**CRITICALLY APPRAISED TOPIC**

**FOCUSED CLINICAL QUESTION**

For adults age 18-45 who are post-anterior cruciate ligament reconstruction (ACLR), do open kinetic chain (OKC) knee extension exercises at 0-30 degrees (deg) of knee flexion versus 30-90 deg of knee flexion put more strain on the new graft?

**AUTHOR**


| | | | |
|---|---|---|---|
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**CLINICAL SCENARIO**

A community therapist has asked for an appraisal of her facility's ACLR rehabilitation protocol for their patients. Their current protocol is for a patellar tendon autograft procedure, and they want to know if the evidence suggests specific differences for hamstring autograft procedures as the orthopedic surgeon recently changed to this technique. She specifically wants to know if OKC knee extension at 0 degrees extension is safe for these patients.

When covering ACLR rehabilitation in our musculoskeletal class, there was some confusion as to whether OKC or closed kinetic chain (CKC) exercises were safer, and which knee flexion angles should be avoided in order to protect the graft. The goal of this literature search is to contribute to the review of the rehabilitation protocol mentioned above as well as provide clarity to DPT students about best practice.

**SUMMARY OF SEARCH**
[Best evidence appraised and key findings]

Eight studies were located that met the inclusion/exclusion criteria including 2 randomized controlled trials, 3 systematic reviews, 2 cross-sectional studies, and 1 narrative review.

- A majority of the literature is aimed at comparing CKC exercises to OKC, and is less focused on strain during specific ranges of motion. There appears to be uncertainty as to when OKC exercises are appropriate to introduce to patients.
- The heterogeneity between protocols makes it difficult to discern clearly if and how OKC exercises affect anterior cruciate ligament (ACL) graft strain and, by extension, anterior tibial laxity.
- There is general consensus that more strain is placed on the ACL (innate or reconstructed graft) when the knee is between 10-30 degrees of flexion.
- The majority of the studies included are of level 1 and 2 quality evidence, and have moderate relevance to the clinical question.

**CLINICAL BOTTOM LINE**

Limited quantity and quality of evidence may suggest OKC exercises within the first 6 weeks of post-ACLR rehabilitation is associated with increased anterior tibial laxity, however most results lack statistical and clinical significance. Due to lack of demonstrable benefits for early introduction of OKC exercises, the literature suggests that gradual introduction of OKC exercises within a protective range of motion is best practice for ACL rehabilitation.

It appears widely agreed upon that ACL strain increases with quadriceps activation in the range of 0-30 deg of knee flexion. It is yet to be definitively proven if this increased strain is problematic for a healing ACL graft. Moreover, strain at 0 deg has not been measured. The role of the screw home mechanism is proposed to provide some added stability to the knee. How much that protects the ACL from strain is unknown.

The limited number of studies and lack of overall quality of the evidence creates a challenge as to which rehabilitation protocol is best.

***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) |
| Adult male<br>ACL reconstruction<br>ACL surgery<br>Anterior cruciate ligament surgery<br>Anterior cruciate ligament reconstruction<br>Hamstring tendon autograft<br>Hamstring autograft<br>ACL rehabilitation | Open chain exercises<br>Knee extension exercises<br>Terminal knee extension exercise | Mid-range knee extension exercise | Graft strain<br>Graft Stress |

**Final search strategy (history):**

*Show your final search strategy (full history) from PubMed. Indicate which "line" you chose as the final search strategy.*

1. ((((("acl reconstruction") OR "anterior cruciate ligament surgery") OR anterior cruciate ligament reconstruction[MeSH Terms]) OR "acl surgery")
2. (("hamstring tendon autograft") OR rehab*)
3. ((((("degrees") OR open chain exercis*) OR "terminal knee extension") OR knee extension exercis*)
4. ((((("graft stress") OR "graft strain") OR tensile strength[MeSH Terms]) OR stress, mechanical[MeSH Terms])
5. #1 AND #2 AND #3 AND #4
    a. 11 results
6. **#1 AND #3 AND #4**
    **a. 73 results**

*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** | **11** | **Removed #2, 73 results** |
| **CINAHL** | **34** | **N/A** |
| **PEDro** | **6** | **N/A** |
| **Cochrane Library** | **3 (trials)** | **Anterior cruciate ligament reconstruction AND open chain exercise, 15 trials** |

