**CRITICALLY APPRAISED TOPIC**

## FOCUSED CLINICAL QUESTION

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|---|
| In adult's s/p ACL reconstruction (P), is lower extremity strength training (I) or neuromuscular re-education (C) more effective in improving quadriceps and hamstring strength measured using an isokinetic dynamometer (O)? |

## AUTHOR


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|---|---|---|---|
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## CLINICAL SCENARIO

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|---|
| The patient is a 20-year-old female collegiate soccer player who tore her left anterior cruciate ligament after planting to shoot during competition. She started rehabilitation one-week post-ACL reconstruction at a clinic near her university and worked with her team's athletic trainers until the end of the school year. She presented to a new clinic two months s/p ACL reconstruction utilizing a patellar tendon graft, and demonstrated significant challenges with quadricep recruitment and patellar stability, causing gait abnormalities, significant quadriceps weakness, and delayed progress in therapy. In order to improve her lower extremity strength and reach her goal of returning to play at the start of her season in 6 months, I would like to know whether lower extremity strength training or neuromuscular re-education is more effective in improving quadriceps and hamstring strength assessed using an isokinetic dynamometer. |

## SUMMARY OF SEARCH

[Best evidence appraised and key findings]

Eight studies have met the inclusion and exclusion criteria, including 2 systematic reviews, 5 randomized controlled trials, and one case study.

- A neuromuscular training protocol, in combination with a standard strengthening protocol, may be more effective than a standard protocol in improving lower extremity muscle strength, based on significant differences in quadriceps and hamstring isokinetic strength at high angular speeds when comparing control and intervention groups.[1]
- Neuromuscular control exercises should be implemented in the plan of care of patients s/p ACL reconstruction- squats, lunges, ascending and descending stairs, jump landings, and single leg hops- to improve quadriceps and hamstring strength, as neuromuscular training alone can likely increase isokinetic strength.[1–3]
- While experimental groups receiving neuromuscular training typically demonstrated a greater percentage of change in isokinetic torque compared to strength training groups, neuromuscular training is less effective in improving lower extremity endurance, making it important to combine a standard strengthening protocol with neuromuscular training.[1,3,4]

## CLINICAL BOTTOM LINE

Adults who have undergone ACL reconstruction and are demonstrating quadriceps and/or hamstring weakness should follow a rehabilitation protocol that includes standard strengthening exercises and neuromuscular control exercises. Strengthening exercises are shown to increase lower extremity muscular endurance, while neuromuscular control exercises are beneficial in increasing lower extremity muscular endurance based on isokinetic dynamometer testing. These strength gains are correlated into increased knee function, such as improved balance, proprioception, and sport-related activities. Increases in strength were not noted prior to 6 months following surgery, making it important for patients to undergo rehabilitation for a minimum of 6 months to achieve improved isokinetic hamstring and quadriceps strength.

***This critically appraised topic has been individually prepared as part of a course requirement and has been peer-reviewed by one other independent course instructor***

*The above information should fit onto the first page of your CAT*

**SEARCH STRATEGY**

| **Terms used to guide the search strategy** | | | |
|---|---|---|---|
| **P**atient/Client Group | **I**ntervention (or Assessment) | **C**omparison | **O**utcome(s) |
| ACL reconstruction, ACL tear, ACL, ACL surgery, ACLR, Anterior cruciate ligament, Female, Adult, Patellar tendon | Strength*, Resistance train* | Neuromuscular re-education, Neuromuscular training, Neuromuscular | Hamstring strength, Quadriceps strength, Lower extremity strength, Isokinetic dynamometer |

**Final search strategy (history):**

PubMED

- ((((ACL reconstruction[Title/Abstract] OR ACL tear[Title/Abstract] OR ACL[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACLR[Title/Abstract] OR anterior cruciate ligament[Title/Abstract]) AND (female[Title/Abstract] AND adult[Title/Abstract])) AND (strength* OR resistance train*)) AND (neuromuscular OR neuromuscular re-education OR neuromuscular training)) AND (hamstring strength OR quadriceps strength OR lower extremity strength OR isokinetic dynamometer) (1 result)
- (((ACL[Title/Abstract] OR ACL reconstruction[Title/Abstract] OR anterior cruciate ligament[Title/Abstract] OR ACL rehabilitation[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACL tear[Title/Abstract]) AND (strength* OR resistance train*)) AND (neuromuscular re-education OR neuromuscular training OR neuromuscular)) AND (hamstring strength OR quadriceps strength OR lower extremity strength OR isokinetic dynamometer) (204 results)
- **(((ACL[Title/Abstract] OR ACL reconstruction[Title/Abstract] OR anterior cruciate ligament[Title/Abstract] OR ACL rehabilitation[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACL tear[Title/Abstract]) AND (strength* OR resistance train*)) AND (neuromuscular re-education OR neuromuscular training OR neuromuscular)) AND (hamstring strength OR quadriceps strength OR lower extremity strength OR isokinetic dynamometer) AND (female) (140 results)**
- **(((ACL[Title/Abstract] OR ACL reconstruction[Title/Abstract] OR anterior cruciate ligament[Title/Abstract] OR ACL rehabilitation[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACL tear[Title/Abstract]) AND (strength* OR resistance train*)) AND (neuromuscular re-education OR neuromuscular training OR neuromuscular)) AND (hamstring strength OR quadriceps strength OR lower extremity strength OR isokinetic dynamometer) AND (female) AND (patellar tendon) (11 results)**
- (((ACL[Title/Abstract] OR ACL reconstruction[Title/Abstract] OR anterior cruciate ligament[Title/Abstract] OR ACL rehabilitation[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACL tear[Title/Abstract]) AND (strength* OR resistance train*)) AND (neuromuscular re-education OR neuromuscular training OR neuromuscular)) AND (hamstring strength OR quadriceps strength OR lower extremity strength) AND (isokinetic dynamometer) AND (female) AND (patellar tendon) (1 result)
- (((ACL[Title/Abstract] OR ACL reconstruction[Title/Abstract] OR anterior cruciate ligament[Title/Abstract] OR ACL rehabilitation[Title/Abstract] OR ACL surgery[Title/Abstract] OR ACL tear[Title/Abstract]) AND (strength* OR resistance train*)) AND (neuromuscular re-education OR neuromuscular training OR neuromuscular OR propriocept*)) AND (hamstring strength OR quadriceps strength OR lower extremity strength) AND (isokinetic dynamometer) AND (female) AND (patellar tendon) (2 results)

PEDro

- **Abstract & Title: ACL reconstruction strength**
- **Problem: muscle weakness**
- **Body Part: lower leg or knee**
- **(47 results)**

