Isokinetic muscle strength and readiness to return to sport following anterior cruciate ligament reconstruction: is there an association? A systematic review and a protocol recommendation

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ABSTRACT

Introduction Following anterior cruciate ligament reconstruction (ACLR), strength is a key variable in regaining full function of the knee. Isokinetic strength is commonly used as part of the return to sport (RTS) criteria.

Aim We systematically reviewed the isokinetic strength evaluation protocols that are currently being used following ACLR. A secondary aim was to suggest an isokinetic protocol that could meet RTS criteria.

Method Articles were searched using ScienceDirect, PubMed and Sage Journals Online, combined with cross-checked reference lists of the publications. Protocol data and outcome measurements and RTS criteria were extracted from each article included in the review.

Results 39 studies met the inclusion criteria and reported their isokinetic strength evaluation protocol following ACLR. The variables that were most commonly used were concentric/concentric mode of contraction (31 studies), angular velocity of 60°/s (29 studies), 3–5 repetitions (24 studies), range of motion of 0–90° (6 studies), and using gravity correction (9 studies). 8 studies reported strength limb symmetry index scores as part of their RTS criteria.

Conclusions There was no standardised isokinetic protocol following ACLR; isokinetic strength measures have not been validated as useful predictors of successful RTS. We propose a standard protocol to allow consistency of testing and accurate comparison of future research.

INTRODUCTION

Injury to the anterior cruciate ligament (ACL) is a common acute knee injury in sports and it provides many challenges to clinicians and researchers.[1] ACL reconstruction (ACLR) surgery is common among athletes who want to return to sport (RTS).[2–4] After ACLR, athletes have demonstrated muscle strength deficit, decreased stability and force attenuation for up to 2 years after reconstruction[3 5–9] and this may influence future knee injury risk.[10 11]

In total 6 to 27% of athletes who RTS after ACLR sustain a new ACL injury (to the same or opposite knee) within 10 years postsurgery.[12–15] As muscle strength deficit has been associated with the potential risk of future knee injury, increasing muscle strength of the quadriceps and hamstrings is a key factor for successful RTS after ACLR surgery.[16–19] Strength evaluation tests following ACLR are commonly performed as part of a battery of tests in clinical and research settings.[20 21] Isokinetic dynamometry provides an objective measure of muscle strength and is used in sport, research and clinical settings.[20 21] A criticism of isokinetic dynamometry is that it lacks functional relevance to sporting and training situations. However, it is considered the 'gold standard' for measuring muscle strength[22] and its convenience, reproducibility and reliability support its use as an appropriate method of assessment after ACLR.[22–24] Two key aspects to indicate knee strength following ACLR surgery are limb symmetry index of the injured and uninjured leg, and hamstring to quadriceps (H/Q) ratios of the injured leg. These measures have commonly been referred to and used as part of the RTS criteria.[2 17 25]

Part of successful rehabilitation is to return the patient to 'normal' strength. 'Normal' limb symmetry index values are reported to be between >70–90%,[2 26 27] while a 'normal' H/Q ratio has been reported to be between 0.5 and 0.8.[28 29] Many clinicians, therefore, aim to return the patient back to these values and use these values as part of their RTS criteria.[28] However, the torque production and results may be affected by aspects of the isokinetic protocol[16] (including modes of contraction, angular velocity, range of motion, number of repetitions and gravity correction).[30–32]

The protocols used for isokinetic strength evaluation following ACLR are, therefore, important factors to review when considering an athlete's readiness to RTS. The primary aim of this study was to systematically review and report the isokinetic strength evaluation protocols that are currently in use when assessing the muscle strength of patients who have undergone ACLR. The secondary aim is to suggest an appropriate strength evaluation protocol following ACLR in accordance with the RTS criteria.