**INCLUSION and EXCLUSION CRITERIA**

| **Inclusion Criteria** |
|---|
| Randomized controlled trials, systematic reviews, clinical practice guidelines, adults 18-45, studies that use re-injury rate as outcome measure, studies that discuss types of exercises performed, studies that assess ACL strain. |
| **Exclusion Criteria** |
| Pediatric studies, case studies, case reports, studies that don't specify type of exercise performed (OKC vs. CKC, knee flexion angle). |

**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 |
|---|---|---|---|---|
| **Fukuda et al (2013)** | **PEDro: 8/11** | **2b, <80% follow up** | **Moderate** | **RCT** |
| **Beynnon et al (1995)** | **STROBE: 17/22** | **1b** | **Moderate** | **Cross-sectional** |
| **Escamilla et al (2012)** | **AMSTAR: 3/11** | **5** | **Moderate** | **Narrative Review** |
| **Luque-Seron and Medina-Porqueres (2016)** | **AMSTAR: 7/11** | **2a, reviewed level 2 studies** | **Moderate** | **Systematic Review** |
| **Mae et al (2010)** | **STROBE: 14/22** | **2b** | **Low** | **Cross-sectional** |
| **Morrissey et al (2000)** | **PEDro: 5/11** | **2b, percentage of follow up unclear** | **Moderate** | **RCT** |
| **Perriman et al (2018)** | **AMSTAR: 10/11** | **1a** | **Moderate** | **Systematic Review** |
| **Wright et al (2008)** | **AMSTAR: 2/11** | **1a** | **Low** | **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:

- **Perriman (2018) The Effect of Open- Versus Closed-Kinetic-Chain Exercises on Anterior Tibial Laxity, Strength, and Function Following Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis**

  This study has a high, 1a level of evidence due to being a systematic review with meta-analysis. It was rated with a 10/11 on the AMSTAR checklist, giving it a low risk of bias. This review has moderate relevance to the

PICO question because it assesses the effect of open and closed kinetic chain exercises on anterior tibial laxity, and does not directly measure ACL strain. The main variables are timing of the initiation of OKC exercises.

- **Beynnon (1995) Anterior Cruciate Ligament Strain Behavior During Rehabilitation Exercises in Vivo**

  This study has a high, 1b level of evidence because it is a cross-sectional study with excellent methodological quality and good reference standards. It has a rating of 17/22 on the STROBE checklist. Despite its low sample size and older publication date, this study is well designed and has appropriate interpretation of the results. This study has moderate relevance to the PICO question because it directly measures ACL strain in vivo during OKC exercises and accounts for degrees of knee flexion angle. All subjects in this study had healthy ACLs, so it does not measure strain of a reconstructed ACL.

**SUMMARY OF BEST EVIDENCE**

**(1) Description and appraisal of "The Effect of Open- Versus Closed-Kinetic-Chain Exercises on Anterior Tibial Laxity, Strength, and Function Following Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis" by Perriman et al (2018)**[1]

**Aim/Objective of the Study/Systematic Review:**

To determine whether OKC quadriceps exercises result in differences in anterior tibial laxity, when compared to CKC exercises, at any time point following ACLR. The secondary aim was to determine whether there are differences in strength, function, quality of life, and adverse events with OKC quadriceps exercises when compared to CKC exercises at any time point.

**Study Design**

[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]

Note: For systematic review, use headings 'search strategy', 'selection criteria', 'methods' etc. For qualitative studies, identify data collection/analyses methods.

Perriman et al is a systematic review and meta-analysis of randomized controlled trials (RCTs).

**Search Strategy:** A systematic search in MEDLINE, Embase, AMED, CINAHL, SPORTDiscus, PEDro, and the Cochrane Central Register of Controlled Trials was conducted. Searches were limited to English, with no limits on publication period. The authors used the following search strategy in CINAHL: "(MH "Anterior Cruciate Ligament") OR (anterior cruciate ligament OR acl) OR [(MH "Knee") OR "knee" OR (MH "Knee Injuries") OR (MH "Knee Surgery")] AND (open chain OR open kinetic chain OR closed chain OR closed kinetic chain OR distal fixat$ OR foot fix$)."

**Selection Criteria:** Titles and abstracts were independently screened for eligibility by two reviewers. Full texts of the remaining articles were then sourced and independently evaluated for inclusion. Any disagreements were resolved through discussion, or by a third reviewer making the final decision.

- Inclusion criteria: RCTs with the following characteristics: (i) participants who had ACLR; (ii) interventions that compared OKC and CKC quadriceps exercises; and (iii) outcomes that included anterior tibial laxity, lower-limb strength, function, or quality of life.
- Exclusion criteria: Any study not an RCT, or not published in English.