Cochrane

- "anterior cruciate ligament reconstruction" in Title Abstract Keyword OR ACL reconstruction in Title Abstract Keyword OR ACL surgery in Title Abstract Keyword AND strength OR resistance training in All Text AND lower extremity strength OR isokinetic dynamometer in All Text (7 results)
- **"anterior cruciate ligament reconstruction" OR ACL reconstruction OR ACL surgery in Title Abstract Keyword AND "patellar tendon" in All Text AND strength OR resistance training in All Text AND lower extremity strength OR isokinetic dynamometer OR quadriceps strength OR hamstring strength in All Text NOT ACL repair in All Text - (Word variations have been searched) (7 results)**
- "anterior cruciate ligament reconstruction" OR ACL reconstruction OR ACL surgery in Title Abstract Keyword AND "patellar tendon" in All Text AND strength OR resistance training in All Text AND lower extremity strength OR quadriceps strength OR hamstring strength in All Text AND isokinetic dynamometer in All Text - (Word variations have been searched)

*In the table below, show how many results you got from your search from each database you searched.*

| Databases and Sites Searched | Number of results | Limits applied, revised number of results (if applicable) |
|---|---|---|
| PubMED | First Search: 25 (narrowed from 140)<br><br>Second Search: 11 | First Search: systematic review, randomized controlled trial, & meta-analysis |
| PEDro | 47 | N/A |
| Cochrane | 7 | N/A |

**INCLUSION and EXCLUSION CRITERIA**

| **Inclusion Criteria** |
|---|
| - All levels of evidence<br>- Patient population who has undergone ACL reconstruction and is 18+ years old<br>- Use of at least 1 knee-related outcome measure related to lower extremity strength<br>- Interventions must include neuromuscular re-education exercises or a general strengthening protocol |
| **Exclusion Criteria** |
| - Studies not published in English<br>- Studies not comparing neuromuscular re-education interventions to strengthening exercises<br>- Literature published prior to 2000<br>- Poster Presentations<br>- Narrative review articles |

**RESULTS OF SEARCH**

**Summary of articles retrieved that met inclusion and exclusion criteria**

*For each article being considered for inclusion in the CAT, score for methodological quality on an appropriate scale, categorize the level of evidence, indicate whether the relevance of the study PICO to your PICO is high/mod/low, and note the study design (e.g., RCT, systematic review, case study).*

| Author (Year) | Risk of bias (quality score)* | Level of Evidence** | Relevance | Study design |
|---|---|---|---|---|
| Kaya (2019)[1] | PEDro (9/11) | Level 1b | High | RCT |
| Risberg (2007)[3] | PEDro (10/11) | Level 1b | High | Single-blind RCT |
| Liu-Ambrose (2003)[2] | PEDro (5/11) | Level 1b | Moderate | Single-blind RCT |
| Cooper (2005)[5] | PEDro (9/11) | Level 1b | Moderate | Single-blind RCT |
| Risberg (2004)[6] | AMSTAR (3/11) | Level 1a | Moderate | Systematic Review |
| Sweeney (2020)[7] | JBI (7/8) | Level 4 | Low | Case Study |
| Pistone (2016)[8] | PEDro (8/11) | Level 1b | Low | RCT |
| Kruse (2012)[4] | AMSTAR (8/11) | Level 2a (includes a cohort study) | Moderate | Systematic Review |

*Indicate tool name and score

**Use Portney & Watkins Table 16.1 (2009); if downgraded, indicate reason why

**BEST EVIDENCE**

The following 2 studies were identified as the 'best' evidence and selected for critical appraisal. Rationale for selecting these studies were:

- The 2007 single-blind randomized controlled trial by Risberg et al. was chosen as best available evidence due to the high level of evidence, quality score, and relevance. This study directly compares the interventions in the PICO question- strength training versus neuromuscular re-education- and provides clinical recommendations for exercises to improve hamstring and quadricep strength in patient's s/p ACL reconstruction. The participant inclusion criteria only included those with a patellar tendon graft, further improving the relevance. The strength results and provided statistics based on isokinetic dynamometer testing between the control and intervention groups can be used by clinicians to implement effective and specific strengthening interventions to improve lower extremity strength and coordination required for activities of daily living and sport specific movements. The level 1b evidence has a low risk for bias based on the PEDro assessment tool (10/11), improving confidence in the results provided.
- The 2019 randomized controlled trial by Kaya et al. was chosen as second-best available evidence for this specific clinical question because of the high relevance, as it directly compares the efficacy of a standard strengthening protocol to a standard strengthening protocol + neuromuscular control exercises to determine the efficacy of improving quadriceps and hamstring strength based on isokinetic dynamometer testing. The researchers recruited adult age participants who had undergone ACL reconstruction in the past two years, however, only male subjects were included in this study. Additionally, participants were not athletes and the study did not recruit participants solely with a patellar tendon graft, potentially impacting the results. The results of this study allow clinicians to prescribe the most effective interventions to improve the patient's lower extremity strength with a goal of returning to prior level of function. This is level 1b evidence and has a low risk of bias on the PEDro scale (9/11), but has the potential to be more biased than the evidence presented by Risberg et al.

**SUMMARY OF BEST EVIDENCE**

**(1) Description and appraisal of (Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: a randomized clinical trial) by (Risberg, 2007)**

| **Aim/Objective of the Study/Systematic Review:** |
|---|
| The objective of the study conducted by Risberg et al was to compare the Cincinnati Knee Scores (CKRS), visual analog scale (VAS) scores for global knee function and pain, and strength between two ACL rehabilitation interventions groups, a traditional strength training (ST) group and a neuromuscular training (NT) group, after a 6-month training program. |
| **Study Design**<br>[e.g., systematic review, cohort, randomised controlled trial, qualitative study, grounded theory. Includes information about study characteristics such as blinding and allocation concealment. When were outcomes measured, if relevant]<br>Note: For systematic review, use headings 'search strategy', 'selection criteria', 'methods' etc. For qualitative studies, identify data collection/analyses methods. |
| This study by Risberg et al. is a single-blinded randomized controlled trial consisting of 74 participants who had undergone ACL reconstruction surgery at Ullevaal Hospital, using a bone-patellar tendon-bone (B-PT-B) graft. After computer-generated randomization, group allocation was concealed from the outcome assessor, participants, and physical therapist until the time of treatment, using a series of opaque envelopes. The participants were assigned to one of two groups, a traditional strength training program or a neuromuscular training program, with the goal of determining key functional outcomes between the groups after their six-month rehabilitation program. These outcomes included the CKRS, VAS for pain and function, the 36-Item Short-Form Health Survey (SF-36), hop tests, isokinetic muscle strength, proprioception, and static and dynamic balance tests. All subjects were hospitalized 1-3 days following surgery, then completed a home exercise program prior to starting rehabilitation at the outpatient clinic, with an emphasis on restoring full range of motion (ROM) and reducing swelling. Both NT and ST programs started one week after surgery, with sessions occurring 2-3 times a week for 6 months. Compliance was defined as participants attending at least 2 sessions a week (80% of the recommendation). The study was chosen to be 6 months because this is the typical rehabilitation protocol following an ACL replacement in Norway, which is covered by the social security system. The NT program was divided into 6 phases, each lasting 3-5 weeks and consisted of balance exercises, plyometric exercises, agility drills, and sport-specific exercises, with additional interventions as |

needed for pain and swelling (i.e cryotherapy, patellofemoral taping, and ROM exercises). The ST program primarily consisted of lower extremity strengthening exercises based on American College of Sports Medicine (ACSM) recommendations, with emphasis placed on strengthening the quadriceps, hamstrings, gluteus medius, and gastrocnemius. The ST program was divided into 4 phases, progressing from prone and supine exercises in phase 1, to weight bearing exercises as pain and swelling reduced. Two experienced physical therapists conducted the preoperative and follow-up assessments at 3 and 6 months and were blinded to the group allocation. The ST and NT groups received therapy at separate outpatient clinics and were treated by a team of two physical therapists. Both groups were asked to keep a training log that included all therapy visits, duration of each visit, and additional time spent exercising outside of the clinic.

