.3)	53 (28.5)	44 (28.2)
Lack of time	2 (1.9)	10 (8.1)	9 (4.8)	17 (10.9)
Lack of equipment needed	5 (4.9)	102 (82.9)	128 (68.8)	15 (9.6)
Lack of financial means	0 (0.0)	34 (27.6)	33 (17.7)	4 (2.6)
Not a valid/reliable	69 (67.0)	3 (2.4)	15 (8.1)	11 (7.1)
No barriers, prefer other method	47 (45.6)	7 (5.7)	34 (18.3)	79 (50.6)
Other	2 (1.9)	5 (4.1)	5 (2.7)	6 (3.9)

[a] Percentages based on the proportion of participants who reported they did not use each of the testing methods.

One similarity we observed across all 3 objective testing methods (IKD, RM, HHD) was that greater than 90% side-to-side symmetry was the most common criterion ATs used to determine whether an ACLR patient was ready to progress to sport-specific activities. When combining those who used greater than 90% or greater than 95% side-to-side symmetry for the 3 objective testing methods, we observed that 63% to 64% of college ATs were using a greater than 90% symmetry criterion. This finding aligns with numerous research reports whose authors used or recommended using greater than 90% quadriceps-strength symmetry as a criterion for returning to sports activities.[8,26–30] Evidence suggests that patients who return to sport with quadriceps-strength symmetry greater than 90% perform better on functional hopping tests,[28] have a lower risk of secondary knee injury,[8] demonstrate more normal joint loading during gait,[29] and have lower odds of developing early clinical knee osteoarthritis.[30] Similar to our findings, authors of the study of US PTs' strength-testing practices also observed that greater than 90% symmetry was the most common return-to-sport activity criterion PTs used for HHD and RM testing, but greater than 85% symmetry was the most common criterion PTs used for IKD testing.

It is important to interpret these findings within the context of the limitations and delimitations of our study. Data were captured using survey methods, so our findings are dependent on participant self-reporting and may not reflect true clinical practices. Although we used multiple recruitment methods in an attempt to capture a large and broad sample of college ATs, we had a low response rate, and our sample size of only N = 243 college ATs was relatively small. For example, of the 2000 NATA members whom we recruited for this survey, only 125 responded (6.3%), with 110 meeting eligibility criteria (5.5%). Unfortunately, a limitation of our recruitment methods was that we do not know the total potential participants who might have received/viewed our CATS emails or social media posts to get a sense of the response rates for those recruitment methods. Another limitation was that our sample included mostly ATs working in the NCAA Division I setting, which may have biased some of our findings. Although our sample was relatively small, demographic data suggest our sample was fairly representative of recent AT demographics from the Board of Certification: 55% female, 81% White, 75% professional AT education at the bachelor's level, and 88% master's degree as the highest level of education.[31] A limitation of our survey was that it did not include some newer methods clinicians are using to assess lower extremity biomechanics in clinical practice, such as the use of force plates. Additionally, we did not ask about the specific outcomes (eg, peak torque, rate of torque development) clinicians are using to quantify quadriceps strength or what ranges of motion ATs were using for isokinetic testing. Lastly, it is possible the terminology we used to describe devices or methods in the survey may not have been familiar to all respondents, which could have biased some responses.

CONCLUSIONS

Although almost all college ATs considered knee-muscle strength an important outcome to assess when considering a return to sport-specific activities after ACLR, college ATs use a wide variety of methods and criteria to assess quadriceps strength after ACLR. Manual muscle testing, a subjective measure of strength, was the most-used method; however, only 18% of college ATs reported using only MMT to assess quadriceps strength. IKD was the second most used testing method, but less than half of college ATs use IKD testing. Greater than 90% side-to-side symmetry was the most common criterion ATs used when using quadriceps strength to guide return to sport decisions. Lack of equipment, lack of financial means, and lack of education/training were common barriers limiting college ATs' use of more objective measures of quadriceps strength. College ATs working in other college settings were more likely to use MMT and less likely to use IKD and HHD testing compared with those working in the NCAA Division I setting.

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DISCLOSURE

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SUPPLEMENTAL MATERIAL

Supplemental Table. Complete survey.

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