**Data Extraction:** Data extracted included study authors, year, design, participants, setting, location, inclusion criteria, exclusion criteria, interventions, outcome measures, and results. Means, standard deviations, and sample sizes were extracted to calculate effect sizes and risk ratios.

**Data Synthesis:** Data were grouped according to outcome and follow-up times for both early (less than 6 weeks) and late (more than 6 weeks) introduction of OKC exercises. Follow-up times were short-term (less than 12 weeks), medium-term (3 to 6 months), long-term (6 to 12 months), and very-long-term (greater than 12 months).

**Risk of Bias Assessment:** Risk of bias was performed by two independent reviewers using the PEDro scale. The PEDro scale is a validated evaluation tool for RCTs.[2] Discrepancies were settled via consensus or by a third reviewer.

**Setting**

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

The authors of this study are physical therapists and university faculty members in Australia.

**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.

- This systematic review included 10 studies. One study had insufficient data to include in the meta-analysis.
- The number of participants combined from all 10 studies was 485, with a mean age range of 24-33 years, and the sample consisted of 74% men.
- There were 5 patellar graft studies, 2 hamstring graft studies, 2 studies that included both graft types, and 1 that did not specify.
- Studies either compared OKC to CKC exercises solely, or to combined OKC and CKC exercises. In 6 studies, the OKC exercises were introduced early (less than 6 weeks post-operatively), and 4 studies introduced them at more than 6 weeks after ACLR.
- PEDro scale scores ranged from 3-8, with a mean of 5.5.
- (N) studies were categorized for quality using GRADE (Grading of Recommendations, Assessment, Development and Evaluations) approach, for respective outcomes:
  - Laxity: Very Low (1), Low (4), Moderate (1)
  - Laxity risk ratio: Very Low (3), Low (2), Moderate (2)
  - Strength: Low (5), Moderate (1)
  - Patient-reported function: Low (2), Moderate (3)

**Intervention Investigated**

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

*Control*

- There were no pure control groups in the studies reported.
- The comparison groups were either the CKC exercise groups, or the late introduction of OKC exercise groups.

*Experimental*

- For this review, the experimental groups were the groups where OKC exercises were introduced within 6 weeks from surgery.
- Experimental groups were also the OKC only exercise groups when being compared to a CKC only group.
- Each study had a different protocol for introducing the OKC exercises early. Most had patients perform OKC exercises in a range of 90-40 deg of knee flexion for the first 4 weeks, then gradually progress towards full extension by 6-8 weeks.

**Outcome Measures**

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

The following outcome measures were used in (N) studies as it pertains to the aim of this systematic review:

- Anterior tibial laxity (6), strength (5), and function (6)

Side-to-side differences in anterior tibial laxity between the healthy leg and that in the ACLR leg were measured in millimeters using arthrometry. Devices used were either KT-1000, Rolimeter, or Knee Signature System arthrometers. A clinically significant threshold of a 2 mm difference in laxity was chosen by the authors based on previous research.

Strength was measured as quadriceps torque in Newton-meters (N*m) via isokinetic device or an isometric contraction with use of a Kin-Com dynamometer. Studies reported deficits in strength in terms of mean differences between limbs. It has been reported that standard error of measurement for isokinetic and isometric quadriceps strength in patients with osteoarthritis are 14.57 N*m and 10.76 N*m, respectively.[3]

Function was measured using performance assessments such as triple crossover hop for distance, single leg hop for distance; or patient reported measures such as Lysholm score or Hughston Clinic questionnaire.

- Hop tests were measured as side-to-side difference in centimeters. Typical cut-off scores for both triple crossover hop test and the single leg hop test are greater than a 10% side-to-side difference.[4]
- Lysholm score is a knee-specific patient reported outcome. It consists of 8 items with a possible score range of 0-100. Higher scores indicate better function and less disability.[5]
- Hughston Clinic questionnaire is another patient reported outcome specific to the knee. The measure consists of 28 items, utilizing a 10 cm visual analog scale to assess knee function.[6]

**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.]

**Anterior tibial laxity**

- Three studies, with a total sample of 203 participants measured the effect on anterior tibial laxity with the introduction of OKC exercises within 6 weeks post-ACLR. Overall, the calculated effect sizes show a slight increase in laxity in the early OKC groups, especially for patients with hamstrings graft. However, at each of the time points the pooled differences were not significantly different (P-value > 0.05). For all subgroups the between group differences and 95% confidence intervals were within the 2 mm clinically meaningful laxity threshold.
- Two studies, N = 93 participants, measured laxity with the introduction of OKC exercises after 6 weeks post-ACLR. Meta-analysis was not performed due to heterogeneity. Both studies reported no between group difference in laxity with a P-value > 0.05.
- Using the GRADE approach, the authors found low-moderate quality evidence in three studies that suggested no between group differences in laxity with the early introduction of OKC exercises compared to CKC.
- The meta-analysis demonstrates low-moderate quality evidence of no increase in the risk of having clinically meaningful laxity, regardless of the intervention, across all time points. Subgroup analyses identified no increased risk within graft types and no differences between subgroups.