METHOD

Search strategy

Two authors (MU, CC) conducted a systematic literature search of the ScienceDirect, PubMed, and Sage Journals Online databases, combined with cross-checked reference lists of the publications using PRISMA guidelines.[33] The literature search was performed between October and December 2013. Two main keywords, "anterior cruciate ligament reconstruction" and "isokinetic dynamometer", were used to search for articles. In each

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search, the two main keywords were followed by either "muscle strength" or "peak torque" or "limb asymmetry" or "return to sport".

Selection criteria

The selection criteria were determined by the lead author (MU) before commencing the article search. To be included in this review, the articles had to have (A) participants who had undergone ACLR surgery; (B) evaluated knee flexor and extensor isokinetic muscle strength up to 24 months following ACLR; (C) been published between January 1980 and October 2013 and (D) been published in English. Studies that assessed participants who had undergone ACLR revision or multiple-ligament reconstruction were excluded. If an article evaluated knee flexors or knee extensors only, these were excluded. Testing of both knee extensors and flexors were included, as both quadriceps and hamstrings have been reported to play a crucial role in the knee function following ACLR[5 6 8] and both are reported as the most commonly used graft-harvesting sites for ACLR.[3 5–9] Articles that evaluated strength at more than 24 months following ACLR were excluded, as strength deficiencies are seen up to 24 months following ACLR.[3 5 6 9] Articles were also excluded if isokinetic muscle strength was tested lying down rather than when seated, and if data were repeated in another article already included in the review.

The title and abstract of each study were reviewed first and if it was not clear whether a study was appropriate for inclusion, the full text of the article was examined. The selection criteria were applied by two independent reviewers (MU, CC). Consensus was used to resolve any disagreements between reviewers, with a third reviewer (BM) consulted if consensus was not achieved.

Data extraction and analysis

Data was extracted from included papers by the lead author (MU). Data identified for descriptive analysis included the isokinetic dynamometer protocol and isokinetic outcome measures. Specifically, data pertained to modes of contraction, angular velocity, number of repetitions, set range of motion and if gravity correction was used. The outcome measurements were peak torque and total work, and the limb symmetry index, H/Q ratio and/or magnitude of the strength outcome measure. Articles that reported RTS criteria in their rehabilitation protocol or reported recommended values for RTS in their article were included as the second aim of the review. The limb symmetry index values and H/Q ratios were extracted for these articles. These values were then reviewed and related to the strength evaluation protocols.

Assessment for risk of bias

The studies included in the systematic review were of different methodological design. The Downs and Black[34] checklist was used for assessing methodological quality because it is appropriate for determining the quality of both randomised and non-randomised studies.[35] The Downs and Black[34] checklist comprises of 27 items and a maximum score of 32 can be obtained if all criteria are met. The checklist is divided into five sections where each article is assessed on its reporting, external validity, internal validity -bias, internal validity—confounding (selection bias) and power. The articles were divided into quality-level categories according to previous literature:[36] excellent (26–28), good (20–25), fair (15–19) and poor (≤14). The assessment of methodological quality was completed by the same two reviewers (MU, CC), independently.

RESULTS

A total of 548 published studies were identified in the original search of the databases and other resources. After duplicates were removed, 263 studies were screened through titles and abstracts. Seventy-five remaining studies were reviewed in full text and 36 of these studies were excluded: 15 studies evaluated strength at more than 24 months following ACLR, 8 studies evaluated knee flexors only, 9 evaluated knee extensors only, 1 study repeated data used in a previous study, 1 study evaluated strength lying down and 2 studies evaluated isometric strength only. A final yield of 39 studies[3 6–9 21 23 29 37–67] were included in this systematic review as presented in the flow chart (figure 1).

