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Quadriceps and Hamstrings Strength Reference Values for Athletes With and Without Anterior Cruciate Ligament Reconstruction Who Play Popular Pivoting Sports, Including Soccer, Basketball, and Handball: A Scoping Review

Quadriceps and hamstrings strength tests are important when evaluating rehabilitation progression and making return-to-sport (RTS) decisions after anterior cruciate ligament reconstruction (ACLR).[7,43,53] Athletes who play pivoting sports and who pass strength tests as part of an RTS testing protocol are at lower risk for a second anterior cruciate ligament (ACL) injury, underscoring the importance of these tests.[18,19,30]

OBJECTIVE: To synthesize and present reference values for quadriceps and hamstrings strength tests in healthy athletes who play pivoting sports and in athletes with anterior cruciate ligament reconstruction (ACLR) who play pivoting sports.

DESIGN: Scoping review.

LITERATURE SEARCH: We searched PubMed, the Cochrane Library, MEDLINE, Embase, and Web of Science up to January 26, 2021.

STUDY SELECTION CRITERIA: We included reference values in 2 different categories: (1) quadriceps and hamstrings strength test outcomes in healthy pivoting-sport athletes, and (2) quadriceps and hamstrings strength test outcomes in pivoting-sport athletes with ACLR at a specific time point during rehabilitation.

DATA SYNTHESIS: We performed a qualitative synthesis for reference values from isokinetic (at 60°/s, 180°/s, and 300°/s) and isometric quadriceps and hamstrings strength tests. We summarized the data for type of sport, sex, sport participation level, and age group.

RESULTS: Of the 42 included studies, 26 reported reference values from healthy soccer players, 4 from healthy basketball players, 4 from healthy handball players, and 11 from other healthy pivoting-sport athletes. The limb symmetry index dominant/nondominant limb (LSI-D/ND) ranged from 98% to 114% for healthy athletes. Six studies reported reference values in pivoting-sport athletes with ACLR at a specific time point during rehabilitation. After 7 months, strength values for athletes with ACLR were comparable to those of healthy pivoting-sport athletes.

CONCLUSION: This scoping review summarizes quadriceps and hamstrings strength reference values for athletes who play the most common pivoting sports, including soccer, basketball, and handball. *J Orthop Sports Phys Ther 2022;52(3):142-155. Epub 31 Dec 2021. doi:10.2519/jospt.2022.10693*

KEY WORDS: *anterior cruciate ligament reconstruction, muscle strength, reference values*

The limb symmetry index (LSI)—a comparison between the operated and nonoperated limbs—is often used to guide RTS decisions. However, clinicians and researchers have long raised concerns about using the nonoperated limb as a reference, as the nonoperated limb also detrains and loses strength after injury and surgery.[57] As a result, the LSI may overestimate operated-knee function and may not be sensitive enough to alert clinicians and athletes to a high risk of second ACL injury.[57]

The use of both LSI and preinjury strength values to guide rehabilitation progression could be a solution, but preinjury data are often unavailable in everyday practice. Strength test reference values derived from healthy athletes who play pivoting sports could solve this problem, but a comprehensive overview of reference values for different sports is currently lacking.

We aimed to synthesize and present reference values for quadriceps and hamstrings strength tests in athletes with and without ACLR who play pivoting sports. The goal of our scoping review was to present information to help clinicians

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understand what "normal" quadriceps and hamstrings strength is for the athletes they work with: what to expect from healthy players without ACLR, and what to expect during rehabilitation and RTS progressions after ACLR. We present reference values for different pivoting sports, sexes, sport participation levels (elite and nonelite), and age groups.

METHODS

This scoping review was conducted and reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[49]

Eligibility Criteria

Inclusion and exclusion criteria were specified for 2 different categories of reference values: (1) quadriceps and hamstrings strength test outcomes in pivoting-sport athletes with ACLR at a specific time point during rehabilitation, from 3 months to RTS, and (2) quadriceps and hamstrings strength test outcomes in healthy pivoting-sport athletes, which can be used as RTS criteria (**TABLE 1**).

Search Strategy

On January 26, 2021, a systematic literature search was performed by an academic librarian. PubMed, the Cochrane Library, MEDLINE, Embase, and Web of Science were searched from database inception to identify relevant articles, using key words specified for the database (supplemental file 1). In addition, a hand search of the reference lists of meta-analyses and systematic reviews was conducted to identify additional studies not found in the primary search.

All database records were exported to the Rayyan application[40] in separate files for quadriceps and hamstrings strength. Duplicates were removed from each file.

Study Selection

Two authors (N.v.M. and W.v.d.W.) independently screened titles and abstracts for eligibility. For all potentially eligible studies, a full-text version was reviewed by 2 authors (W.v.d.W. and N.v.d.H.). Any disagreements in both steps were resolved by consensus. After this, both quadriceps and hamstrings strength Rayyan[40] files were combined, and duplicates were removed.

Data Synthesis

One author (N.v.M.) extracted all relevant study characteristics and reference value data. Study characteristics included author and year of publication, population characteristics, test details, and test outcome variables. Reference values were categorized as pivoting-sport athlete with or without ACLR, type of sport, sex, sport level (elite or nonelite), and age group (adolescent [16-19 years of age] or young adult [20-35 years of age]).[60]

Test outcome variables were reported as the following reference values: peak torque; peak torque normalized to body weight (BW); total work (only reported for an endurance test with at least 10 repetitions and when a test range was described); LSI, calculated as [(operated leg/nonoperated leg) × 100%] for athletes with ACLR LSI-D/ND calculated as [(dominant leg)/(nondominant leg) × 100%] for healthy athletes[54]; concentric hamstrings-to-quadriceps ratio; dynamic control ratio (eccentric hamstrings-to-concentric quadriceps); and maximum voluntary isometric contraction (MVIC). Limb symmetry indexes and ratios were extracted or calculated from the individual studies. When LSIs based on both peak torque and peak torque normalized to BW were available, only the LSI based on peak torque normalized to BW was reported.

When 3 or more studies reported on the same sport, we created a reference value table for the sport. We grouped data from all other sports (reported in

TABLE 1 Inclusion and Exclusion Criteria for Reference Values Derived From Healthy and ACL-Reconstructed Pivoting-Sport Athletes

	Inclusion	Exclusion
Population	• Adolescents (mean age, 16-19 y) or young adults (mean age, 20-35 y) • Athletes performing pivoting sports (clear sports description, Tegner score ≥6, or level 1 or 2 sports[a]) • Athletes with ACLR - Potential concomitant MCL or LCL injuries - Potential concomitant meniscal or cartilage injuries • Male or female athletes • Elite or recreational athletes	• Healthy athletes: history of ACL injury or surgery in the past, or other lower extremity or lower back injury when tested • Athletes with ACLR - ACL revision surgery or contralateral ACL injury in the past - Concomitant PCL injuries
Outcome	• Strength tests for quadriceps or hamstrings with an isokinetic dynamometer (isometric or concentric/eccentric at 60°/s-180°/s-300°/s[50]) or a handheld dynamometer • Absolute values or limb symmetry indexes reported as an outcome • Athletes with ACLR: tests performed at a specific time point during rehabilitation, from 3 mo until the moment of return to sport	• No separate results for male and female athletes • No separate results for elite or recreational athletes • Athletes with ACLR: tests performed more than 1 y after ACLR
Publication type	• All original research types • Language: English, Dutch, or German	• Meta-analyses, systematic or narrative reviews, conference abstracts, posters

Abbreviations: ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.
[a]Level 1 sports are sports with frequent pivoting movements (eg, soccer, handball, basketball); level 2 sports are sports with lateral movements and less pivoting than level 1 sports (eg, racket sports, alpine skiing).[22]

2 or fewer studies) in 1 extra reference value table.