**Strength**

- Two studies, with a total sample of 113 participants, measured the effect on strength with the early introduction of OKC exercises post-ACLR. There was low-moderate quality evidence that demonstrated no between group differences in strength (P > 0.05). This was consistent with each graft type.
- Three studies (N = 102) measured the effect on quadriceps strength when OKC exercises were introduced after 6 weeks. Meta-analysis was not performed due to heterogeneity of follow-up time points. There was limited evidence of no between group difference with short-term or long-term follow-up. One study reported statistically significant increased quadriceps strength with OKC exercise at medium-term follow-up (MD=20.70 Nm; 95% CI: 2.32-39.08 Nm; P = 0.03 favoring OKC).

**Function**

- Four studies with a total sample of 230 participants, measured the effect on patient-reported function when OKC exercises were introduced prior to 6 weeks. Three studies used the Lysholm score and one used the Hughston Clinic questionnaire. There was low-moderate quality evidence suggesting no between-group differences (P > 0.05) at short-, medium-, and very-long–term follow-up.
- There was limited evidence from 1 study (N = 49) that found no between-group differences on the Hughston Clinic Questionnaire at medium-term follow-up when OKC exercises were introduced after 6 weeks.
- Three studies assessed physical function (N = 116) using the triple crossover hop and the single-leg hop for distance. No studies were pooled in a meta-analysis due to heterogeneity in tests, time points, or intervention.
- One study compared performance measures with an early OKC group, and they reported no between-group difference in triple crossover hop performance at any of the four follow-up time points as well as no

significant difference in single-leg hop test performance.

- Two studies (N = 71) measured the effect on functional performance when OKC exercises were introduced after 6 weeks. A meta-analysis was not performed, as these studies took measurements at different follow-up time points. No significant difference was found between groups for either performance test in both studies.

**Original Authors' Conclusions**

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

There is low-moderate quality evidence suggesting that introducing OKC exercises before 6 weeks post-ACLR creates an increase in anterior tibial laxity, albeit without statistical or clinical significance. There is limited evidence suggesting no significant difference in laxity when introducing OKC exercises after 6 weeks post-ACLR. "Patellar grafts appeared to be less vulnerable to the early introduction of OKC quadriceps strengthening exercises" (p. 560). No significant between-group differences were found for quadriceps strength or function, for both early and late introduction of OKC exercises. Early introduction of OKC exercises do not appear to provide significant benefits, therefore the implementation of this practice is questionable.

**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.]

**AMSTAR score**: 10/11; a priori design provided: yes; two independent data extractors: yes; comprehensive search: yes; status of publication: yes; list of studies: yes; characteristics of studies: yes; quality assessment: yes; quality assessment used in conclusions: yes; appropriate methods to combine studies: yes; publication bias assessed: no; conflict of interest stated; yes.

**Strengths:**

- **Selection bias:** The authors reduced their vulnerability to selection bias by having two independent reviewers screen the articles for inclusion.
- **Selection criteria:** The authors were unequivocal regarding the eligibility requirements to be included in the review. Furthermore, the criteria chosen was specific to the clinical question being addressed.
- **Quality assessment:** The authors used reputable evaluation tools (PEDro, GRADE) to assess the included studies for risk of bias and for overall quality. The authors considered this evaluation when making their conclusions.
- **Data synthesis:** The authors effectively organized the data collected in such a way that was logical and easily understood. The meta-analyses were properly conducted, and not conducted when there was insufficient data or too much heterogeneity.