**Setting**

[e.g., locations such as hospital, community; rural; metropolitan; country]

This participants in this study were recruited prior to ACL reconstruction surgery at Ullevaal Hospital in Oslo, Norway. Rehabilitation and data collection for the ST program occurred at the Norwegian Sport Medicine Clinic, and rehabilitation and data collection for the NT program took place at the Department of Physical Medicine and Rehabilitation at Ullevaal University Hospital.

**Participants**

[N, diagnosis, eligibility criteria, how recruited, type of sample (e.g., purposive, random), key demographics such as mean age, gender, duration of illness/disease, and if groups in an RCT were comparable at baseline on key demographic variables; number of dropouts if relevant, number available for follow-up]

Note: This is not a list of the inclusion and exclusion criteria. This is a description of the actual sample that participated in the study. You can find this descriptive information in the text and tables in the article.

There were 74 participants in this study who underwent ACL reconstruction at the same hospital using a B-PT-B graft. Subjects were recruited at Ullevaal Hospital in Oslo, Norway when they were scheduled for surgery. There were 27 females and 47 males included in the study, with a mean age of 28.4 years (range of 16.7 to 40.3 years). Participants were excluded from the study if they did not live close enough to the outpatient clinics to participate in rehabilitation, if their ACL tear occurred more than 3 years prior to surgery, if they required a meniscal repair, if they had a previous knee injury or surgery to either knee, or if there was evidence of degenerative arthritis in the subchondral bone. Upon discharge from the hospital following reconstruction, participants were randomly assigned to one of two rehabilitation programs. The NT group had 13 females with an average age of 27.2 and 26 males with an average age of 27.7, and the ST group had 14 females with an average age of 26.5 and 21 males with an average age of 31.2. Of the 74 participants recruited at the start of the study, after 3 months 67 participants (92%) returned for a follow-up examination, and after 6 months 65 participants (89%) returned for their follow-up.

**Intervention Investigated**

[Provide details of methods, who provided treatment, when and where, how many hours of treatment provided]

*Control*

This randomized controlled trial aimed at determining the efficacy of a traditional strength training program compared to a neuromuscular training program on functional knee outcomes, including strength. The traditional strength training program was the control group, as there is substantial research behind strength training but very little research behind implementing neuromuscular control into ACL rehabilitation protocols, although neuromuscular control likely improves functional movement patterns and is shown to reduce the risk of re-injury. Two physical therapists provided treatment to this group 2-3 times a week for 6 months at an outpatient clinic. Additionally, this group averaged 57.6 visits and spent on average 62.9 hours in the outpatient clinic.

*Experimental*

The goal of this study was to provide more evidence supporting or opposing the implementation of neuromuscular training in ACL rehabilitation protocols, as there had previously only been 2 randomized controlled trials conducted to assess knee functional outcomes after an NT or ST program. Risberg at al. hypothesized participants in the NT program would demonstrate superior knee function after rehabilitation compared to ST subjects. This experimental group received therapy from two physical therapists at an hospital-based outpatient clinic 2-3 times a week for 6 weeks. The NT group averaged a significantly lower number of visits than the ST group, with a mean of 42.2 visits and an average of 43.8 minutes spent in the clinic. The NT program included 6 phases, including early postoperative phase (goal of reducing swelling and regaining full ROM), walking phase, balance and dynamic joint stability phase, muscle strength phase, running phase, jumping phase, and plyometric and agility training phase.

**Outcome Measures**

[Give details of each measure, maximum possible score and range for each measure, administered by whom, where]

The primary outcome measure analysed in this study was knee function using the Cincinnati Knee Score (CKRS). This standardized self-reported outcome measure was specifically designed to assess outcomes following ACL reconstruction.[9] It is well-validated and reliable, with an intraclass correlation coefficient (ICC) of 0.88 for test re-test reliability. An ICC of 0.75-0.9 indicates good reliability.[10] The maximum score is 100, indicating full knee function. The questionnaire includes domains including pain, swelling, giving way, general activity level, walking, stair climbing, running, jumping, and twisting activities. The sample size for this study was determined based on the results of a previous study utilizing the CKRS and was considered to be clinically relevant. It was determined that a minimum of 72 participants needed to be included to detect a difference with a power of 90% and a p-value <0.05, using a standard deviation of 13 in the power calculation based on a previous study. The minimal clinically important difference (MCID) of the CKRS is 14.0 6 months following ACL reconstruction.[11]

Secondary outcome measures included:

- Hamstring and quadriceps strength were measured using a Cybex 6000 isokinetic dynamometer
    - The test protocol consisted of 5 repetitions at an angular velocity of 60 degrees per second to test muscle strength, a 1-minute rest break, then 30 repetitions at 240 degrees per second to measure muscular endurance. This protocol was performed on each leg to analyze strength differences between the injured and uninjured leg.
    - Total work was calculated for each participant based on these measurements using the strength index: (injured leg strength/non-injured leg strength) *100
    - Isokinetic muscle testing shows good to high reliability based on ICC's ranging from 0.81-0.97.
- Pain and knee function were assessed using a VAS for pain intensity and a second VAS for global knee function
    - To quantify pain, participants were asked to rank their score from 0-100 during or immediately after activity. 0 represented no pain, while 100 represented intolerable pain. The same scale was used for self-reported knee function, with 0 representing no knee function and 100 representing pre-injury knee function.
    - Reliability of VAS measures appears to be high, with 90% of pain ratings within 9 points and 95% within 16 points. The ICC is 0.97 and 95% CI = 0.96-0.98.[12]
- Health related quality of life was measured using the SF-36
    - The 8 domains assessed on this self-reported outcome measure include physical function, physical role limitations, emotional role limitations, bodily pain, general health, vitality, social function, and mental health. Each domain is scored on a scale of 0-100, with a higher score representing better health and quality of life.
    - The internal consistency of this outcome measure is good, with the Cronbach alpha exceeding 0.70 for group comparisons and >0.90 for comparisons within the physical function domain.
- Static and dynamic balance were evaluated using a KAT2000 platform
    - This device is inflated with air to modify test difficulty and allow for normalization based on each participants body weight. Balance is recorded using a computerized tilt sensor that records position on the platform and deviation from the reference position 18.2 times per second.
    - Each participant completed a single leg static balance test on the injured and uninjured legs and a double leg dynamic balance test. Each of these tests consisted of three trials with no practice trials allowed.
- Proprioception was assessed using a threshold to detection of passive motion (TTDPM) device
    - Each participant's starting position was at 15 degrees of knee flexion, followed by the knee moving into into flexion and extension at a constant angular velocity of 0.5 degrees per second. After knee movement, the participant was asked to identify if the knee had been moved into flexion or extension. This was conducted on each leg, with three repetitions on each leg.
    - The TTDPM device demonstrates good reliability, with an ICC of 0.83.
- Knee performance was assessed by administering functional tests, including a one-leg hop test, triple jump test, and stair hop test
    - The one-leg hop and triple jump tests were performed two times on each leg, and for the stair hop test participants hopped up and down 22 steps on one leg then repeated on the other leg.
    - Comparisons were made between the injured and uninjured leg using the formula: (injured leg/uninjured leg) * 100
    - The one-leg hop test has excellent reliability, with an ICC of 0.97.
    - The triple jump test has good reliability, with an ICC ranging from 0.81 to 0.97.