Methodological quality assessment scores ranged between scores of 12 and 26 of a possible 32 points (see online supplementary table S1), with a median score of 18. None of the papers were classified as excellent. Seven were classified as good,[43 45–47 53 55 66] 26 as fair[3 5–9 21 23 37–39 41 42 44 48–50 52 54 56 60–67] and 6 as poor.[29 40 51 57–59] Thirty studies did not include all important adverse events that could have an effect on the intervention reported (criterion 8),[5–7 9 21 23 29 38–40 42–52 54 56 57 59 60 63 64–67] 23 studies did not adequately describe the source population and how they were recruited (criterion 11 and 12),[3 5 6 8 21 37–40 42 44 48–52 54 57–60 64 65] 24 studies did not describe if the source population was recruited in the same time period (criterion 22),[3 8 9 23 29 37–42 44 48–52 54–58 63 64 66] and 29 studies did not report sample size calculation (criterion 27).[3 6–8 21 23 29 38–44 49–53 56–61 63–67] Other criterion, such as criterion 22 and 23, were not commonly fulfilled due to most studies not being randomised, while criterion 14 and 15 were not commonly reported due to lack of blinding.

Variables extracted for each study can be found in online supplementary table S2. Table 1 shows the number and percentage of studies reporting the protocol variables. All studies reported mode of contraction as concentric/concentric, where a patient completes concentric knee extension and flexion contractions, or concentric/eccentric, where a patient performs concentric knee extension and eccentric knee flexion. Mode of contraction and angular velocity were reported in all the studies reviewed, but not all studies reported all aspects of their protocols. Of the 39 studies, 11 (28%) did not report number of repetitions,[7 9 39 43 45 46 52 54 58 61 66] 25 (64%) did not report range of motion,[3 6–9 29 38 39 41 43 47–51 54 55 57 58 60 61 63 64–66] and 29 (74%) studies did not report if gravity correction was used.[3 6 7 9 21 29 37 38–45 47 49 50 53–55 57 58 60 61 64–67]

In table 2, the outcome measurements and results that were reported are presented. Peak torque was the most commonly reported, with 32 of 38 studies reporting it as one of the outcome measurements. One study did not report the outcome measure that they used.[41] All 39 studies reported their results as a limb symmetry index score, a H/Q ratio and/or a magnitude. Five (13%) reported magnitude only, that is, the studies only reported strength measures in their respective outcome measurement (torque and/or work) and did not compare injured and uninjured leg strength measures or H/Q ratios. Thirty-four studies (87%) reported their results as limb symmetry index and/or H/Q ratio. All 34 studies reported limb symmetry index scores, while only 6 (18%) reported H/Q ratio.

Fifteen studies (38%) reported strength as a component of their RTS criteria. Of these, eight studies used limb symmetry index as the RTS criterion. The limb symmetry index scores are reported in table 2, and show a variation from >70–90%. The remaining seven of these studies reported strength criteria as