All outcome variables reported in 2 or more studies were presented as a weighted mean with a weighted standard deviation. The weighted mean was calculated as the sum of (study mean × study sample size), divided by the sum of all study sample sizes.

The weighted standard deviation was calculated as the sum of (study variance × study sample size), divided by the sum of all study sample sizes. Study variance was calculated as study mean minus weighted mean.

Outcome variables reported in a single study were displayed as mean ± SD. Standard deviation was not available if we calculated the LSI or ratio from data extracted from a specific study.

RESULTS

Study Selection

After removing duplicates, the systematic literature search yielded 712 articles for quadriceps strength and 246 articles for hamstrings strength. After screening titles, abstracts, and full texts for eligibility, 926 articles were excluded, leaving 32 articles for quadriceps and hamstrings strength combined. Hand searching reference lists of meta-analyses and systematic reviews provided 10 additional articles; 42 articles were included for data synthesis (**FIGURE**).

Overview of Strength Testing Protocols

Data on study characteristics are described in supplemental file 2. All included studies performed strength measurements using an isokinetic dynamometer, with a Biodex (Biodex Medical Systems, Shirley, NY) or Cybex (Life Fitness, Rosemont, IL) being used most often (55% and 33%, respectively). Thirty-nine studies measured isokinetic strength only, 2 measured isometric strength only, and 1 measured isokinetic and isometric strength.

Isokinetic Strength Testing Protocols

Two studies measured concentric quadriceps strength only, 28 studies measured concentric quadriceps and hamstrings strength, 6 studies measured concentric quadriceps and concentric plus eccentric hamstrings strength, and 4 studies measured concentric plus eccentric quadriceps and hamstrings strength.

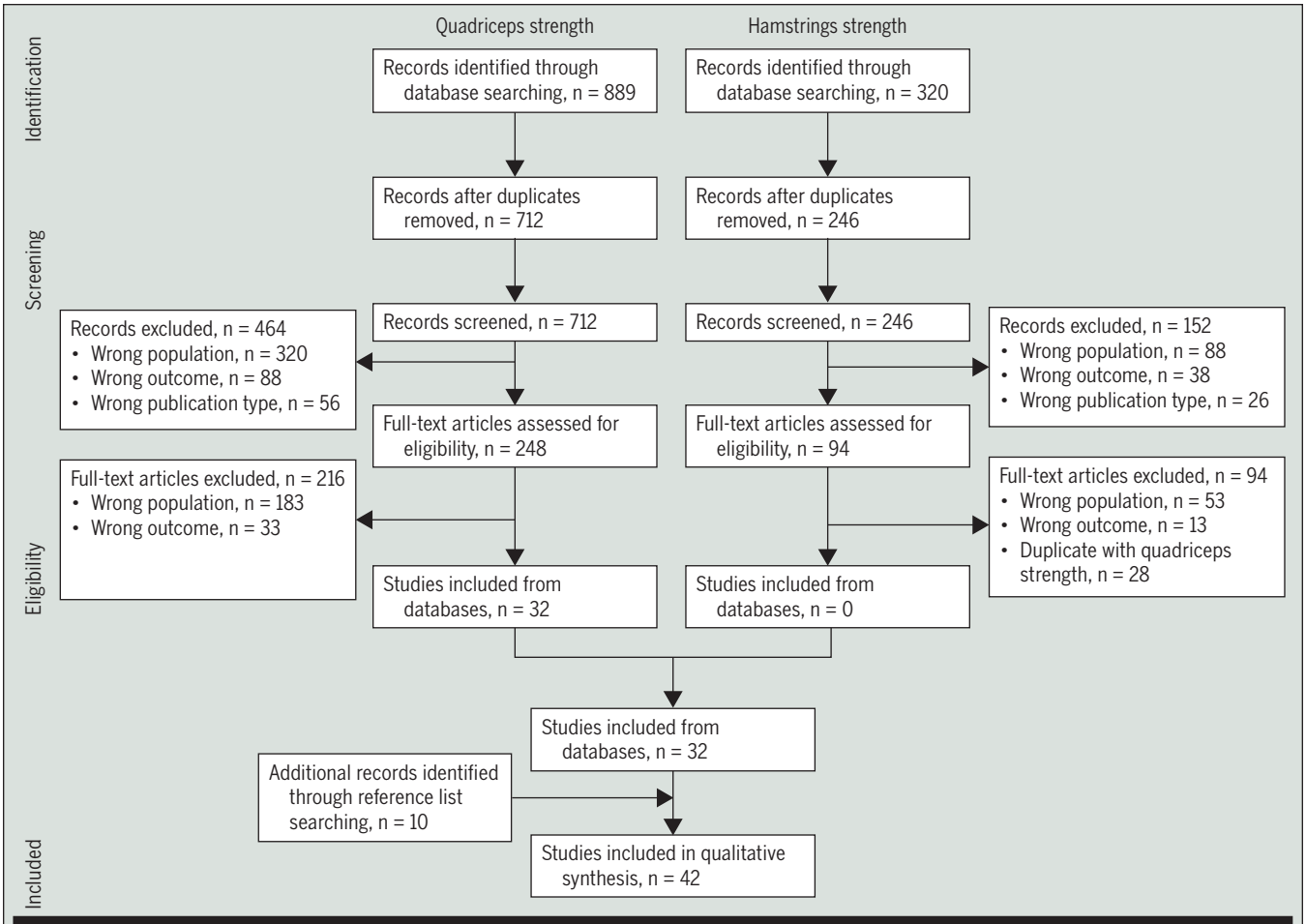


FIGURE. PRISMA flow chart of the study inclusion process.

Thirty-six studies performed concentric strength measurements at 60°/s, usually with 3 or 5 repetitions (39% and 42%, respectively). Seventeen studies reported strength measurements at 180°/s and/or 300°/s, typically with 3 or 5 repetitions (29% and 35%, respectively). One study that reported total work as an outcome parameter performed more than 10 repetitions at these higher speeds.[63] Eccentric strength was typically measured over 5 repetitions (70%). Range of motion was not specified in 33% of all isokinetic studies. In those that reported range of motion, 100° to 0° of flexion and 90° to 0° of flexion were mentioned in 15% and 33%, respectively. Rest between sets and whether gravity correction was performed were usually not described.

Isometric Strength Testing Protocols

Isometric strength measurements were all performed at different knee angles (45°, 70°, or 90° of flexion) and with different durations (2, 3, or 4 seconds).

Quadriceps and Hamstrings Strength Test Results

Soccer Strength results from healthy soccer players were reported in 26 studies.[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62] There were data from 1987 soccer players (84% male) who were 24.0 ± 2.1 years of age (**TABLE 2**).

Basketball Strength results from healthy basketball players were reported in 4 studies.[16,29,33,47] There were data from 99 healthy basketball players (74% male) who were 22.5 ± 0.99 years of age (**TABLE 3**).

Handball Strength results from healthy handball players were reported in 4 studies.[2,16,31,44] There were data from 310 handball players (5% male) who were 21.3 ± 1.3 years of age (**TABLE 4**).