**Weaknesses:**

- **Publication bias:** No mention of publication bias performed by authors.
- **Quality of selected studies:** The majority of selected studies were of low or moderate quality. Additionally, there was considerable heterogeneity among the study characteristics and populations, which limited the ability to pool results and perform meta-analyses. Adverse events, such as re-rupture, were poorly reported.
- **Weak internal validity:** Only a few of the included studies provided detailed descriptions of the interventions carried out (timing, sets/reps/resistance). This hinders our ability to replicate the interventions and to clearly conclude which rehabilitation protocols increase anterior tibial laxity. Most early OKC protocols were carried out in a protective range of motion, therefore it is difficult to know how patients would respond to unrestricted OKC exercises in the first 6 weeks.
- **Weak external validity:** The heterogeneity of subject populations in the included studies makes it difficult to conclude how each sex would respond to the early introduction of OKC exercises. The majority of subjects included were male, so it would be difficult to apply these results to females.

**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.]

This systematic review provides low-moderate quality evidence that early introduction of OKC exercises have no statistically or clinically significant effect on anterior tibial laxity following ACLR.

This is a very well executed systematic review as the authors independently reviewed articles, included quality and bias assessments, and performed data analysis in the appropriate manner. However, the quality and heterogeneity of studies are the main limitations of this study. The conclusions of the study, therefore, should be interpreted with caution.

The authors' main conclusion that early introduction of OKC exercises does not provide any demonstrable benefits to overcome the risk of increased laxity is the safe deduction. However, the Heijne and Werner study provided the most detail in terms of the degrees of knee flexion angle at which the OKC exercises were performed and at which week they were implemented.[7] This study found a slight increase in laxity for patients with hamstrings graft, but it was still within the 2 mm threshold for clinically meaningful laxity.[7]

It appears OKC exercises may have more impact on tibial laxity when the ACLR is performed using hamstrings graft as compared to patellar tendon graft. Therefore, when having discussions with surgeons about the chosen rehabilitation protocol, this finding may be helpful to consider.

**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.]

**Relevance & Applicability:** The evidence from this systematic review has moderate relevance to the clinical scenario.

- This study addresses the timing of OKC exercises and their effect on anterior tibial laxity, and does not address the range of motion through which the exercises were performed.
- A few studies included in the review mention the degrees through which the exercises were performed, which helps the relevance to the clinical question.
- This review revealed that performing OKC exercises within 6 weeks after ACLR does not produce a statistically significant increase in tibial laxity. This information can be used to inform discussions with surgeons and patients regarding rehabilitation protocols.

**Practicality & Feasibility:** The limited evidence from this review is feasible to serve as guidelines when treating a patient post-ACLR.

- The few studies that provided detailed descriptions of the exercises can inform decision making when progressing a patient through a rehabilitation protocol.
- The findings from the included studies in this review can be used to confirm or question the rehabilitation protocol chosen by a particular surgeon or orthopedics department.
- Since the early introduction of OKC exercises did not appear to provide any benefits in the form of strength or function, it may be safer to wait until the graft has healed and integrated before performing these exercises – especially in the case of hamstrings grafts.

- **(2) Description and appraisal of "Anterior Cruciate Ligament Strain Behavior During Rehabilitation Exercises in Vivo" by Beynnon et al (1995)**[8]

**Aim/Objective of the Study/Systematic Review:**

To investigate the effects of commonly prescribed rehabilitation activities on ACL strain behavior in vivo. Specifically, to determine if differences in ACL strain values occur between:

- Active flexion-extension motion of the knee with and without weights attached to the ankle
- Isometric quadriceps muscle contraction at different knee angles
- Isometric hamstrings muscle contraction at different knee angles
- Simultaneous contraction of the quadriceps and hamstrings muscles at different knee angles

**Study Design**

[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]

Note: For systematic review, use headings 'search strategy', 'selection criteria', 'methods' etc. For qualitative studies, identify data collection/analyses methods.

- Cross-sectional design
- Subjects volunteered. No randomization or allocation to groups was performed.
- Subjects were excluded if they exhibited clinical "instability of any of the four major knee ligaments, pathologic conditions that would affect normal stability of the knee, cardiovascular problems, debilitating disease, or previous operations on the knee" (p.25).
- ACL and knee range of motion was assessed prior to arthroscopic knee surgery.
- Outcome measures were collected within the 60-minute time frame following implantation of the Hall effect transducer, and respective arthroscopic surgery.
- All subjects performed 20 cycles of active knee flexion-extension before beginning the study, to ensure the transducer was working properly. Each subject underwent anterior-posterior shear loading of the tibia at 30 deg of knee flexion before and after each activity to ensure reliability of the transducer measurements.
- One-way ANOVA was performed for the active flexion-extension activities as well as the isometric measurements. T-tests were performed for the isometric and co-contraction activities.