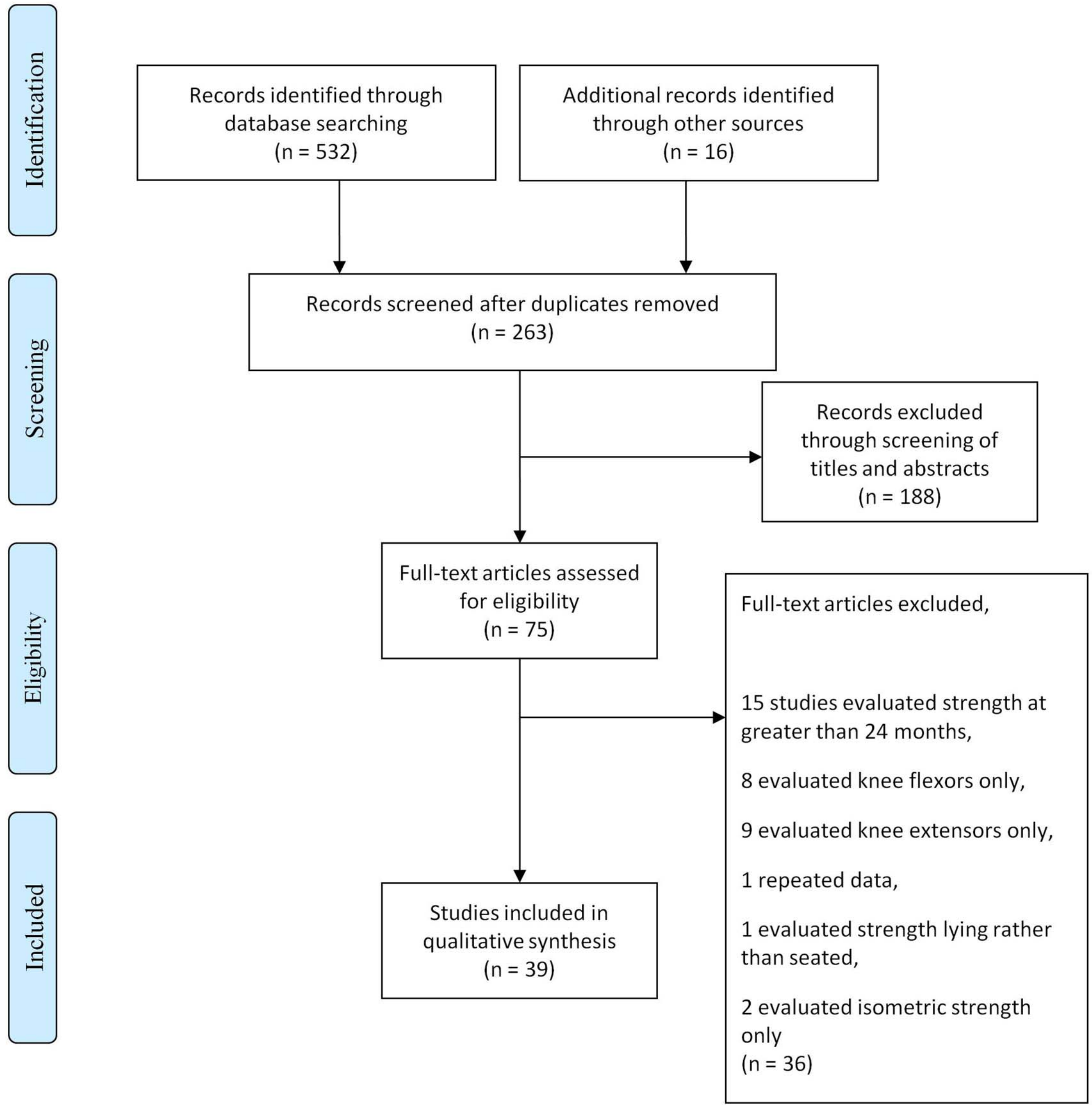

Figure 1 Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow chart of search and included and excluded studies.

returning to ‘normal’/‘adequate’/‘good’ or preoperation level of strength, rather than a specific score.

From 39 studies, 8 (21%) reported objective RTS strength criteria.[40 41 43 50 51 54 56 66] The protocol data, outcome measurements and RTS criteria for these studies are presented in table 3. All RTS criteria were reported as limb symmetry index scores.

DISCUSSION

We found no standardised isokinetic strength evaluation protocol following ACLR. If there is a need to objectively assess a patient's strength following ACLR, a requirement exists for a defined protocol. In this systematic review, mode of contraction, angular velocity, number of repetitions, range of motion and the use of gravity correction were the main variables that were extracted from each article.

Isokinetic strength evaluation protocol

Thirty-one studies (79%) used concentric mode of contraction for testing rather than using concentric and eccentric contractions. The mode of contraction significantly affects torque output. Eccentric torque output is significantly greater than concentric torque output and could, therefore, be misleading if indirectly compared.[68] In sports, concentric and eccentric contractions are performed, and therefore post-ACLR, testing concentric and eccentric strength could be important.