Other Pivoting Sports All other pivoting

TABLE 2 Quadriceps and Hamstrings Strength Reference Values From Healthy Soccer Players[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62]

		Isokinetic[a]			Isometric[a]
Sex/Sport Level	**Population[a]**	**60°/s**	**180°/s**	**300°/s**	**90°**
Male					
Elite	n = 58 adolescents Age, 17.1 ± 0.8 y[15,21,41]	Quadriceps Peak torque, 182 ± 28 Nm D/ND LSI[b] = 102% ± 15% Hamstrings Peak torque, 97 ± 18 Nm D/ND LSI[b] = 108% ± 18% Eccentric peak torque, 151 ± 29 Nm Ratio DCR[c] = 84%[d]	Quadriceps Peak torque, 145 ± 13 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 244 ± 42 Nm Hamstrings Peak torque, 87 ± 15 Nm D/ND LSI[b] = 98%[d] Eccentric peak torque, 138 ± 21 Nm Ratios HQR[e] = 61% ± 9% DCR[c] = 96% ± 20%	Quadriceps Peak torque, 122 ± 14 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 249 ± 41 Nm Hamstrings Peak torque, 72 ± 9 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 141 ± 23 Nm Ratios HQR[e] = 61% ± 7% DCR[c] = 117% ± 23%	Quadriceps MVIC, 409 ± 78 N Hamstrings MVIC, 173 ± 38 N
	n = 1499 young adults Age, 24.9 ± 1.2 y[2,6,9,11,12,14,17,20,21,24,33,34,45,46,51,55,59,62]	Quadriceps Peak torque, 239 ± 16 Nm Peak torque per BW, 3.17 ± −0.10 Nm/kg D/ND LSI[b] = 99% ± 2% Eccentric peak torque, 299 ± 12 Nm Hamstrings Peak torque, 138 ± 4 Nm Peak torque per BW, 1.78 ± −0.10 Nm/kg D/ND LSI[b] = 102% ± 3% Eccentric peak torque, 187 ± 19 Nm Eccentric peak torque per BW, 2.60 ± −0.26 Nm/kg Ratios HQR[e] = 60% ± 3% DCR[c] = 75% ± 3%	Quadriceps Peak torque, 168 ± 14 Nm Peak torque per BW, 2.56 ± −0.10 Nm/kg D/ND LSI[b] = 103% ± 0% Eccentric peak torque, 249 ± 40 Nm Hamstrings Peak torque, 106 ± 7 Nm Peak torque per BW, 1.62 ± −0.05 Nm/kg D/ND LSI[b] = 102% ± 0% Eccentric peak torque, 154 ± 1 Nm Ratios HQR[e] = 62% ± 6% DCR[c] = 101% ± 3%	Quadriceps Peak torque, 134 ± 6 Nm Peak torque per BW, 1.87 ± −0.01 Nm/kg D/ND LSI[b] = 102% ± 0% Eccentric peak torque, 256 ± 15 Nm Hamstrings Peak torque, 93 ± 7 Nm Peak torque per BW, 1.33 ± −0.01 Nm/kg D/ND LSI[b] = 101% ± 4% Eccentric peak torque, 162 ± 4 Nm Ratios HQR[e] = 68% ± 6% DCR[c] = 126% ± 5%	

Table continues on page 146.

TABLE 2 Quadriceps and Hamstrings Strength Reference Values From Healthy Soccer Players[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62] (continued)

		Isokinetic[a]			Isometric[a]
Sex/Sport Level	**Population[a]**	**60°/s**	**180°/s**	**300°/s**	**90°**
Nonelite	n = 10 adolescents Age, 17.8 ± 0.1 y[29]		Quadriceps Peak torque, 125 ± 15 Nm Peak torque per BW, 2.05 ± –0.20 Nm/kg Hamstrings Peak torque, 105 ± 7 Nm Peak torque per BW, 1.70 ± –0.10 Nm/kg Ratio HQR[e] = 86% ± 7%	Quadriceps Peak torque, 90 ± 15 Nm Peak torque per BW, 1.50 ± –0.20 Nm/kg Hamstrings Peak torque, 70 ± 5 Nm Peak torque per BW, 1.15 ± –0.05 Nm/kg Ratio HQR[e] = 82% ± 10%	
	n = 106 young adults Age, 23.5 ± 1.5 y[10,11,48,56]	Quadriceps Peak torque, 225 ± 0 Nm Peak torque per BW, 2.76 ± –0.41 Nm/kg D/ND LSI[b] = 106% ± 1% Eccentric peak torque, 310 ± 10 Nm Eccentric peak torque per BW, 2.69 ± –0.45 Nm/kg Hamstrings Peak torque, 130 ± 5 Nm Peak torque per BW, 1.57 ± –0.23 Nm/kg D/ND LSI[b] = 106% ± 6% Eccentric peak torque, 150 ± 10 Nm Eccentric peak torque per BW, 1.56 ± –0.35 Nm/kg Ratios HQR[e] = 61% ± 3% DCR[c] = 71% ± 7%	Quadriceps Peak torque, 150 ± 3 Nm Hamstrings Peak torque, 105 ± 7 Nm Ratio HQR[e] = 71% ± 8%	Quadriceps Peak torque, 125 ± 5 Nm Peak torque per BW, 1.27 ± –0.23 Nm/kg D/ND LSI[b] = 106%[d] Hamstrings Peak torque, 90 ± 7 Nm Peak torque per BW, 0.98 ± –0.19 Nm/kg D/ND LSI[b] = 114%[d] Ratio HQR[e] = 79% ± 1%	
Female					
Elite	n = 213 young adults Age, 21.3 ± 0.6 y[2,44]	Quadriceps Peak torque, 149 ± 3 Nm Peak torque per BW, 2.32 ± –0.36 Nm/kg D/ND LSI[b] = 101%[d] Hamstrings Peak torque, 87 ± 1 Nm Peak torque per BW, 1.36 ± –0.21 Nm/kg D/ND LSI[b] = 103%[d] Ratio HQR[e] = 59% ± 1%		Quadriceps Peak torque, 83 ± 12 Nm Hamstrings Peak torque, 60 ± 9 Nm Ratio HQR[e] = 72% ± 11%	
Nonelite	n = 101 young adults Age, 20.3 ± 4.1 y[39]	Quadriceps Peak torque, 88 ± 15 Nm D/ND LSI[b] = 101%[d]	Quadriceps Peak torque, 60 ± 10 Nm D/ND LSI[b] = 101%[d]		

Abbreviations: BW, body weight; D, dominant; DCR, dynamic control ratio; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; ND, nondominant.

[a] *Values are mean ± SD unless otherwise indicated.*

[b] *Calculated as [(dominant leg)/(nondominant leg) × 100%].*

[c] *A ratio of eccentric hamstrings strength to concentric quadriceps strength.*

[d] *Standard deviation was not available.*

[e] *A ratio of concentric hamstrings strength to concentric quadriceps strength.*

sports (volleyball, hockey, futsal, American football, Australian football, judo, alpine skiing, and modern ballet) were grouped with unspecified pivoting sports in **TABLE 5**. Strength results from other pivoting sports were reported in 11 studies.[1,2,4,10,13,26,36-38,42,63] There were data from 1566 pivoting-sport athletes (92% male) who were 21.7 ± 1.9 years of age.

Pivoting-Sport Athletes With ACLR Strength results from 6 studies of pivoting-sport athletes with ACLR at a specific time point during rehabilitation were combined in **TABLE 6**.[8,25,28,37,56,61] Strength tests were completed at 3, 4, 6, 7, 9, and 10 months after ACLR for 816 pivoting-sport athletes with ACLR (80% male) who were 21.8 ± 3.0 years of age. After 7 months, strength values for athletes with ACLR were comparable to those of healthy pivoting-sport athletes.

DISCUSSION

We aimed to synthesize and present reference values for quadriceps and hamstrings strength tests for pivoting-sport athletes with and without ACLR. We presented separate results for types of pivoting sport (including soccer, basketball, and handball), sexes, sport participation levels, and age groups. We aim for the reference values to help guide clinicians regarding what is normal strength for pivoting-sport athletes, and what to expect during rehabilitation and RTS progressions after ACLR.