Each of these outcome measures were administered by two experienced physical therapists who were blinded to the group allocation. Outcome measures were performed preoperatively, at a 3-month follow-up, and at a 6-month follow-up at the clinics where they were receiving therapy- the Norwegian Sport Medicine Clinic for the ST group and the Department of Physical Medicine and Rehabilitation at Ullevaal University Hospital for the NT group.

**Main Findings**

[Provide summary of mean scores/mean differences/treatment effect, 95% confidence intervals and p-values etc., where provided; you may calculate your own values if necessary/applicable. You may summarize results in a table but you must explain the results with some narrative.]

**Neuromuscular Versus Strength Training After ACL Reconstruction**

**Table.**
Mean (SD) Outcome Measurements for the Strength Training (ST) Group and the Neuromuscular Training (NT) Group Preoperatively and 3 and 6 Months Postoperatively[a]

| | Preoperative (n=74) | | 3 mo (n=67) | | 6 mo (n=65) | |
|---|---|---|---|---|---|---|
| | ST Group (n=35) | NT Group (n=39) | ST Group (n=31) | NT Group (n=36) | ST Group (n=31) | NT Group (n=34) |
| KT-1000 (mm difference) | 7.9 (3.6) | 7.2 (4.3) | 2.6 (2.9) | 2.9 (2.8) | 3.0 (2.9) | 3.4 (2.6) |
| Cincinnati Knee Score | 65.3 (13.0) | 65.2 (17.0) | 61.4 (11.7) | 64.3 (11.5) | 73.4 (9.6) | 80.5 (12.3)[b] |
| VAS for pain during activity (mm) | 35.4 (23.3) | 35.2 (26.5) | 25.9 (18.6) | 31.8 (22.6) | 24.6 (20.3) | 20.7 (21.0) |
| VAS for knee function (mm) | 33.9 (25.3) | 39.1 (25.5) | 51.7 (26.0) | 50.1 (23.8) | 59.3 (23.1) | 72.4 (22.1)[c] |
| Triple jump test (%) | 94.6 (10.2) | 91.8 (12.3) | | | 83.1 (15.4) | 88.5 (10.4) |
| One-leg hop test (%) | 93.7 (11.3) | 90.1 (15.5) | | | 81.0 (18.2) | 84.9 (10.9) |
| Stairs hop test (%) | 84.8 (18.1) | 78.4 (21.0) | | | 79.8 (16.4) | 79.8 (25.7) |
| Balance index, static, uninvolved leg[d] | 566 (266) | 557 (246) | 509 (170) | 457 (218) | 443 (156) | 433 (168) |
| Balance index, static, involved leg[d] | 602 (258) | 592 (311) | 532 (211) | 455 (170) | 460 (159) | 445 (191) |
| Balance index, dynamic[d] | 1,100 (451) | 947 (266) | 911 (335) | 850 (311) | 917 (394) | 769 (235) |
| Proprioception[e] (TTDPM), uninvolved leg (°) | 1.22 (0.67) | 1.19 (0.66) | 1.13 (0.45) | 1.04 (0.52) | 1.21 (0.52) | 1.22 (0.86) |
| Proprioception[e] (TTDPM), involved leg (°) | 1.14 (0.74) | 1.02 (0.52) | 1.39 (0.90) | 1.13 (0.45) | 1.22 (0.52) | 1.20 (0.76) |
| Flexion total work 60°/s (%) | 80.6 (19.5) | 82.9 (20.4) | | | 88.3 (14.4) | 86.3 (14.3) |
| Flexion total work 240°/s (%) | 87.6 (18.4) | 86.8 (24.2) | | | 94.7 (16.1) | 90.8 (21.1) |
| Extension total work 60°/s (%) | 79.0 (18.0) | 79.4 (20.6) | | | 67.3 (16.1) | 79.1 (17.1) |
| Extension total work 240°/s (%) | 84.7 (12.8) | 83.7 (17.9) | | | 78.0 (16.0) | 79.0 (16.8) |

[a] There were significantly improved Cincinnati Knee Scores and visual analog scale (VAS) scores for knee function at 6 months in the NT group compared with the ST group. TTDPM=threshold to detection of passive motion.
[b] $P=.05$.
[c] $P=.02$.
[d] Total number of subjects=51.
[e] Total number of subjects=47.

| Statistical Analysis of Isokinetic Strength 6 months Post-op (ST vs. NT Programs) | | |
|---|---|---|
| Isokinetic Motion | Cohen's d | P-value* |
| Flexion total work $60^0$/s (%) | 0.14 (small effect) | 0.58 (not significant) |
| Flexion total work $240^0$/s (%) | 0.21 (medium effect) | 0.41 (not significant) |
| Extension total work $60^0$/s (%) | 0.71 (medium-high effect) | 0.01 (significant) |
| Extension total work $240^0$/s (%) | 0.06 (small effect) | 0.8 (not significant) |

*p-value based on 95% confidence interval

When comparing preoperative ST and NT groups, there were no significant differences at baseline. The authors of this study solely reported the mean and standard deviation of each outcome measure prior to surgery and at the 3- and 6-month follow-ups. To gain more conclusive insight into the statistical significance of these results to determine the most effective intervention group, I have calculated the effect size and p-values of each isokinetic strength measurement. The effect size (cohen's d) and statistical significance (p-value) were calculated between the ST and NT groups to determine the efficacy of each intervention program on hamstring and quadriceps isokinetic muscular strength and endurance 6-months after ACL reconstruction. Based on the effect size and statistical significance calculations, implementing a NT program compared to a ST program is not superior in improving flexion muscular strength (flexion total work $60^0$/s), flexion muscular endurance (flexion total work $240^0$/s), or extension endurance (extension total work $240^0$/s) after a 6-month rehabilitation program. However, NT rehabilitation interventions are shown to significantly increase extension muscular strength after 6 months of rehabilitation based on the medium-high effect size (cohen's d = 0.71) and statistical significance (p = 0.01).