Previous research has reported that patients find the eccentric movement more difficult than the concentric movement[69 70] as it requires greater skill and motor control compared with concentric contraction, and as such may yield lower reliability and reproducibility.[69] Previous studies have shown a ‘very high’ and ‘high’ reproducibility and reliability for isokinetic concentric and eccentric knee extension and flexion; however, in all studies, the eccentric knee extension and flexion reliability and reproducibility is lower than the concentric.[24 69 70 71] Although the concentric mode of contraction is more commonly used in clinical and research settings,[40 59 66] it does not necessarily mean it is the better mode of contraction. However, due to its frequency of use, there is an abundance of comparable data.[3 6 7 9 21 29 37–41 43 44 48–51 53–62 64–67] If eccentric strength evaluation is used, a familiarisation session may be required to ensure good reliability and different RTS criteria may have to be considered.

Angular velocity influences both the torque and work output, and as such, should be considered when assessing strength and using it as part of the RTS criteria.[30 40 56 59] The two most common angular velocities reported were 60°/s and 180°/s in

Table 1 Strength evaluation protocol data used in studies (N (%))

Protocol	Studies (N (%))
Mode of contraction	
Concentric/concentric	31 (79)
Concentric/eccentric	8 (21)
Angular velocity (°/s)*	
30	1 (3)
60	29 (74)
90	3 (8)
120	5 (13)
180	18 (46)
230	1 (3)
240	11 (28)
270	1 (3)
300	7 (18)
450	1 (3)
Number of repetitions*	
3–5	24 (62)
6–10	7 (18)
>10	7 (18)
Not reported	11 (28)
Range of motion (°)*	
0–100	3 (8)
0–90	6 (15)
5–90	1 (3)
10–90	3 (8)
20–90	2 (5)
40–90	2 (5)
45–90	1 (3)
Not reported	25 (64)
Gravity correction	
Yes	9 (23)
No	1 (3)
Not reported	29 (74)

*Some studies used more than one test, therefore the total sum of percentages do not equal 100%.

29 (74%) and 18 (46%) studies, respectively. Abundant data exists for these selected velocities and have been shown to highlight strength deficits.[37 40 50 55 57 61 63 66] Torque output decreases as angular velocity increases above 60°/s, and the maximum torque output is shown to be between 0 and 60°/s.[72] For this reason, if the angular velocity that is used for strength evaluation is greater than 60°/s, strength deficiencies might not be highlighted. If strength deficiencies are not highlighted due to high angular velocity, it might be falsely assumed that the RTS strength criterion is achieved. It is, therefore, important to use an angular velocity that will consistently highlight strength deficiencies.

Other strength evaluation protocol data, such as number of repetitions, range of motion and the use of gravity correction, will also affect the outcome measures and depend largely on the previous protocol variables used. When reporting peak torque, five repetitions are recommended because peak torque is achieved at the fourth repetition.[73] By using five repetitions, there is a greater chance of recording the highest peak torque and less chance of fatigue. Maximal range of motion is recommended to allow the patient to maximise the isokinetic phase by reaching the preset angular velocity and achieve maximum voluntary activation.[74] Angular position can provide valuable information about the mechanical properties of the contracting muscle and range of motion can affect the peak torque output; therefore, it is important to set the same range of motion for each patient.[72] Finally, the use of gravity correction is important for reporting accurate strength results for the H/Q muscles.[11] If gravity correction is not used during concentric/concentric mode of testing, the quadriceps strength scores will decrease due to the upward motion acting against gravity and hamstrings strength scores will increase due to the downward motion acting with gravity.[75]

Table 2 Outcome measurements and results reported in studies (N (%))

Result measures	Studies (N (%))
Outcome measures*	
Peak torque	32 (82)
Total work	11 (28)
Peak torque and total work	9 (23)
Not reported	1 (3)
Results reported as*	
LSI and/or H/Q ratio	34 (87)
Magnitude of outcome measure only	5 (13)
*RTS strength criterion**	
LSI: (%)	
≥70–75	4 (10)
≥80–85	3 (8)
≥90–95	2 (5)
Not reported	31 (79)

*Some studies report more than one variable for the results, therefore the total sum of percentages do not equal 100%.
H/Q, Hamstring to Quadriceps; LSI, Limb Symmetry Index; RTS, return to sport.