Strength Testing Modes

Isokinetic dynamometry is the gold standard for strength tests. We chose to report reference values at 60°/s, 180°/s, and 300°/s. This was based on a recent Delphi study, in which experts (physical therapists, orthopaedic surgeons, and

TABLE 3 Quadriceps and Hamstrings Strength Reference Values From Healthy Basketball Players[16,29,33,47]

Sex/Sport Level	Population[a]	Isokinetic[a] 60°/s	180°/s	300°/s
Male				
Elite	n = 73 young adults Age, 22.7 ± 0.6 y[33,47]	Quadriceps Peak torque, 289 ± 3 Nm Peak torque per BW, 3.21 ± –0.47 Nm/kg D/ND LSI[b] = 105%[c] Hamstrings Peak torque, 157 ± 8 Nm Peak torque per BW, 2.06 ± –0.35 Nm/kg D/ND LSI[b] = 107%[c] Ratio HQR[d] = 55% ± 3%	Quadriceps Peak torque, 190 ± 12 Nm Peak torque per BW, 1.73 ± –0.31 Nm/kg D/ND LSI[b] = 98%[c] Hamstrings Peak torque, 107 ± 7 Nm Peak torque per BW, 1.45 ± –0.27 Nm/kg D/ND LSI[b] = 100%[c] Ratio HQR[d] = 58% ± 9%	Quadriceps Peak torque, 147 ± 27 Nm Hamstrings Peak torque, 82 ± 19 Nm Ratio HQR[d] = 56% ± 10%
Female				
Elite	n = 14 young adults Age, 24.4 ± 2.6 y[16]	Quadriceps Peak torque, 185 ± 15 Nm Peak torque per BW, 2.50 ± –0.15 Nm/kg Hamstrings Peak torque, 100 ± 10 Nm Peak torque per BW, 1.50 ± –0.8 Nm/kg Ratio HQR[d] = 57% ± 9%	Quadriceps Peak torque, 120 ± 10 Nm Peak torque per BW, 1.70 ± –0.08 Nm/kg Hamstrings Peak torque, 55 ± 5 Nm Peak torque per BW, 0.90 ± –0.06 Nm/kg Ratio HQR[d] = 55% ± 10%	Quadriceps Peak torque, 75 ± 10 Nm Peak torque per BW, 1.20 ± –0.08 Nm/kg Hamstrings Peak torque, 30 ± 4 Nm Peak torque per BW, 0.50 ± –0.08 Nm/kg Ratio HQR[d] = 51% ± 10%
Nonelite	n = 12 young adults Age, 20.1 ± 0.4 y[29]		Quadriceps Peak torque, 105 ± 8 Nm Peak torque per BW, 1.90 ± –0.20 Nm/kg Hamstrings Peak torque, 75 ± 7 Nm Peak torque per BW, 1.40 ± –0.10 Nm/kg Ratio HQR[d] = 69% ± 15%	Quadriceps Peak torque, 60 ± 5 Nm Peak torque per BW, 1.05 ± –0.10 Nm/kg Hamstrings Peak torque, 47 ± 7 Nm Peak torque per BW, 0.85 ± –0.08 Nm/kg Ratio HQR[d] = 78% ± 8%

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; ND, nondominant.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[c]*Standard deviation was not available.*
[d]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*

scientists) recommended a protocol of concentric knee extension and flexion testing, including 5 repetitions at 60°/s, 20 repetitions at 180°/s, and 15 repetitions at 300°/s, with 60 seconds of rest between sets.[50]

Isokinetic dynamometry is unfortunately only accessible for a small proportion of clinicians, due to its nonportability and high cost.[52]

When isokinetic dynamometry is not available, (belt-stabilized) handheld dynamometry can be a reliable alternative for measuring quadriceps and hamstrings strength.[23,27] Handheld dynamometry strength measurements can be compared to MVIC reference values in our scoping review. However, the MVIC reference values in our review are all measured with isokinetic dynamometry, and the validity of handheld dynamometry measurements, when judged against isokinetic dynamometry measurements, remains debated.[23,35]

Strength Tests During Rehabilitation After ACLR

Because RTS is a continuous process that starts from the beginning of rehabilitation, it is important to evaluate strength multiple times throughout rehabilitation.[5,53] Regular testing allows for easy modification of strength training programs, tailored to the athlete's strength training status and needs. The reference values from our scoping review may help guide goal setting and evaluation during rehabilitation, and guide clinicians to ideal and realistic expectations. Although reference values during rehabilitation are reported for 3, 4, 6, 7, 9, and 10 months post surgery, approximately 2 months are needed between measurements to observe clinically meaningful changes.[5] There are, of course, individual differences in how fast athletes make meaningful progress, but it is important not to test too little or too often in order to keep athletes motivated. With adequate rehabilitation, it is possible to strive for strength values comparable to those of healthy pivoting-sport athletes as soon as 7 months after ACLR.[56]

Strength Tests as Part of the RTS Decision

Return-to-sport decisions after ACLR should be based on a battery of tests.[3] However, the specific content of such a battery is the subject of ongoing and strident debate. Conflicting research in the ACL field compounds a complex debate. One key issue is that some studies include athletes who do not return to pivoting sports—a main confounder when interpreting the results, because not returning to pivoting sports almost eliminates the risk for a second ACL injury.[58] Therefore, when reading studies about the association between RTS tests and second ACL injuries, one should be aware of this. When eliminating the confounding factor of pivoting-sport participation, quadriceps strength test results are associated

TABLE 4 Quadriceps and Hamstrings Strength Reference Values From Healthy Handball Players[2,16,31,44]

		Isokinetic[a]		
Sex/Sport Level	**Population[a]**	**60°/s**	**180°/s**	**300°/s**
Male				
Elite	n = 17 young adults Age, 25.9 ± 4.1 y[2]	Quadriceps Peak torque, 266 ± 51 Nm Hamstrings Peak torque, 163 ± 18 Nm Ratio HQR[b] = 63% ± 12%		Quadriceps Peak torque, 181 ± 36 Nm Hamstrings Peak torque, 113 ± 22 Nm Ratio HQR[b] = 63% ± 9%
Female				
Elite	n = 293 young adults Age, 21.1 ± 0.9 y[2,16,31,44]	Quadriceps Peak torque, 169 ± 5 Nm Peak torque per BW, 2.44 ± –0.05 Nm/kg D/ND LSI[c] = 100%[d] Hamstrings Peak torque, 95 ± 2 Nm Peak torque per BW, 1.38 ± –0.02 Nm/kg D/ND LSI[c] = 103%[d] Ratio HQR[b] = 57% ± 1%	Quadriceps Peak torque, 110 ± 7 Nm Peak torque per BW, 1.70 ± –0.08 Nm/kg Hamstrings Peak torque, 40 ± 7 Nm Peak torque per BW, 0.90 ± –0.06 Nm/kg Ratio HQR[b] = 55% ± 10%	Quadriceps Peak torque, 91 ± 16 Nm Peak torque per BW, 1.10 ± –0.08 Nm/kg Hamstrings Peak torque, 53 ± 18 Nm Peak torque per BW, 0.50 ± –0.06 Nm/kg Ratio HQR[b] = 61% ± 5%

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; ND, nondominant.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*
[c]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[d]*Standard deviation was not available.*

with ACL and knee reinjuries and cannot be denied as an important part of an RTS test battery.[3,18,19,30]

Clinical Relevance

If preinjury values are unavailable for injured athletes or previous-season values are unavailable for healthy athletes, clinicians could choose to use the reference tables from our scoping review as a guide to the expected quadriceps and hamstrings strength values for an individual athlete. Besides peak torque and MVICs for torque, peak torque normalized to BW and MVICs normalized to BW are reported as absolute reference values. We suggest using peak torque normalized to BW and MVIC normalized to BW for comparing between athletes, because they better account for the athlete's body weight. When these metrics are unavailable, peak torque or MVIC values are the best alternative.

