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### Evaluation of the Effect of Two Exercise Regimes in Producing Forces on Anterior Cruciate Ligaments: A Systematic Review

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#### Abstract

**Background:** Anterior cruciate ligament (ACL) injuries are common. A goal of rehabilitation is to restore functional capacity. Currently, there are contrary opinions regarding the effectiveness of using either closed or open kinetic chain exercises (CKC, OKC) only, or a combination of both, following ACL injury, to obtain the most effective outcome. The debate also reflects the approach which places the least force on the ACL itself. **Objective:** To identify the evidence of effectiveness of closed versus open kinetic chain exercises, or a combination of both, in anterior cruciate ligament rehabilitation. **Methods:** A systematic review was undertaken of experimental studies published since 1990. Included studies were on humans with ACL injury. The ACL ligament could be healthy, ruptured, deficient or reconstructed. Studies on animals and cadavers were excluded. The methodological quality of included studies was appraised with the PEDro tool. Studies were graded according to hierarchy level, methodological quality, statistical significance, effect size, and clinical relevance. Recommendations were made on the strength of the body of evidence. The outcome measure of interest was force on the ACL during exercise.

**Results:** 23 eligible studies were included. The majority of studies reflected lower level experimental designs with moderate methodological quality. Three studies showed a significant difference in ACL force comparing CKC and OKC exercises, 11 demonstrated trends towards significant differences in outcome and nine showed no significant differences. **Conclusion:** There is moderate evidence to recommend CKC exercises or a combination of CKC and OKC exercises, rather than OKC exercises alone, for ACL rehabilitation when considering forces on the ACL.

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#### Background

This systematic review considered the available research evidence for best practice in rehabilitation of Anterior cruciate ligament ACL injuries, considering strain placed on the ACL during exercise. ACL injuries are common disorders resulting from workplace or recreational injuries, which are frequently treated by physiotherapists using a variety of approaches.<sup>1</sup> A common goal after ACL injury, or reconstruction surgery, is to protect the ligament, and strengthen surrounding structures whilst reducing forces on the patellofemoral joint.<sup>2</sup> Open kinetic chain (OKC) and closed kinetic chain (CKC) exercises are two exercise approaches which are often used in rehabilitation programs. There is currently no agreement in the research literature on whether OKC or CKC exercises produce a better outcome, specifically regarding which exercise places the least stress/strain on the ACL during rehabilitation. Minimising strain protects this important knee structure during rehabilitation, as well as the integrity of entire knee joint. This systematic review of the research literature was undertaken to obtain

a clearer picture of which of these two treatment approaches alone, or in combination, optimises recovery by minimising ACL strain during exercise.

Treatment approaches using OKC and CKC exercises for ACL injuries have been subject of debate over the past decade. It was first reported in 1993 that greater anterior tibial displacement (ATD) occurred during open compared with closed kinetic chain resistance exercises of the knee extensors.<sup>3</sup> This facilitated a shift towards CKC training in clinical practice in the following years. Reasons to support a change in rehabilitation approaches towards CKC training were also provided by Fleming, Oksendahl & Beynnon,<sup>1</sup> (p.134) such as:

1. 'reducing the anterior-directed intersegmental forces that act on the tibia relative to the femur
2. increasing tibiofemoral compressive forces
3. increasing co-contraction of the hamstrings
4. mimicking functional activities more closely than OKC exercises

5. reducing the incidence of patellofemoral complications'.

However, it has since been queried whether the two exercise regimes actually differ in the strain placed on the ACL.<sup>4</sup> There are also suggestions that a combination of CKC and OKC exercises could be more effective than one exercise type alone.<sup>1,2</sup> There is currently no convincing argument regarding which exercise approach produce the least stress/strain on the ACL.<sup>5-7</sup> Thus, a better understanding of the effects of these exercises is required from reviewing the literature.

The literature provides a variety of definitions for CKC and OKC exercises, and there is ongoing discussion regarding whether these terms describe these therapeutic exercises appropriately. For the purpose of this systematic review the most common definitions are used. OKC exercises are typically non-weight bearing, and motion occurs independently in one joint with the distal segment free to move, such as when seated knee extension is performed with resistance applied distally. Conversely CKC exercises are typically weight bearing. Movement at one joint, produces movement at several other joints, the terminal segment is normally fixed, and the resistance can be applied proximally and distally. A good example for a CKC exercise would be a squat.<sup>8-10</sup> The aim of this systematic review was to review and evaluate the current evidence on the difference in effect of CKC versus OKC exercises, in order to determine if one approach produces less strain on the ACL and therefore should be favoured during rehabilitation.