Reporting outcome measures and results

Conventionally, isokinetic strength measures are reported as peak torque and/or total work.[20] Peak torque during isokinetic movements is a measure of the maximal force exerted during knee extension and flexion. Since it eliminates any submaximal repetitions, peak torque is a good measure of maximal strength.[76] Conversely, total work is a better measure of the endurance of the muscle.[52 72] In this review, peak torque was reported in 32 studies and total work was reported in 11 studies. The limb symmetry index scores in the studies reporting-specific RTS strength criteria were all reported using peak torque. Both peak torque and total work have shown to have high test-retest reliability and to be accurate measures of strength for knee extensors and flexors.[20 69 71 77] As peak torque is the most commonly used outcome measure when reporting limb symmetry index and H/Q ratio, an abundance of comparable data is available.[6 9 43 46 47 51–54 59] Peak torque should, therefore, be used as an outcome measure when considering the RTS strength criteria, though the importance of quadriceps and hamstring muscle endurance following ACLR and its role as part of RTS criteria should be further investigated. The limb symmetry index and H/Q ratio are dependent on the method of testing, and a change in the protocol variables, such as mode of contraction or angular velocity, will change the outcome measures and in turn, the results reported.[30–32 73]

RTS strength criteria

A secondary finding of the research was that although isokinetic strength is frequently measured in ACLR research, only 15 studies (38%) reported isokinetic strength as part of their RTS

Table 3 Isokinetic muscle strength evaluation protocol data, outcome measurements and results used in studies reporting RTS strength criteria

Study	Time of strength assessment postsurgery (months)	Mode of contraction	Angular velocity (°/s)	Gravity correction	Repetitions	Range of motion (°)	Outcome measurements	Isokinetic results reported as:	Isokinetic strength LSI RTS criteria (%)
Cardone *et al*[40]	2, 4, 6	Conc/conc	60, 180, 240	Not reported	4	20–90 (at 2 months postsurgery), 0–90	Peak torque, total work	LSI, magnitude	≥75
Carter and Edinger[41]	6	Conc/conc	180, 300	Not reported	5, 15	Not reported	Not reported	LSI	≥80
Feller and Webster[43]	4, 8, 12	Conc/conc	60, 240	Not reported	Not reported	Not reported	Peak torque	LSI	≥70
Keays *et al*[50]	6	Conc/conc	60, 120	Not reported	5	Not reported	Peak torque	LSI, magnitude	≥90
Kobayashi *et al*[51]	1, 6, 12, 24	Conc/conc	60, 180	Yes	5	Not reported	Peak torque	LSI	≥70 (quadriceps)
Osteras *et al*[54]	6	Conc/conc	60, 240	Not reported	Not reported	Not reported	Peak torque	LSI, magnitude	≥85 (quadriceps), ≥90% (hamstring)
Silva *et al*[56]	5	Conc/conc	60, 180	Yes	3	0–90	Peak torque	LSI, H/Q ratio, magnitude	≥85 (quadriceps)
Yuksel *et al*[66]	18–24	Conc/conc	60, 180	Not reported	Not reported	Not reported	Peak torque	LSI	>70

Conc, Concentric; H/Q, Hamstring to Quadriceps; LSI, Limb symmetry index; RTS, return to sport.