**Setting**

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

The study was conducted at the McClure Musculoskeletal Research Center, Department of Orthopaedics and Rehabilitation, University of Vermont, Burlington, VT

**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.

- 11 study subjects volunteered for the study. The authors did not provide demographic characteristics. The authors did reveal that the sample consisted of both men and women, age ranges from 22-41 years, and all with healthy ACLs.
- 9 of the 11 subjects had partial meniscectomy performed, one had a debridement of an osteochondral lesion, and one had removal of plica. Knee range of motion of the examined limb was similar to that of the contralateral knee during pre-operative examination for all subjects.

**Intervention Investigated**

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

*Control*

There was no control group for this study.

*Experimental*

After the respective arthroscopic procedure was performed, a Hall effect transducer was implanted on the subject's healthy ACL. All procedures were performed under local anesthetic, so subjects could maintain control of their lower extremity musculature.

Once the transducer and other measurement devices were in place, subjects were asked to perform the following activities:

- Active knee flexion-extension with and without 45 Newton (N) ankle weight
- Isometric quadriceps and hamstrings activation at 15, 30, 60, and 90 deg of knee flexion
- Co-contraction of quadriceps and hamstrings muscles at 15, 30, 60, and 90 deg of knee flexion

**Outcome Measures**

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

The outcome measure was collected by the authors in the operating room following the arthroscopic procedure.

ACL Strain: Percent deformation of the ligament as measured by the Hall effect transducer. Ligaments can be strained to about 5-7% without damage.[9] Maximum strain that ligament can withstand before failure is approximately 12-15%.[9]

Knee flexion angle was measured in degrees by the electrogoniometer portion of the knee Signature System. Anterior-posterior load was measured in Newtons by a load sensor applied to the proximal tibia. Quadriceps and hamstrings muscle torque was measured in Newton-meters by an "extension-flexion load sensor" mounted on a T-bar and attached to the distal tibia (p.25). Each isometric contraction torque was 30 N*m for the quadriceps and -10 N*m for the hamstrings. Throughout data collection, outputs from all devices were "transferred to a data-acquisition board for analog-to-digital conversion at a frequency of 20 Hz and stored on a computer intraoperatively" (p.26).

**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.]

- During active ROM, ACL strain values were at a minimum when the knee was flexed to 90 deg, and peaked with the knee at about 10 deg of flexion. ACL strain values were of greater magnitude during the eccentric flexion phase than during the concentric extension phase of motion. (See **Figure 5** below)
- With the 45 N ankle weight applied, the strain rates were greater through the entire range of motion. However, only with statistical significance at 10 and 20 deg of knee flexion ($P < 0.01$). (See **Figure 5** below)
- The mean transition point from unstrained to strained occurred at approximately 35 deg of knee flexion. With the ankle weight, this transition point shifted to about 45 deg of knee flexion. (See **Figure 5** below)
- During isometric quadriceps contraction, the combined ACL strain values at 15 and 30 deg were significantly larger than those at 60 and 90 deg of knee flexion ($P < 0.01$). (See **Figure 6** below)
- Strain values at 15 deg were significantly greater than those at 30 deg ($P = 0.018$). (See **Table 2** and **Figure 6** below)
- Similarly, with co-contraction, combined strain values at 15 and 30 deg of knee flexion were significantly greater than those at 60 and 90 deg ($P < 0.01$). (See **Figure 8** below)
- ACL strain remained low or unstrained at all angles of knee flexion during isometric hamstrings activation. (See **Figure 7** below)

**Figure 5:** ACL strain values during active knee flexion-extension. Solid line is without weight; dotted line is with ankle weight. (p.28)[8]