**Original Authors' Conclusions**

[Paraphrase as required. If providing a direct quote, add page number]

Risberg et al concluded there were no significant differences between the NT and ST programs for any of the isokinetic strength tests performed after 6-months of rehabilitation, but it is likely strength measures would have demonstrated greater increases with extra emphasis on plyometric exercises in addition to the prescribed protocol. While there was not a significant difference in isokinetic strength between the two groups, the NT group demonstrated significantly higher scores on the CKRS and VAS global knee functioning scale when compared to the ST group.

**Critical Appraisal**

**Validity**

[Summarize the internal and external validity of the study. Highlight key strengths and weaknesses. Comment on the overall evidence quality provided by this study.]

This randomized controlled trial is level 1b evidence and scored a 10/11 on the PEDro risk of bias tool. This score indicates low risk for bias and high internal validity. One of the main strengths of this study in relation to the clinical question is the high relevance to the patient population, as all participants included in this study were undergoing rehabilitation within their first 6-months following ACL reconstruction and all participants surgeries utilized a B-PT-B graft like the patient in the clinical scenario. Additionally, the aim of the study directly answered the clinical question and allows for implementation of a NT program based on the clinical reasoning provided. Using an objective strength measure, like the dynamometer, versus a more subjective measure, like manual muscle testing increased interrater reliability and made the results more reproducible. The primary limitation in this study involves the rehabilitation protocols, which could have likely caused a type 2 error. Both protocols involved similar exercises and there was likely overlap between the two programs with the ST group utilizing some NT exercises and the NT group participating in some ST exercises. Another limitation in this study is the rehabilitation locations, as the NT program completed therapy at a smaller outpatient clinic with less equipment than the ST group. To gain more conclusive evidence into the efficacy of these two programs on strength and other secondary outcome measures assessed, power calculations should have been provided in addition to the CKRS.

**Interpretation of Results**

[This is YOUR interpretation of the results taking into consideration the strengths and limitations as you discussed above. Please comment on clinical significance of effect size / study findings. Describe in your own words what the results mean.]

Based on the statistical significance and effect size, NT interventions are effective in improving quadriceps muscular strength when compared to a standard ST program based on the p-value of 0.01 ($p<0.05$). Hamstring strength and quadriceps muscular endurance does not demonstrate significant improvements when comparing the NT and ST programs, but implementing NT interventions could be beneficial in improving quadriceps muscular strength after 6-month. The results are unknown after 3 months due to lack of isokinetic testing at the 3-month follow-up.

**Applicability of Study Results**

[Describe the relevance and applicability of the study to your clinical question and scenario. Consider the practicality and feasibility of the intervention in your discussion of the evidence applicability.]

These outcomes are highly relevant to this clinical scenario, as the study assesses lower extremity muscular strength in adult participants following B-PT-B graft ACL reconstructions. The patient in this clinical scenario had been participating in rehabilitation since the week following surgery and was less than 6-months post-operation further improving clinical relevance. The interventions provided in this study are very practical and feasible, as they can be performed in a typical outpatient clinic with little extra equipment. The NT protocol would likely benefit this patient, as she presented to clinic with significant quadriceps weakness despite participating in a typical strengthening ACL protocol. This intervention would likely not only improve her quadriceps strength, but also improve her gait abnormalities and improve her chances of returning to play at the start of her season in 6 months.

**(2) Description and appraisal of (Effects on Lower Extremity Neuromuscular Control Exercises on Knee Proprioception, Muscle Strength, and Functional Level in Patients with ACL Reconstruction) by (Kaya, 2019)**

| **Aim/Objective of the Study/Systematic Review:** |
|---|
| Kaya et al. conducted this randomized controlled trial to compare the effects of a standard rehabilitation program versus a standard rehabilitation program + lower extremity motor control exercises on knee proprioception, quadriceps and hamstring strength, and knee function following tibialis anterior tendon allograft ACL reconstruction. The aim of this study was to provide more evidence to support or refute the implementation of neuromuscular control exercises in ACL rehabilitation protocols. |
| **Study Design**<br>[e.g., systematic review, cohort, randomised controlled trial, qualitative study, grounded theory. Includes information about study characteristics such as blinding and allocation concealment. When were outcomes measured, if relevant]<br>Note: For systematic review, use headings 'search strategy', 'selection criteria', 'methods' etc. For qualitative studies, identify data collection/analyses methods. |
| This randomized controlled trial conducted by Raya et al. utilized a study design with participants randomly allocated into two groups using Random Allocation Software. The researcher who allocated the groups was blinded to the results, the researcher who assessed each of the outcome measures at the follow-up's was blinded to the groups, the researcher who analysed all data measured after the outcome measures were administered was blinded to the rehabilitation protocol, and the physical therapist who treated the participants using the specified treatment program was blinded to follow-up outcome measures. The follow-ups occurred at 3 weeks, 6 weeks, 3 months, 6 months, a year, and two years follow surgery. Allocation concealment was not specifically mentioned in the article so it cannot be confirmed, but it is likely the group allocation was concealed based on the efforts in place to blind all researchers to prevent bias. The outcome measures assessed in this study include hamstring and quadriceps muscle strength, knee proprioception, and a one-leg hop test. Both groups rehabilitation included the standard rehabilitation program, and Group 1 started neuromuscular exercises three weeks after surgery. Neuromuscular exercises included single leg balance, balance with a reach, lunges, step-ups and step downs, single leg bridges and ball exercises. Neuromuscular exercises were progressed in a temporal sequence over the course of 24 weeks. |
| **Setting**<br>[e.g., locations such as hospital, community; rural; metropolitan; country] |
| Patients recruited for this study had undergone ACL reconstruction surgery at Hacettepe University in Ankara, Turkey. Ankara is the capital of Turkey, meaning this study was conducted in a large urban city. While it is not specifically stated, it can be assumed the patients participated in their rehabilitation at an outpatient clinic in Ankara, Turkey based noted exercises performed and the 2-year timeline of this study. |
| **Participants**<br>[N, diagnosis, eligibility criteria, how recruited, type of sample (e.g., purposive, random), key demographics such as mean age, gender, duration of illness/disease, and if groups in an RCT were comparable at baseline on key demographic variables; number of dropouts if relevant, number available for follow-up]<br>Note: This is not a list of the inclusion and exclusion criteria. This is a description of the actual sample that participated in the study. You can find this descriptive information in the text and tables in the article. |
| The researchers of this study recruited 57 male participants between the ages of 14 and 55 who had undergone ACL reconstruction using a tibialis anterior tendon allograft at Hacettepe University. The mean age of participants in group 1 was 29.35 (range of 16-53 years) and a mean of 31.6 (range of 23-53 years) in group 2. Additional inclusion criteria included participants who had surgery within two years of their injury and had no previous history of knee surgery. Patients were excluded from the study if they required a meniscal repair, meniscectomy, on chondral surgery. Participants were divided into two groups- Group 1's rehabilitation included the standard rehabilitation program + lower extremity motor control exercises and Group 2's rehabilitation included only the standard rehabilitation program- using Random Allocation Software. There were no significant difference in age (p = 0.64), height (p = 0.97), or body weight (p = 0.98) are baseline between the two groups. The researcher allocating groups was blinded to the group details. Out of the 40 participants initially randomized, three dropped out in group 1 and 5 dropped out in group 2.<br><br>The table below was provided on page 4 detailing the number of participants assessed for inclusion in the program and the number who were lost to follow-up in each group. |