Besides using absolute reference values, it is important to consider using an LSI. However, because the LSI-D/ND is used for reporting differences between the dominant leg and the nondominant leg in healthy pivoting-sport athletes, we advise clinicians to use the same measure

TABLE 5 Quadriceps and Hamstrings Strength Reference Values From Other Healthy Pivoting-Sport[a] Athletes[1,2,4,10,13,26,36-38,42,63]

		Isokinetic[b]			Isometric[b]
Sex/Sport Level	**Population[b]**	**60°/s**	**180°/s**	**300°/s**	**70°**
Male					
Elite	n = 20 adolescents Age, 17.0 ± 0.5[4]	Quadriceps Peak torque per BW, 3.42 ± –0.40 Nm/kg D/ND LSI[c] = 99%[d] Hamstrings Peak torque per BW, 1.63 ± –0.16 Nm/kg D/ND LSI[c] = 103%[d] Ratio HQR[e] = 48% ± 6%		Quadriceps Peak torque per BW, 1.92 ± –0.20 Nm/kg D/ND LSI[c] = 102%[d] Hamstrings Peak torque per BW, 1.27 ± –0.17 Nm/kg D/ND LSI[c] = 102%[d] Ratio HQR[e] = 67% ± 12%	
	n = 1361 young adults Age, 22.5 ± 1.2 y[2,4,26,36,38,63]	Quadriceps Peak torque, 309 ± 3 Nm Peak torque per BW, 2.89 ± –0.03 Nm/kg D/ND LSI[c] = 102% ± 0% Hamstrings Peak torque, 208 ± 3 Nm Peak torque per BW, 1.94 ± –0.01 Nm/kg D/ND LSI[c] = 101% ± 0% Ratio HQR[e] = 68% ± 1%	Quadriceps Peak torque per BW, 2.52 ± –0.28 Nm/kg Hamstrings Peak torque per BW, 1.75 ± –0.27 Nm/kg Ratio HQR[e] = 70% ± 9%	Quadriceps Peak torque, 136 ± 40 Nm Peak torque per BW, 1.93 ± –0.07 Nm/kg D/ND LSI[c] = 103%[d] TW, 1813 ± 480 J (15 reps; range, 90°) TW D/ND LSI[c] = 102%[d] Hamstrings Peak torque, 94 ± 29 Nm Peak torque per BW, 1.29 ± –0.05 Nm/kg D/ND LSI[c] = 104%[d] TW, 1596 ± 486 J (15 reps; range, 90°) TW D/ND LSI[c] = 99%[d] Ratio HQR[e] = 68% ± 1%	Quadriceps MVIC per BW, 417 ± 56 N/kg Hamstrings MVIC per BW, 186 ± 24 N/kg Ratio HQR[e] = 45%[d]
Nonelite	n = 61 young adults Age, 23.7 ± 0.4 y[10,37]	Quadriceps Peak torque per BW, 2.70 ± –0.18 Nm/kg D/ND LSI[c] = 105% ± 3% Hamstrings Peak torque per BW, 1.58 ± –0.04 Nm/kg D/ND LSI[c] = 102% ± 2% Ratio HQR[e] = 55% ± 10%		Quadriceps Peak torque per BW, 1.33 ± –0.25 Nm/kg D/ND LSI[c] = 106%[d] Hamstrings Peak torque per BW, 0.86 ± –0.23 Nm/kg D/ND LSI[c] = 106%[d] Ratio HQR[e] = 65% ± 15%	

Table continues on page 150.

TABLE 5 Quadriceps and Hamstrings Strength Reference Values From Other Healthy Pivoting-Sport[a] Athletes[1,2,4,10,13,26,36-38,42,63] (continued)

		Isokinetic[b]			Isometric[b]
Sex/Sport Level	Population[b]	60°/s	180°/s	300°/s	70°
Female					
Elite	n = 34 young adults Age, 21.0 ± 0.0 y[2,26]	Quadriceps Peak torque, 180 ± 42 Nm Hamstrings Peak torque, 92 ± 18 Nm Ratio HQR[c] = 53% ± 10%		Quadriceps Peak torque, 87 ± 18 Nm Hamstrings Peak torque, 62 ± 11 Nm Ratio HQR[c] = 72% ± 10%	Quadriceps MVIC per BW, 396 ± 45 N/kg Hamstrings MVIC per BW, 166 ± 22 N/kg Ratio HQR[c] = 42%[d]
Nonelite	n = 53 adolescents Age, 19.4 ± 1.3 y[13]	Ratio HQR[c] = 63% ± 8%		Ratio HQR[c] = 74% ± 15%	
	n = 37 young adults Age, 22.6 ± 1.5 y[1,42]	Quadriceps Peak torque, 123 ± 8 Nm Peak torque per BW, 2.27 ± –0.27 Nm/kg Hamstrings Peak torque, 0.49 ± –0.10 Nm Peak torque per BW, 0.96 ± –0.22 Nm/kg	Quadriceps Peak torque, 86 ± 5 Nm Peak torque per BW, 1.60 ± –0.22 Nm/kg Hamstrings Peak torque, 39 ± 8 Nm Peak torque per BW, 0.73 ± –0.17 Nm/kg	Quadriceps Peak torque, 61 ± 8 Nm Peak torque per BW, 1.20 ± –0.15 Nm/kg Hamstrings Peak torque, 30 ± 7 Nm Peak torque per BW, 0.58 ± –0.14 Nm/kg	

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; ND, nondominant; reps, repetitions; TW, total work.
[a]*Sports included volleyball, hockey, futsal, American football, Australian football, judo, alpine skiing, and modern ballet.*
[b]*Values are mean ± SD unless otherwise indicated.*
[c]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[d]*Standard deviation was not available.*
[e]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*

for supporting pivoting-sport athletes with ACLR when they are making RTS decisions. The LSI-D/ND between the dominant and nondominant legs ranged from 98% to 114% in healthy athletes. We suggest that clinicians use this as a benchmark for pivoting-sport athletes with ACLR instead of an LSI greater than 90%, as often advised.[32]

When athletes with ACLR do not meet the expected absolute values and have an LSI between the dominant and nondominant legs below the healthy reference, consider additional strength training before return to pivoting sports.

Limitations

We provided an extensive and detailed overview of quadriceps and hamstrings strength absolute and LSI reference values. However, there will always be outliers in each set of athletes, as reference values are based on a Gaussian curve.

We used broad selection criteria to maximize generalizability. However, due to sparse data in the group of athletes with ACLR, we were not able to present separate results for different graft types. Graft type can affect strength at different stages of rehabilitation. Therefore, we suggest interpreting reference values for pivoting-sport athletes with ACLR as minimum requirements and striving for higher values earlier in the rehabilitation process. It is probably better to use these reference values together with reference values from healthy pivoting-sport athletes, because we do not have insight into postoperative rehabilitation protocols.

Although we present these strength test reference values to help clinicians judge what "normal" strength is for pivoting-sport athletes, it has not yet been investigated whether there is an association between meeting reference values and sustaining a second ACL injury.

CONCLUSION

We synthesized and present absolute quadriceps and hamstrings strength reference values for pivoting-sport athletes with and without ACLR. Data from 42 articles are organized by type of sport (eg, soccer, basketball, handball), sex, sport participation level, and age group. In addition to using absolute reference values, the LSI between dominant and nondominant legs is valuable to use for RTS decisions. This LSI between dominant and nondominant legs ranged from 98% to 114% in healthy athletes.