criteria. Of these 15 studies, 8 reported RTS isokinetic strength criteria, such as limb symmetry of the quadriceps and hamstring strength, but different desirable ranges of limb symmetry index were reported in these studies, indicating the variability in the RTS strength criteria being used.[40 41 43 50 51 54 56 66] Previous research has reported that the limb symmetry index varies between concentric and eccentric contractions.[47 52 63] These studies do not show if one mode of contraction highlights side-to-side differences more than the other and it might be beneficial to use both modes of contractions as it may highlight any asymmetries between the injured and uninjured leg. Seven of the studies used 60°/s as their lowest angular velocity, while one used 180°/s. The studies reported a desirable limb symmetry index that ranged from ≥70% to 90%. However, many studies report an increase in limb symmetry index with higher angular velocities.[7 29 30 45 59] This could mean that in some studies the RTS criterion was met more easily than in others.

'Normal' strength has been classified in relation to the strength of the uninjured limb; thus limb symmetry index scores are commonly reported following ACLR.[41] In this review, 34 (87%) studies reported their results as limb symmetry index scores and it was the only result included as a measure for strength RTS criterion. Barber-Westin and Noyes[16] concluded that a limb symmetry index of >90% should be reached before RTS, while Van Grinsven *et al*[19] reported that a limb symmetry index of >95% was required. In spite of this, of the eight studies[40 41 43 50 51 54 56 66] that reported limb symmetry values as part of their RTS criteria, only Cardone *et al*[40] reported if their RTS strength criterion predicted RTS. Their participants did not show any signs of difficulty on RTS, and they, therefore, suggested that a deficit of 25% in extension strength between injured and non-injured leg at an angular velocity of 60°/s is a reliable RTS criterion. This study, however, had a relatively short follow-up and did not extend its conclusion to hamstring strength. It cannot be assumed that any of these RTS strength criteria are reliable. Together, these findings highlight that isokinetic knee strength has not been sufficiently validated as a useful criterion measure for RTS.

Methodological considerations

A limitation of the current review is that due to the historical 33 year span of data (1980–2013), changes in surgical and rehabilitation practices (arthroscopic surgery, immediate weight-bearing, accelerated rehabilitation protocols) have occurred. These likely affected the isokinetic dynamometer protocols such as the specific angular velocity and range of motion protocols applied. Furthermore, inclusion criteria did not specify a minimum period post-ACLR at which the strength assessment occurred. However, studies which had a short time line post-ACLR testing, also tested at a time period of at least 5 months postsurgery.[7 29 40 43 45–47 49 51 56 57] Previous research has demonstrated intermanufacturer (Cybex, Kin-Com and Biodex) variance exists using the same protocol.[78 79] This highlights a further potential limitation that the review did not take into account the different types of isokinetic dynamometers utilised. Following the methodological quality assessment, a potential limitation was the studies' poor description of the source population and recruitment. One could hypothesise that this could affect the generalisability of the results. A final limitation is that the prospective relationship between strength measures and RTS outcomes has yet to be determined. Therefore, the secondary aim of suggesting an isokinetic strength protocol based on the RTS criteria was not possible to fulfil. Instead, we propose an isokinetic strength protocol based on those proposed in the current literature.

In summary, we propose the following protocol as the most valid assessment for RTS: five repetitions of concentric knee extension and flexion at an angular velocity of 60°/sec, at a set range of motion of 0–100°, using gravity correction, and measuring peak torque.

What are the new findings?

- The literature does not show a clear standardised strength evaluation protocol following anterior cruciate ligament reconstruction (ACLR).
- There is no consensus in the literature as to what is an appropriate return to sport (RTS) strength criteria following ACLR.
- The proposed standardised isokinetic strength protocol following ACLR includes five repetitions of concentric knee extension and flexion at 60°/s.

How might it impact on clinical practice in the near future?

- The proposed standard protocol can be used in prospective studies to analyse if isokinetic strength is associated with successful return to sport (RTS).
- It will standardise isokinetic assessment of the knee post-ACLR in clinical practice and enable effective comparison of data and the potential to share this across clinics.
- It may contribute to RTS criteria following ACLR.

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