Table 2: Consolidated Standards of Reporting Trials (CONSORT) table.

| | | |
|---|---|---|
| 1. Assessed for eligibility | $n = 57$ | |
| 2. Enrolment | $n = 57$<br>*Exclusions: $n = 17$<br>Meniscal repair/ meniscectomy/chondral repair: $n = 13$<br>Female patients: $n = 4$ | |
| | Group I | Group II |
| 3. Randomized | $n = 20$ | $n = 20$ |
| 4. Lost to follow-up | $n = 3$ | $n = 5$ |
| 5. 6 months after surgery | $n = 17$ | $n = 15$ |
| 6. 24-month follow-up | $n = 17$ | $n = 15$ |

Group I: neuromuscular control exercises were performed; Group II: standard rehabilitation program was performed; $n$: number of patients.

**Intervention Investigated**

[Provide details of methods, who provided treatment, when and where, how many hours of treatment provided]

*Control*

The control group in this randomized controlled trial is the standardized rehabilitation program. All participants in this group started rehabilitation one day after surgery. One physical therapist carried out the rehabilitation for 24 weeks. The timeline of this standard rehabilitation protocol was very vague compared to the motor control group. There is no mention of how many times a week the participants received therapy or how many total hours they were in clinic receiving treatment. The exercises in this group progressed based on the participants functional progress, but these milestones were not directly stated.

*Experimental*

Based on the proposed hypothesis, the experimental group in this study is the standard rehabilitation program + motor control exercises. The purpose of this study was to determine if patients demonstrated better outcomes when rehabilitation protocols included a standard rehabilitation program + motor control exercises compared to participants who only participated in the standard rehabilitation program. One physical therapist administered the rehabilitation program over the course of 9 months. These exercises were progressed based on temporal criteria with the specific protocol noted below (provided on page 3 & 4):

Table 1: Neuromuscular control exercises program.

| | |
|---|---|
| 1st–3rd days | *Mobilization*: tolerated weight-bearing mobilization with crutches<br>*Exercises*:<br>Quadriceps isometric setting *with towel under the heel*, straight leg raising (SLR) with full knee extension (with weights at ankle), raising the leg above the ground 40–50 cm in 10 seconds, holding for 10 seconds, and slowly lowering in 40 seconds<br>*Restriction*: avoid active terminal knee extension (30° to full extension) |
| 3rd days-3rd week | *Range of motion*: 0 to 90° flexion<br>*Mobilization*: tolerated weight-bearing mobilization w/wo crutches<br>*Exercises*:<br>Quadriceps isometric setting with towel under the heel, SLR with full knee extension (with weights at ankle), raising the leg above the ground 40–50 cm in 10 seconds, holding for 10 seconds, and slowly lowering in 40 seconds, and heel slides (at 0–90° flexion)<br>*Restriction*: avoid active terminal knee extension (30° to full extension) |
| 3rd–6th week | *Range of motion*: 0 to 120° flexion<br>*Mobilization*: tolerated to full weight-bearing mobilization with knee brace<br>*Exercises*:<br>Single leg stance, balance reach leg and balance reach arm exercises, lunges (all directions), step-up (all directions) on other side of the patients, and bilateral squat<br>*Restriction*: avoid active terminal knee extension (30° to full extension) |
| 6th–12th week | *Exercises*:<br>Single leg stance, balance reach leg and balance reach arm exercises, lunges (all directions), step-up (all directions), step-down (all directions), one-legged squat, box heel touches (all directions), and single leg pelvic bridge on operated side of the patients, and ball exercises during athletic position |
| 12th–24th week | *Exercises*:<br>Single leg straight leg dead lift, sumo squat, and weights added to all exercises<br>Special stair exercises: (stair should be 18 cm in height and 30 cm in depth)<br>*Explanation*:<br>Stair exercise (1): stand behind a stair. While one foot on the ground, put the other foot on the stair and flex the knee about 45° flexion. Raise the body to full knee extension at one leg in 60 seconds and slowly lowering the body to 45° knee flexion in 60 seconds. During the exercises, the patient should control his/her lower leg to keep straight (keep away from varus/valgus)<br>Stair exercise (2): stand on a stair. Lower the body at one leg in 60 seconds and slowly turn and raise the body in 60 seconds During the exercises, the patient should control his/her lower leg to keep straight (keep away from varus/valgus) |
| To 9th month | (3) running program (started at the 13th week)<br>(4) jumping (multidirectional) (started at the 18th week)<br>(5) plyometrics and agility exercises (started at the 20th to 24th week)<br>*Restriction*: return to sports is not allowed before 9 months after surgery |

**Outcome Measures**

[Give details of each measure, maximum possible score and range for each measure, administered by whom, where]

- Isometric hamstring and quadriceps strength were measured using a Biodex System Pro 3
    - Prior to testing, patients warmed up for 5 minutes at $60^0$/s, followed by a 2-minute rest break. Concentric peak torque of the knee muscles were measured on each leg at $30^0$/s, $60^0$/s, $180^0$/s, and $330^0$/s with the knee joint at between 0-$90^0$ of flexion. Three maximal repetitions were performed at each velocity with a 5-minute rest break in between.
    - Isokinetic muscle testing shows high to excellent reliability based on ICC's ranging from 0.81-0.97.[3]
- Knee proprioception was evaluated using a Biodex System Pro 3
    - Participants were tested using an active angle reproduction (AAR) system with their eyes closed and head turned away from the dynamometer. The patient was asked to move their knee to a specific angle and the difference between the actual angle and target angle were recorded. The participants got 6 attempts for each target angle.
    - The ICC of AAR testing is 0.716 with eyes open and 0.404 with eyes closed. This indicates poor reliability of this measure with eyes closed (ICC <0.5) and moderate reliability with eyes open.
- Knee function was assessed using a one-legged hop test
    - Patients were asked to hop as far as possible and land on the same leg. 3 trials were conducted on each leg.
    - The one-legged hop has excellent reliability, with ICC ranging from 0.97-0.99.
    - The standard error of measure (SEM) for the one-legged hop test ranges from 4.61-17.74 cm.[13]
    - The goal is to have less than a 10% difference in hop distance between the injured and uninjured legs.[13]

Each of these measures was administered by the same physical therapist who was blinded to the group allocations. These outcome measures were administered at 3 weeks, 6 weeks, 3 months, 6 months, 1 year, and 2 years following ACL reconstruction.

**Main Findings**

[Provide summary of mean scores/mean differences/treatment effect, 95% confidence intervals and p-values etc., where provided; you may calculate your own values if necessary/applicable. Use a table to summarize results if possible.]