TABLE 6 Quadriceps and Hamstrings Strength Reference Values for Pivoting-Sport Athletes During Rehabilitation After ACLR[8,25,28,37,56,61]

Time Point/ Sex/Sport Level	Population,[a] Graft Type	Isokinetic[a] 60°/s	Isokinetic[a] 180°/s	Isokinetic[a] 300°/s	Isometric[a] 45°
3 mo					
Male					
Nonelite	n = 156 adolescents; age, 18.8 ± 3.1 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.41 ± −0.44 Nm/kg NO-leg peak torque per BW, 2.46 ± −0.58 Nm/kg LSI[b] = 58% ± 17% Hamstrings O-leg peak torque per BW, 1.18 ± −0.36 Nm/kg NO-leg peak torque per BW, 1.40 ± −0.48 Nm/kg LSI[b] = 86% ± 19%			
Female					
Nonelite	n = 164 adolescents; age, 17.4 ± 2.8 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.13 ± 0.54 Nm/kg NO-leg peak torque per BW, 2.28 ± −0.42 Nm/kg LSI[b] = 48% ± 16% Hamstrings O-leg peak torque per BW, 0.93 ± −0.27 Nm/kg NO-leg peak torque per BW, 1.20 ± −0.31 Nm/kg LSI[b] = 79% ± 22%			
4 mo					
Male					
Elite	n = 20 young adults; age, 24.2 ± 5.1 y[28] BPTB	Quadriceps O-leg peak torque, 101 ± 35 Nm NO-leg peak torque, 176 ± 38 Nm LSI[b] = 57%[c] Hamstrings O-leg peak torque, 92 ± 24 Nm NO-leg peak torque, 107 ± 21 Nm LSI[b] = 86%[c]	Quadriceps O-leg peak torque, 84 ± 22 Nm NO-leg peak torque, 126 ± 26 Nm LSI[b] = 67%[c] Hamstrings O-leg peak torque, 76 ± 17 Nm NO-leg peak torque, 85 ± 17 Nm LSI[b] = 89%[c]		Quadriceps O-leg MVIC, 142 ± 48 N NO-leg MVIC, 213 ± 55 N LSI[b] = 67%[c] Hamstrings O-leg MVIC, 107 ± 21 N NO-leg MVIC, 105 ± 26 N LSI[b] = 102%[c]
Nonelite	n = 38 young adults; age, 24.2 ± 4.7 y[56] BPTB and hamstrings	Quadriceps O-leg peak torque, 189 ± 52 Nm O-leg peak torque per BW, 2.40 ± −0.50 Nm/kg NO-leg peak torque, 262 ± 58 Nm NO-leg peak torque per BW, 3.30 ± −0.50 Nm/kg LSI[b] = 72% ± 12% Hamstrings O-leg peak torque, 128 ± 31 Nm NO-leg peak torque, 143 ± 31 Nm LSI[b] = 89% ± 14%			

Table continues on page 152.

TABLE 6 Quadriceps and Hamstrings Strength Reference Values for Pivoting-Sport Athletes During Rehabilitation After ACLR[8,25,28,37,56,61] (continued)

Time Point/ Sex/Sport Level	Population,[a] Graft Type	Isokinetic[a] 60°/s	Isokinetic[a] 180°/s	Isokinetic[a] 300°/s	Isometric[a] 45°
6 mo					
Male					
Elite	n = 20 young adults; age, 24.2 ± 5.1 y[28] BPTB	Quadriceps O-leg peak torque, 122 ± 37 Nm NO-leg peak torque, 179 ± 40 Nm LSI[b] = 68%[c] Hamstrings O-leg peak torque, 99 ± 24 Nm NO-leg peak torque, 111 ± 21 Nm LSI[b] = 89%[c]	Quadriceps O-leg peak torque, 99 ± 31 Nm NO-leg peak torque, 129 ± 32 Nm LSI[b] = 77%[c] Hamstrings O-leg peak torque, 79 ± 16 Nm NO-leg peak torque, 84 ± 14 Nm LSI[b] = 94%[c]		Quadriceps O-leg MVIC, 165 ± 40 N NO-leg MVIC, 225 ± 50 N LSI[b] = 73%[c] Hamstrings O-leg MVIC, 111 ± 21 N NO-leg MVIC, 110 ± 22 N LSI[b] = 101%[c]
Nonelite	n = 156 adolescents; age, 18.8 ± 3.1 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 2.03 ± −0.51 Nm/kg NO-leg peak torque per BW, 2.79 ± −0.56 Nm/kg LSI[b] = 72% ± 15% Hamstrings O-leg peak torque per BW, 1.45 ± −0.34 Nm/kg NO-leg peak torque per BW, 1.52 ± −0.34 Nm/kg LSI[b] = 95% ± 17%			
	n = 118 young adults; age, 23.6 ± 5.8 y[37] BPTB	Quadriceps O-leg peak torque per BW, 2.00 ± −0.45 Nm/kg NO-leg peak torque per BW, 2.60 ± −0.45 Nm/kg LSI[b] = 77% ± 14% Hamstrings O-leg peak torque per BW, 1.46 ± −0.29 Nm/kg NO-leg peak torque per BW, 1.51 ± −0.28 Nm/kg LSI[b] = 97% ± 12%			
Female					
Nonelite	n = 164 adolescents; age, 17.4 ± 2.8 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.61 ± −0.45 Nm/kg NO-leg peak torque per BW, 2.53 ± −0.45 Nm/kg LSI[b] = 63% ± 16% Hamstrings O-leg peak torque per BW, 1.22 ± −0.25 Nm/kg NO-leg peak torque per BW, 1.35 ± −0.31 Nm/kg LSI[b] = 91% ± 18%			

Table continues on page 153.

TABLE 6 Quadriceps and Hamstrings Strength Reference Values for Pivoting-Sport Athletes During Rehabilitation After ACLR[8,25,28,37,56,61] (continued)

		Isokinetic[a]			Isometric[a]
Time Point/ Sex/Sport Level	**Population,[a] Graft Type**	**60°/s**	**180°/s**	**300°/s**	**45°**
7 mo					
Male					
Nonelite	n = 60 young adults; age, 25.8 ± 2.3 y[56,61] BPTB and hamstrings[d]	Quadriceps O-leg peak torque, 223 ± 51 Nm O-leg peak torque per BW, 2.90 ± −0.50 Nm/kg NO-leg peak torque, 267 ± 58 Nm NO-leg peak torque per BW, 3.30 ± −0.50 Nm/kg LSI[b] = 85% ± 13% Hamstrings O-leg peak torque, 144 ± 30 Nm NO-leg peak torque, 149 ± 34 Nm LSI[b] = 98% ± 8%	Quadriceps LSI[b] = 80% ± 12% Hamstrings LSI[b] = 102% ± 11%	Quadriceps LSI[b] = 82% ± 11% Hamstrings LSI[b] = 102% ± 27%	
9 mo					
Male					
Nonelite	n = 298 young adults; age, 24.2 ± 4.6 y[8] BPTB, hamstrings, and quadriceps	Quadriceps O-leg peak torque per BW, 2.24 ± −0.47 Nm/kg LSI[b] = 84% ± 14% Hamstrings O-leg peak torque per BW, 1.53 ± −0.29 Nm/kg LSI[b] = 97% ± 14%			
10 mo					
Male					
Nonelite	n = 38 young adults; age, 24.2 ± 4.7 y[56] BPTB and hamstrings	Quadriceps O-leg peak torque, 257 ± 51 Nm O-leg peak torque per BW, 3.20 ± −0.60 Nm/kg NO-leg peak torque, 270 ± 61 Nm NO-leg peak torque per BW, 3.40 ± −0.50 Nm/kg LSI[b] = 94% ± 15% Hamstrings O-leg peak torque, 150 ± 31 Nm NO-leg peak torque, 153 ± 34 Nm LSI[b] = 98% ± 8%			

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BPTB, bone-patellar tendon-bone; BW, body weight; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; NO, nonoperated; O, operated.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Calculated as [(operated leg)/(nonoperated leg) × 100%].*
[c]*Standard deviation was not available.*
[d]*At 60°/s, BPTB and hamstrings; at 180°/s and 300°/s, BPTB.*

KEY POINTS

FINDINGS: Detailed reference values are presented for athletes with and without anterior cruciate ligament reconstruction (ACLR) who play the most common pivoting sports (including soccer, basketball, and handball).