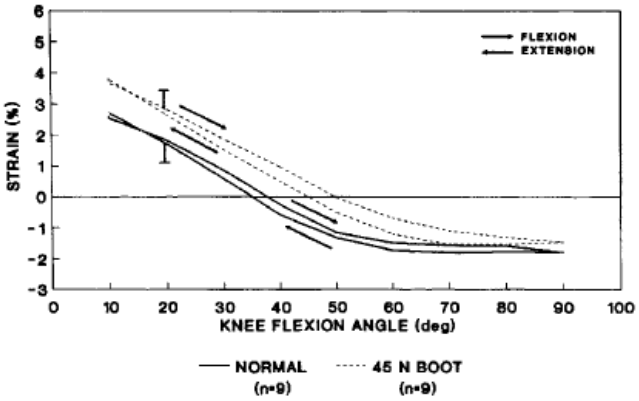


**Table 2:** Peak ACL strain values for various activities from the study (p.31)[8]

| Activity[a] | Peak strain % | Subjects (N) |
|---|---|---|
| Iso quads at 15° (to 30 N-m of extension torque) | 4.4 | 8 |
| Active ROM with a 45-N weight boot | 3.8 | 9 |
| Lachman test (150 N of anterior shear load at 30°)[b] | 3.7 | 10 |
| Active ROM[b] | 2.8 | 18 |
| Simultaneous quads and hams contraction at 15° | 2.8 | 8 |
| Iso quads at 30° (to 30 N-m of extension torque)[b] | 2.7 | 18 |
| Anterior drawer test (150 N of anterior shear load at 90°)[b] | 1.8 | 10 |
| Iso hams at 15° (to −10 N-m of flexion torque) | 0.6 | 8 |
| Simultaneous quads and hams contraction at 30° | 0.4 | 8 |
| Passive ROM[b] | 0.1 | 10 |
| Iso quads at 60° (to 30 N-m of extension torque) | 0.0 | 8 |
| Iso quads at 90° (to 30 N-m of extension torque)[b] | 0.0 | 18 |
| Simultaneous quads and hams contraction at 60° | 0.0 | 8 |
| Simultaneous quads and hams contraction at 90° | 0.0 | 8 |
| Iso hams at 30°, 60°, and 90° (to −10 N-m of flexion torque) | 0.0 | 5 |

**Figure 6:** Mean ACL strain values produced during isometric quadriceps contraction (p.29)[8]

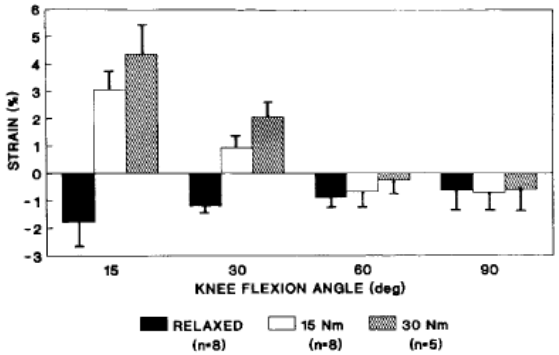



**Figure 7:** Mean ACL strain values produced during isometric hamstrings contraction (p.29)[8]

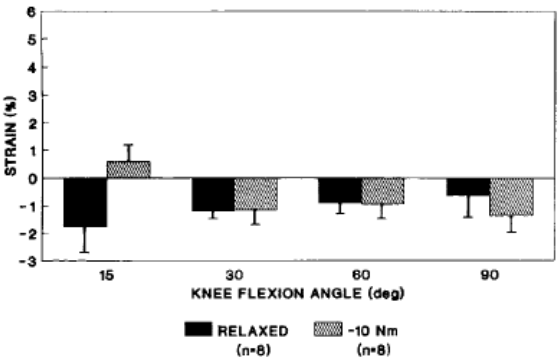
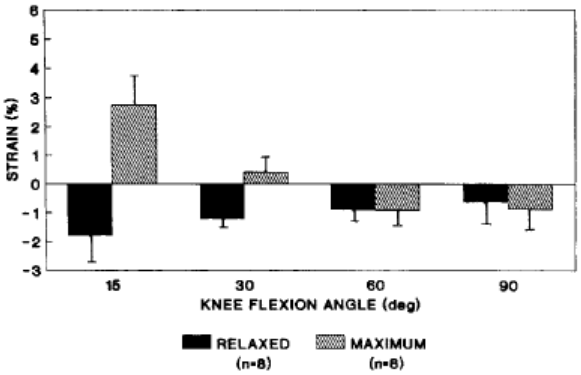



**Figure 8:** Mean ACL strain values produced during co-contraction of quadriceps and hamstrings (p.30)[8]




**Original Authors' Conclusions**

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

The authors concluded that ACL strain increases from approximately 30 deg of knee flexion to full extension. The ACL is relatively unstrained at angles larger than 30 deg of knee flexion, likely due to the posteriorly directed shear

force imposed on the tibia from the patellar tendon. The investigators suggested that this study identifies certain rehabilitation activities that do not strain the ACL; largely consisting of hamstrings activation at any knee flexion angle, and quadriceps activation at knee flexion angles between 35 deg and 90 deg.

**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.]

**STROBE Guidelines:** 17/22

**Downs and Black:** Internal validity - 5/7; External validity - 1/3

**Strengths:**

- **Standardization of methods:** The authors explained in excellent detail what was performed with each participant. They employed appropriate methods to increase standardization and reliability of the measurements.
- **Data analysis:** The authors utilized appropriate data analysis methods to create interpretable results from the study.
- **Internal validity:** This study has adequate internal validity due to the appropriate data collection and analysis methods. However, the small sample size limits the statistical power of the findings.