TABLE 3: Descriptive and compared values of muscle strength, joint position sense, and hop tests obtained for the operated side and the other side of patients.

| | | Group I ($n = 17$) | | | Group II ($n = 15$) | | |
|---|---|---|---|---|---|---|---|
| | | Operated side (mean ± SD) | Other side (mean ± SD) | $p$ | Operated side (mean ± SD) | Other side (mean ± SD) | $p$ |
| Quadriceps muscle strength (Nm) | 30°/s | 138.71 ± 35.7 | 162.24 ± 49.12 | **0.01*** | 138.67 ± 34.05 | 160.27 ± 39.05 | **0.001*** |
| | 60°/s | 128.06 ± 33.47 | 140.94 ± 30.53 | 0.19 | 120.13 ± 36.86 | 147.00 ± 37.16 | **0.001*** |
| | 180°/s | 88.82 ± 24.09 | 93.53 ± 24.77 | 0.39 | 94.93 ± 40.88 | 98.73 ± 26.61 | 0.60 |
| | 330°/s | 57.00 ± 9.50 | 58.82 ± 18.47 | 0.64 | 62.80 ± 25.36 | 68.20 ± 26.15 | 0.28 |
| Hamstring muscle strength (Nm) | 30°/s | 98.88 ± 25.66 | 112.94 ± 28.60 | **0.01*** | 96.73 ± 23.64 | 114.20 ± 29.88 | **0.02*** |
| | 60°/s | 99.00 ± 20.46 | 101.18 ± 20.93 | 0.62 | 92.13 ± 25.00 | 109.20 ± 26.07 | **0.01*** |
| | 180°/s | 79.41 ± 16.62 | 82.00 ± 18.37 | 0.62 | 79.07 ± 27.59 | 85.20 ± 23.12 | 0.45 |
| | 330°/s | 73.24 ± 11.24 | 74.41 ± 11.78 | 0.77 | 76.13 ± 20.49 | 77.67 ± 24.73 | 0.74 |
| JPS (°) | 75° | 74.55 ± 1.54 | 74.61 ± 2.98 | 0.93 | 75.85 ± 3.77 | 76.92 ± 3.42 | 0.22 |
| | 45° | 45.63 ± 2.94 | 45.19 ± 4.11 | 0.64 | 47.32 ± 6.05 | 47.18 ± 5.84 | 0.92 |
| | 15° | 15.44 ± 1.74 | 15.78 ± 2.40 | 0.64 | 16.95 ± 3.13 | 17.07 ± 2.49 | 0.93 |
| Hop test (cm) | 141.37 ± 34.35 | 156.12 ± 24.04 | **0.01*** | 146.53 ± 19.56 | 157.31 ± 19.53 | **<0.001*** | |

*Paired sample $t$-test. JPS: joint position sense; Group I: neuromuscular control exercises were performed; Group II: standard rehabilitation program was performed; SD: standard deviation; $n$: number of patients.

The table above was provided on page 5 and includes the means, standard deviation and p-values of each isokinetic strength measurement with a comparison of the operated and non-operated knee in each group. Based on the p-values provided, hamstring and quadriceps muscular strength ($180^0$/s & $330^0$/s angular speed) differences are significant between the operated and uninvolved sides in each group based on $p < 0.05$.

TABLE 4: Descriptive and compared values of muscle strength, joint position sense, and hop tests obtained for the operated side of the patients in Group I and the operated side of patients in Group II.

| | | Group I ($n = 17$) | | Group II ($n = 15$) | | | |
|---|---|---|---|---|---|---|---|
| | | Operated side (mean ± SD) | Other side (mean ± SD) | Operated side (mean ± SD) | Other side (mean ± SD) | $F$ | $p$ |
| Quadriceps muscle strength (Nm) | 30°/s | 138.71 ± 35.7 | 162.24 ± 49.12 | 138.67 ± 34.05 | 160.27 ± 39.05 | 0.362 | 0.55 |
| | 60°/s | 128.06 ± 33.47 | 140.94 ± 30.53 | 120.13 ± 36.86 | 147.00 ± 37.16 | 0.037 | 0.85 |
| | 180°/s | 88.82 ± 24.09 | 93.53 ± 24.77 | 94.93 ± 40.88 | 98.73 ± 26.61 | 2.389 | 0.13 |
| | 330°/s | 57.00 ± 9.50 | 58.82 ± 18.47 | 62.80 ± 25.36 | 68.20 ± 26.15 | 10.138 | **0.01*** |
| Hamstring muscle strength (Nm) | 30°/s | 98.88 ± 25.66 | 112.94 ± 28.60 | 96.73 ± 23.64 | 114.20 ± 29.88 | 0.371 | 0.55 |
| | 60°/s | 99.00 ± 20.46 | 101.18 ± 20.93 | 92.13 ± 25.00 | 109.20 ± 26.07 | 0.371 | 0.55 |
| | 180°/s | 79.41 ± 16.62 | 82.00 ± 18.37 | 79.07 ± 27.59 | 85.20 ± 23.12 | 1.565 | 0.22 |
| | 330°/s | 73.24 ± 11.24 | 74.41 ± 11.78 | 76.13 ± 20.49 | 77.67 ± 24.73 | 7.102 | **0.01*** |
| JPS (°) | 75° | 74.55 ± 1.54 | 74.61 ± 2.98 | 75.85 ± 3.77 | 76.92 ± 3.42 | 28.990 | **0.001*** |
| | 45° | 45.63 ± 2.94 | 45.19 ± 4.11 | 47.32 ± 6.05 | 47.18 ± 5.84 | 7.899 | **0.01*** |
| | 15° | 15.44 ± 1.74 | 15.78 ± 2.40 | 16.95 ± 3.13 | 17.07 ± 2.49 | 9.014 | **0.01*** |
| Hop test (cm) | 141.37 ± 34.35 | 156.12 ± 24.04 | 146.53 ± 19.56 | 157.31 ± 19.53 | 2.323 | 0.14 | |

*Independent sample *t*-test. JPS: joint position sense; Group I: neuromuscular control exercises were performed; Group II: standard rehabilitation program was performed; SD: standard deviation; *n*: number of patients.

This table was provided on page 5. Based on the statistical significance (p-values) calculated to compare hamstring and quadriceps muscular strength ($30^0$/s & $60^0$/s) and muscular endurance ($180^0$/s & $330^0$/s), the standard rehabilitation program was more effective in improving muscular endurance in both hamstrings and quadriceps ($p<0.05$) than the standard rehabilitation + motor control exercise group.

| **Effect Size, cohen's d** | |
|---|---|
| Quadriceps strength $30^0$/s | 0.0 (no effect) |
| Quadriceps strength $60^0$/s | 0.23 (small effect) |
| Quadriceps strength $180^0$/s | 0.18 (very small effect) |
| Quadriceps strength $330^0$/s | 0.3 (small effect) |
| Hamstring strength $30^0$/s | 0.13 (very small effect) |
| Hamstring strength $60^0$/s | 0.30 (small effect) |
| Hamstring strength $180^0$/s | 0.02 (very small effect) |
| Hamstring strength $330^0$/s | 0.17 (very small effect) |

This table identifies the effect size of each isokinetic muscle measurement between the operated side on group one and the operated side on group 2. Based on these calculations, the addition of neuromuscular control exercises has at most a small effect on lower extremity muscle strength, with the most effect occurring on hamstring strength at and angular speed of $60^0$/s. While the standard rehabilitation program shows statistical significance in improving quadriceps and hamstring muscular endurance when compared to the standard rehabilitation + motor control group, the effect size is small and an increased same size should be included in future studies.