IMPLICATIONS: Quadriceps and hamstrings strength test reference values help clinicians judge what "normal" strength is for healthy pivoting-sport athletes, and what to expect during rehabilitation and return-to-sport (RTS) progressions after ACLR.

CAUTION: The association between meet-

ing reference values and (safe) RTS after ACLR requires more study.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Dr van Melick performed data synthesis and drafted the article. All authors contributed to study design, study selection, and revision of the article.

DATA SHARING: All data relevant to the study are included in this article or are available as online supplemental files. All reference values are available at www.aclreferencevalues.nl.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this article.

REFERENCES

1. Agopyan A. Hamstring flexibility is not correlated with isokinetic knee muscle strength in female modern dancers. *Med Probl Perform Art*. 2018;33:95-101. https://doi.org/10.21091/mppa.2018.2016
2. Andrade MDS, de Lira CAB, Koffes FDC, Mascarin NC, Benedito-Silva AA, da Silva AC. Isokinetic hamstrings-to-quadriceps peak torque ratio: the influence of sport modality, gender, and angular velocity. *J Sports Sci*. 2012;30:547-553. https://doi.org/10.1080/02640414.2011.644249
3. Ashigbi EYK, Banzer W, Niederer D. Return to sport tests' prognostic value for reinjury risk after anterior cruciate ligament reconstruction: a systematic review. *Med Sci Sports Exerc*. 2020;52:1263-1271. https://doi.org/10.1249/MSS.0000000000002246
4. Bittencourt NFN, Amaral GM, dos Anjos MTS, D'Alessandro R, Silva AA, Fonseca ST. Isokinetic muscle evaluation of the knee joint in athletes of the Under-19 and Under-21 male Brazilian national volleyball team. *Rev Bras Med Esporte*. 2005;11:302e-306e.
5. Bodkin SG, Rutherford MH, Diduch DR, Brockmeier SF, Hart JM. How much time is needed between serial "return to play" assessments to achieve clinically important strength gains in patients recovering from anterior cruciate ligament reconstruction? *Am J Sports Med*. 2020;48:70-77. https://doi.org/10.1177/0363546519886291
6. Bogdanis GC, Kalapotharakos VI. Knee extension strength and hamstrings-to-quadriceps imbalances in elite soccer players. *Int J Sports Med*. 2016;37:119-124. https://doi.org/10.1055/s-0035-1559686
7. Burgi CR, Peters S, Ardern CL, et al. Which criteria are used to clear patients to return to sport after primary ACL reconstruction? A scoping review. *Br J Sports Med*. 2019;53:1154-1161. https://doi.org/10.1136/bjsports-2018-099982
8. Carolan D, King E, Richter C, Franklyn-Miller A, Moran R, Jackson M. Differences in strength, patient-reported outcomes, and return-to-play rates between athletes with primary versus revision ACL reconstruction at 9 months after surgery. *Orthop J Sports Med*. 2020;8:2325967120950037. https://doi.org/10.1177/2325967120950037
9. Carvalho A, Brown S, Abade E. Evaluating injury risk in first and second league professional Portuguese soccer: muscular strength and asymmetry. *J Hum Kinet*. 2016;51:19-26. https://doi.org/10.1515/hukin-2015-0166
10. Cheung RT, Smith AW, Wong DP. H:Q ratios and bilateral leg strength in college field and court sports players. *J Hum Kinet*. 2012;33:63-71. https://doi.org/10.2478/v10078-012-0045-1
11. Cometti G, Maffiuletti NA, Pousson M, Chatard JC, Maffulli N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med*. 2001;22:45-51. https://doi.org/10.1055/s-2001-11331
12. Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of injury preventive warm-up programs on knee strength ratio in young male professional soccer players. *PLoS One*. 2012;7:e50979. https://doi.org/10.1371/journal.pone.0050979
13. Devan MR, Pescatello LS, Faghri P, Anderson J. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. *J Athl Train*. 2004;39:263-267.
14. Eniseler N, Şahan Ç, Vurgun H, Mavi HF. Isokinetic strength responses to season-long training and competition in Turkish elite soccer players. *J Hum Kinet*. 2012;31:159-168. https://doi.org/10.2478/v10078-012-0017-5
15. Forbes H, Sutcliffe S, Lovell A, McNaughton LR, Siegler JC. Isokinetic thigh muscle ratios in youth football: effect of age and dominance. *Int J Sports Med*. 2009;30:602-606. https://doi.org/10.1055/s-0029-1202337
16. Grammatikopoulou M, Zakas A, Zakas N, Vergou A, Sendelidis T. Peak torque and strength curve characteristic of the quadriceps and hamstring muscles in elite female basketball and handball players. *J Hum Mov Stud*. 2005;48:75-89.
17. Greig M. The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors. *Am J Sports Med*. 2008;36:1403-1409. https://doi.org/10.1177/0363546508314413
18. Grindem H, Engebretsen L, Axe M, Snyder-Mackler L, Risberg MA. Activity and functional readiness, not age, are the critical factors for second anterior cruciate ligament injury—the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2020;54:1099-1102. https://doi.org/10.1136/bjsports-2019-100623
19. 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. https://doi.org/10.1136/bjsports-2016-096031
20. Grygorowicz M, Michalowska M, Walczak T, et al. Discussion about different cut-off values of conventional hamstring-to-quadriceps ratio used in hamstring injury prediction among professional male football players. *PLoS One*. 2017;12:e0188974. https://doi.org/10.1371/journal.pone.0188974
21. Gür H, Akova B, Pündük Z, Küçükoğlu S. Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players. *Scand J Med Sci Sports*. 1999;9:81-87. https://doi.org/10.1111/j.1600-0838.1999.tb00213.x
22. Hefti F, Müller W, Jakob RP, Stäubli HU. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc*. 1993;1:226-234. https://doi.org/10.1007/BF01560215
23. Hirano M, Katoh M, Gomi M, Arai S. Validity and reliability of isometric knee extension muscle strength measurements using a belt-stabilized hand-held dynamometer: a comparison with the measurement using an isokinetic dynamometer in a sitting posture. *J Phys Ther Sci*. 2020;32:120-124. https://doi.org/10.1589/jpts.32.120
24. Hoshikawa Y, Iida T, Muramatsu M, Nakajima Y, Fukunaga T, Kanehisa H. Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *J Sports Sci*. 2009;27:129-138. https://doi.org/10.1080/02640410802428063
25. Hunnicutt JL, Xerogeanes JW, Tsai LC, et al. Terminal knee extension deficit and female sex predict poorer quadriceps strength following ACL reconstruction using all-soft tissue quadriceps tendon autografts. *Knee Surg Sports Traumatol Arthrosc*. 2021;29:3085-3095. https://doi.org/10.1007/s00167-020-06351-4
26. Jordan MJ, Aagaard P, Herzog W. Rapid hamstrings/quadriceps strength in ACL-reconstructed elite alpine ski racers. *Med Sci Sports Exerc*. 2015;47:109-119. https://doi.org/10.1249/MSS.0000000000000375
27. Katoh M. Reliability of isometric knee extension muscle strength measurements made by a hand-held dynamometer and a belt: a comparison of two types of device. *J Phys Ther Sci*. 2015;27:851-854. https://doi.org/10.1589/jpts.27.851
28. Knezevic OM, Mirkov DM, Kadija M, Milovanovic D, Jaric S. Evaluation of isokinetic and isometric strength measures for monitoring muscle function recovery after anterior cruciate ligament reconstruction. *J Strength Cond Res*. 2014;28:1722-1731. https://doi.org/10.1519/JSC.0000000000000307
29. Kobayashi Y, Takeuchi T, Hosoi T, Arai Y, Loeppky JA. Comparison of aerobic and anaerobic power and leg strength between young distance runners and basketball/soccer players. *Biol Sport*. 2006;23:211-224.
30. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting

six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016;50:946-951. https://doi.org/10.1136/bjsports-2015-095908
31. Lund-Hanssen H, Gannon J, Engebretsen L, Holen K, Hammer S. Isokinetic muscle performance in healthy female handball players and players with a unilateral anterior cruciate ligament reconstruction. *Scand J Med Sci Sports*. 1996;6:172-175. https://doi.org/10.1111/j.1600-0838.1996.tb00085.x
32. McGrath TM, Waddington G, Scarvell JM, et al. The effect of limb dominance on lower limb functional performance – a systematic review. *J Sports Sci*. 2016;34:289-302. https://doi.org/10.1080/02640414.2015.1050601
33. Metaxas TI, Koutlianos N, Sendelides T, Mandroukas A. Preseason physiological profile of soccer and basketball players in different divisions. *J Strength Cond Res*. 2009;23:1704-1713. https://doi.org/10.1519/JSC.0b013e3181b3e0c5
34. Minozzo F, Lopez P, Machado CLF, Wilhelm EN, Grazioli R, Pinto RS. Alternative assessment of knee joint muscle balance of soccer players through total work-based hamstring: quadriceps ratios. *Eur J Sport Sci*. 2018;18:1398-1404. https://doi.org/10.1080/17461391.2018.1495271
35. Muff G, Dufour S, Meyer A, et al. Comparative assessment of knee extensor and flexor muscle strength measured using a hand-held vs. isokinetic dynamometer. *J Phys Ther Sci*. 2016;28:2445-2451. https://doi.org/10.1589/jpts.28.2445
36. Nunes RF, Buzzachera CF, Almeida FA, Da Silva JF, Flores LJ, Da Silva SG. Relationships between isokinetic muscle strength, measures of aerobic fitness, single sprint performance, and repeated-sprint ability in elite futsal players. *Gazz Med Ital Arch Sci Med*. 2016;173:205-213.
37. O'Malley E, Richter C, King E, et al. Countermovement jump and isokinetic dynamometry as measures of rehabilitation status after anterior cruciate ligament reconstruction. *J Athl Train*. 2018;53:687-695. https://doi.org/10.4085/1062-6050-480-16
38. Orchard J, Marsden J, Lord S, Garlick D. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med*. 1997;25:81-85. https://doi.org/10.1177/036354659702500116
39. Östenberg A, Roos E, Ekdahl C, Roos H. Isokinetic knee extensor strength and functional performance in healthy female soccer players. *Scand J Med Sci Sports*. 1998;8:257-264. https://doi.org/10.1111/j.1600-0838.1998.tb00480.x
40. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. *Syst Rev*. 2016;5:210. https://doi.org/10.1186/s13643-016-0384-4
41. Padulo J, Trajković N, Cular D, et al. Validity and reliability of isometric-bench for knee isometric assessment. *Int J Environ Res Public Health*. 2020;17:4326. https://doi.org/10.3390/ijerph17124326
42. Pua YH, Koh MT, Teo YY. Effects of allometric scaling and isokinetic testing methods on the relationship between countermovement jump and quadriceps torque and power. *J Sports Sci*. 2006;24:423-432. https://doi.org/10.1080/02640410500189124
43. Rambaud AJM, Ardern CL, Thoreux P, Regnaux JP, Edouard P. Criteria for return to running after anterior cruciate ligament reconstruction: a scoping review. *Br J Sports Med*. 2018;52:1437-1444. https://doi.org/10.1136/bjsports-2017-098602
44. Risberg MA, Steffen K, Nilstad A, et al. Normative quadriceps and hamstring muscle strength values for female, healthy, elite handball and football players. *J Strength Cond Res*. 2018;32:2314-2323. https://doi.org/10.1519/JSC.0000000000002579
45. Ruas CV, Minozzo F, Pinto MD, Brown LE, Pinto RS. Lower-extremity strength ratios of professional soccer players according to field position. *J Strength Cond Res*. 2015;29:1220-1226. https://doi.org/10.1519/JSC.0000000000000766
46. Śliwowski R, Grygorowicz M, Hojszyk R, Jadczak Ł. The isokinetic strength profile of elite soccer players according to playing position. *PLoS One*. 2017;12:e0182177. https://doi.org/10.1371/journal.pone.0182177
47. Theoharopoulos A, Tsitskaris G, Nikopoulou M, Tsaklis P. Knee strength of professional basketball players. *J Strength Cond Res*. 2000;14:457-463. https://doi.org/10.1519/00124278-200011000-00014
48. Tourny-Chollet C, Leroy D. Conventional vs. dynamic hamstring-quadriceps strength ratios: a comparison between players and sedentary subjects. *Isokinet Exerc Sci*. 2002;10:183-192. https://doi.org/10.3233/IES-2002-0102
49. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169:467-473. https://doi.org/10.7326/M18-0850
50. van der Horst N, van Denderen R. Isokinetic hamstring and quadriceps strength interpretation guideline for football (soccer) players with ACL reconstruction: a Delphi consensus study in the Netherlands. *Sci Med Footb*. In press. https://doi.org/10.1080/24733938.2021.2024592
51. van Dyk N, Bahr R, Burnett AF, et al. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *Br J Sports Med*. 2017;51:1695-1702. https://doi.org/10.1136/bjsports-2017-097754
52. van Melick N, Hoogeboom TJ, Pronk Y, et al. Less than half of ACL-reconstructed athletes are cleared for return to play based on practice guideline criteria: results from a prospective cohort study. *Int J Sports Phys Ther*. 2006;15:1006-1018.
53. 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. https://doi.org/10.1136/bjsports-2015-095898
54. van Melick N, van Rijn L, Nijhuis-van der Sanden MWG, Hoogeboom TJ, van Cingel REH. Fatigue affects quality of movement more in ACL-reconstructed soccer players than in healthy soccer players. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:549-555. https://doi.org/10.1007/s00167-018-5149-2
55. Voutselas V, Papanikolaou Z, Soulas D, Famisis K. Years of training and hamstring-quadriceps ratio of soccer players. *Psychol Rep*. 2007;101:899-906. https://doi.org/10.2466/pr0.101.3.899-906
56. Welling W, Benjaminse A, Lemmink K, Dingenen B, Gokeler A. Progressive strength training restores quadriceps and hamstring muscle strength within 7 months after ACL reconstruction in amateur male soccer players. *Phys Ther Sport*. 2019;40:10-18. https://doi.org/10.1016/j.ptsp.2019.08.004
57. 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. https://doi.org/10.2519/jospt.2017.7285
58. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44:1861-1876. https://doi.org/10.1177/0363546515621554
59. Wik EH, Mc Auliffe S, Read PJ. Examination of physical characteristics and positional differences in professional soccer players in Qatar. *Sports (Basel)*. 2018;7:9. https://doi.org/10.3390/sports7010009
60. World Health Organization. Adolescent health. Available at: https://www.who.int/health-topics/adolescent-health/#tab=tab_1. Accessed January 12, 2021.
61. Xergia SA, Pappas E, Georgoulis AD. Association of the single-limb hop test with isokinetic, kinematic, and kinetic asymmetries in patients after anterior cruciate ligament reconstruction. *Sports Health*. 2015;7:217-223. https://doi.org/10.1177/1941738114529532
62. Zabka FF, Valente HG, Pacheco AM. Isokinetic evaluation of knee extensor and flexor muscles in professional soccer players. *Rev Bras Med Esporte*. 2011;17:189-192. https://doi.org/10.1590/S1517-86922011000300008
63. Zvijac JE, Toriscelli TA, Merrick WS, Papp DF, Kiebzak GM. Isokinetic concentric quadriceps and hamstring normative data for elite collegiate American football players participating in the NFL Scouting Combine. *J Strength Cond Res*. 2014;28:875-883. https://doi.org/10.1519/JSC.0b013e3182a20f19

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