**Weaknesses:**

- **Subject selection:** The authors did not specify in the article how the subjects were recruited, other than describing them as "volunteers" (p.24). The authors did not provide any demographic data on the subjects.
- **Sample size:** This study included 11 participants, which hinders the statistical power of the results.
- **External validity:** The lack of size of the cohort, as well as the lack of demographic information about the subjects hinder the generalizability of the results to other populations.

**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.]

Despite the small sample size, this study provides real-time, in vivo data on the strain incurred by the ACL during various rehabilitation activities. The study is well designed and provides reliable, valid measurements. It is clear from the results of this study that ACL strain increases as the knee moves closer to extension. The question remains, is this strain clinically meaningful enough to cause problematic laxity with regards to an ACL graft? The activities in this study stopped at 10 deg of extension due to risk of impingement of the transducer. Therefore, the strain between 10 deg and full extension are unknown. The screw home mechanism of the knee might provide some stability to the knee, thereby protecting the ACL.

It appears safe to assume that the forces imposed on the innate ACL are similar to those on an ACL graft. Therefore, the results of this study can help guide rehabilitation decision-making post-ACLR. Due to the time needed for the ACL graft to heal and incorporate with the bone tunnels, it appears to be safer to refrain from quadriceps activation in the range of 0-35 deg of knee flexion in the early phases of rehabilitation.

Interestingly, the authors claimed partial meniscectomy does not alter knee biomechanics. However, more contemporary research suggests otherwise.[10] Missing meniscal tissue likely has more impact on weight-bearing knee arthrokinematics, however is should still be considered. This should be taken into consideration when interpreting the results from this study, as nine of the eleven participants received partial meniscectomy.

**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.]

**Relevance & Applicability:** The evidence from this study has moderate relevance to the clinical question.

- This study measured ACL strain at various degrees of knee flexion during OKC exercises, however the strain values were measured on healthy ACLs rather than grafts.
- As stated above, the results can inform clinical decision-making when proceeding through or creating a rehabilitation protocol for ACLR.

**Practicality & Feasibility:** There was no intervention in this study. However, the measurement methods appear to be reproducible. It might be difficult to recruit volunteers to participate in a 60-minute study while undergoing an arthroscopic knee procedure.

## 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.]

After critical review of both studies it appears that OKC exercises, particularly those performed between 0 and 35 deg of knee flexion, increase strain on the ACL. Although the strain magnitudes appear to be within the physiologic ranges an intact ACL can withstand, placing healing grafts under this level of stress may prove problematic. The majority of intervention protocols in the Perriman review appear to have performed the OKC exercises within a limited range of motion consistent with the findings of the Beynnon study. Once the subjects reached approximately 6 weeks post-operatively, the 0-30 deg range became available for them.[1] This factor may have impacted the results found in those studies. It is possible that if OKC exercises were performed at knee flexion angles less than 30 deg within the first 6 weeks post-ACLR, anterior tibial laxity may have been increased.

The heterogeneity of the evidence reviewed by Perriman et al and the small sample size in the Beynnon study raise a flag of skepticism with regards to the conclusions. The anterior tibial laxity associated with early introduction of OKC exercises was not statistically or clinically significant. Furthermore, the strain values found by Beynnon et al cannot be applied to the majority of patients due to lack of statistical power of the study.

Both studies produced results that were consistent with what they intended to measure. The rehabilitation protocols executed by the included studies in the Perriman review could be easily applied to patients in a clinical setting. Furthermore, they all appear to be safe and effective for returning patients to a functional level. The guidelines put forth by Beynnon et al can be easily incorporated into a rehabilitation protocol. It makes clinical and scientific sense to protect a new ACL graft from unnecessary strain while it heals and incorporates with the femoral tunnels, thereby reducing the likelihood of failure.

Future research is needed to directly measure the strain on ACL grafts with both open and closed kinetic chain activities following reconstructive surgery. The technological and ethical limitations may prove this to be quite challenging. More consistent randomized controlled trials investigating the effect of timing of the introduction of OKC exercises on anterior tibial laxity is needed to provide better quality evidence. For all studies, long-term follow-up is necessary to investigate the risk of re-tear with certain rehabilitation protocols and the functional implications of performing OKC exercises within the 0-35 deg range following ACLR.

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