**Original Authors' Conclusions**

[Paraphrase as required.  If providing a direct quote, add page number]

Raya et al concluded incorporating neuromuscular control exercises in a patients ACL rehabilitation plan of care is more effective in reducing the difference in strength between the operative and non-operative legs, while the standard rehabilitation program is more effective in improving muscular endurance. Based on these results, the authors recommend including neuromuscular control exercises and standard rehabilitation exercises in ACL rehabilitation protocols to increase quadriceps and hamstring strength and endurance.

**Critical Appraisal**

**Validity**

[Summarize the internal and external validity of the study. Highlight key strengths and weaknesses. Comment on the overall evidence quality provided by this study.]

This randomized controlled trial conducted by Kaya et al is level 1b evidence and scored 9/11 on the PEDro risk of bias tool. This represents high internal validity due to low risk of bias. The key strength of this study in relation to this clinical scenario is the direct comparison of my two interventions and clearly stated conclusions regarding the most effective intervention protocols to improve quadriceps and hamstring muscular strength. Like the study conducted by Risberg et al, this study also used an isokinetic dynamometer to objectively measure lower extremity muscle strength and endurance to reduce potential subjective variability if a more subjective measure was used to quantify muscle strength. Additionally, the neuromuscular control protocol was clearly noted and will be easily reproduced in clinic. The main limitation identified is the lack of information regarding the standard rehabilitation protocol, including exercises, where the rehabilitation took place, and how often participants received treatment. Based on this clinical scenario it would have been more effective and relevant is some of the participants included in the study have undergone ACL reconstruction using a patellar tendon graft and were female, as the type of graft used may impact knee function outcomes and strength.

**Interpretation of Results**

[This is YOUR interpretation of the results taking into consideration the strengths and limitations as you discussed above. Please comment on clinical significance of effect size / study findings. Describe in your own words what the results mean.]

Based on the p-values and effect sizes calculated and analysed when comparing the standard rehabilitation group versus the standard rehabilitation + motor control group, a standard rehabilitation protocol is most effective in improving hamstring muscular endurance ($p<0.05$), while neuromuscular control exercises are most effective in improving hamstring and quadriceps muscular strength. While there is statistical significance based on the p-values, further research needs to be conducted due to the small effect sizes on all isokinetic measure regardless of angular speed.

**Applicability of Study Results**

[Describe the relevance and applicability of the study to your clinical question and scenario. Consider the practicality and feasibility of the intervention in your discussion of the evidence applicability.]

This study is less relevant to this clinical scenario than the randomized controlled trial conducted by Risberg et al. due to the participant selection. This study only included patients who were nonathletes, male, and had undergone tibialis anterior tendon graft ACL reconstruction, while the patient in this clinical scenario is a female who had undergone ACL reconstruction using a patellar tendon graft. While the participant demographics are less relevant, the clinical question presented in this study directly compares the two interventions stated in this PICO question- the efficacy of a strengthening program versus a neuromuscular control program in improving hamstring and quadriceps strength. Additionally, this study used an isokinetic dynamometer to objectively measure muscle strength and this was the primary outcome measure utilized in this study, compared to strength being a secondary measure in the Risberg et al study. The result of this study are also applicable to the clinical question, as it can be inferred neuromuscular control exercises added to a standard rehabilitation program are effective in improving muscular strength and should be implemented into this patients plan of care to improve her chances of returning to play at the start of her soccer season in 6 months. This intervention is very feasible, as these exercises can easily be administered in a typical outpatient clinic without additional equipment and are time efficient.

## SYNTHESIS AND CLINICAL IMPLICATIONS

[Synthesize the results, quality/validity, and applicability of the two studies reviewed for the CAT. Future implications for research should be addressed briefly. Limit: 1 page.]

Prior to these studies, there was very little evidence addressing ACL protocols including the inclusion of neuromuscular control exercises, and both of these randomized controlled trials aimed to provide additional research into the efficacy of these exercises when compared to a traditional strength training program. Both studies appraised in this CAT yielded similar results regarding efficacy of a strengthening protocol versus a strengthening protocol + neuromuscular control exercises in improving knee function, but the study conducted by Kaya et al. provided more statistical evidence supporting the effects on lower extremity strength that was relevant to the clinical question. The first study is high relevant to the clinical case, as it addresses the correct patient population based on age, gender, type of ACL graft, time since surgery, and interventions implemented in each rehabilitation program. While the study conducted by Kaya et al. provided more evidence to back inclusion of a neuromuscular program in ACL rehabilitation protocols, it was less relevant to the clinical case because the differences in gender and graft type could play a significant role in the overall knee outcomes.

Neither study successfully rejected the null hypothesis, as the study conducted by Risberg et al. did not provide statistical analysis for secondary outcome measures (i.e strength measures) and concluded there was no difference in lower extremity strength between the strength training group and neuromuscular training group after 6 months of rehabilitation. Additionally, while Kaya et al. directly measured lower extremity strength and detailed tables of the results were provided, all measures had a small effect size and only hamstring endurance demonstrated statistical significance based on $p < 0.05$. This study also had a relatively small sample size, with 17 participants in group 1 and 15 participants in group 1, but this w=did not affect risk of bias because the follow up rate was 80%.

After appraising these articles, future research should be conducted with larger sample sizes to improve clinical reasoning and determine most specific protocols using a combination of these exercises. Rehabilitation should be provided to both groups in the same clinic to allow for the same equipment opportunities, increasing internal validity. This will provide more conclusive results into the efficacy of strength training versus neuromuscular control exercises in improving lower extremity strength following ACL reconstruction. Also, including participants regardless of ACL reconstruction graft will allow for increased external validity and improved generalizability between patients. One of the key limitations in the study conducted by Risberg et al was the similarities in exercises between intervention program. This could have caused the two groups to have similar strength improvements, preventing researchers from effectively determining the efficacy of each protocol individually and causing a type 2 error (i.e false negative indicating there was no difference in strength improvements between the two intervention groups). Future studies should place greater emphasis on ensuring groups solely participate in strengthening or neuromuscular exercises to prevent overlap between intervention groups. Based on the current research, I would include a combination of neuromuscular and strengthening exercises in my patients plan of care, with a focus of improving not only lower extremity strength and endurance, but balance, proprioception, and sport-related activities. While these measures were not part of the original PICO question, they are important to take into consideration when working with patients, especially athletes, to aid in return to sport and reduce the risk of re-injury.

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