#### Methods

**Research question:** What is the difference in effect of closed versus open kinetic chain exercises in producing strain on anterior cruciate ligament?

**Evidence sources:** Electronic databases searched comprised Medline, AHMED, CINAHL, Journals@Ovid Full Text, SPORTDiscus, Cochrane, PEDro, PUBMED, and Google Scholar for the years 1990-2006.

**Search terminology:** Appendix 1 provides details on the search definitions and terms. All possible combinations of search terms were used in the databases. Only evidence available in full text articles in English language was included.

**Selection criteria:** Only experimental studies were included. Eligible studies could comprise studies of OKC with, or without control, CKC with, or without control or CKC compared to OKC exercises (with one intervention acting as the "control"). Any human study on healthy ACLs, or ruptured, deficient and/ or reconstructed ACLs was included in order to test the effectiveness of closed versus open kinetic chain exercises in producing strain on anterior cruciate ligament under all possible conditions. Studies on animals and cadavers were not included. Any outcome measure was recorded if it reported ACL strain. Functional outcomes were considered as secondary outcome measures. The evidence dimensions of the studies included in this review were considered in terms of the National Health and Medical Research Council definition (NH&MRC 1999). This included hierarchy of evidence, quality of methodology, statistical precision and effect size, and clinical relevance of findings.

**Hierarchy of evidence:** Eligible studies identified by the search strategy were consigned to the appropriate research design hierarchy level using the model of Lloyd-Smith.<sup>11</sup> The Lloyd-Smith hierarchy is reported in Table 1. For this review, levels 1b, 2a, 2b and 3 were eligible for inclusion as these research designs provide evidence of effectiveness appropriate to the research question.<sup>11</sup> Thus the relevant studies in this review could be randomised controlled trials (Level 1b) controlled or randomised studies (Level 2a), experimental trials without blinding, or without randomisation (Level 2b), and non-controlled experimental studies, retrospective case studies or case series (Level 3).

**Table 1 Number of reviewed article based on the hierarchy level of evidence**

Study design	Level of hierarchy	Number
Meta-analysis	1a	
Randomized controlled trial	1b	7
Randomized trial	2a	1
Controlled trial	2a	2
Trial	2b	13
Non-experimental descriptive studies or comparative/ case studies	3	
Respectable opinion	4	

In order to produce the most up-to-date analysis of current literature, the decision was made for this review to use only primary research. Therefore, should any relevant systematic reviews of effectiveness studies be found during this search, relevant primary studies would be extracted from the systematic review reference list

and added to the list of primary studies already identified in the search strategy. The "parent" systematic review would then not be included as a data source in the review.

**Methodological quality:** Included studies were

appraised for methodological quality using the 11 item PEDro scale.<sup>12</sup> Two independent reviewers appraised all studies and scores were compared for agreement. Discrepancies between scores were resolved by discussion. The methodological quality of studies was then categorised as excellent – good – moderate – poor to allow easier comparison between study findings. The PEDro appraisal scores were arbitrarily classified as 11-10 excellent, 9-7 good, 6-4 moderate, and 3-0 poor.

**Statistical precision:** The statistical precision of results was reported if available as 95% confidence intervals or *p-values* associated with testing differences between intervention and control outcome measures in each study. Ninety-five percent confidence intervals not encompassing 0, or *p-values* of < 0.05 were sought as evidence of statistical significance. As it was expected that there would be more than one outcome measure reported in most studies, the importance of study findings was classified using the frequency of what was reported. A classification of *good* was applied when statistically significant differences were reported for all outcome measures in the study (of which at least one would be a measure of ACL strain), a classification of *fair* was made when only some statistically significant differences were reported for the outcome measures, and a classification of *none* was made when no statistically significant differences were reported for any outcome measure.

**Effect size:** The effect size was extracted directly from the text if it was available. Where the components of effect size were reported but not the calculation itself, it was calculated using a formula which incorporated the mean and standard deviation of intervention and control groups for each outcome measure.<sup>13</sup>

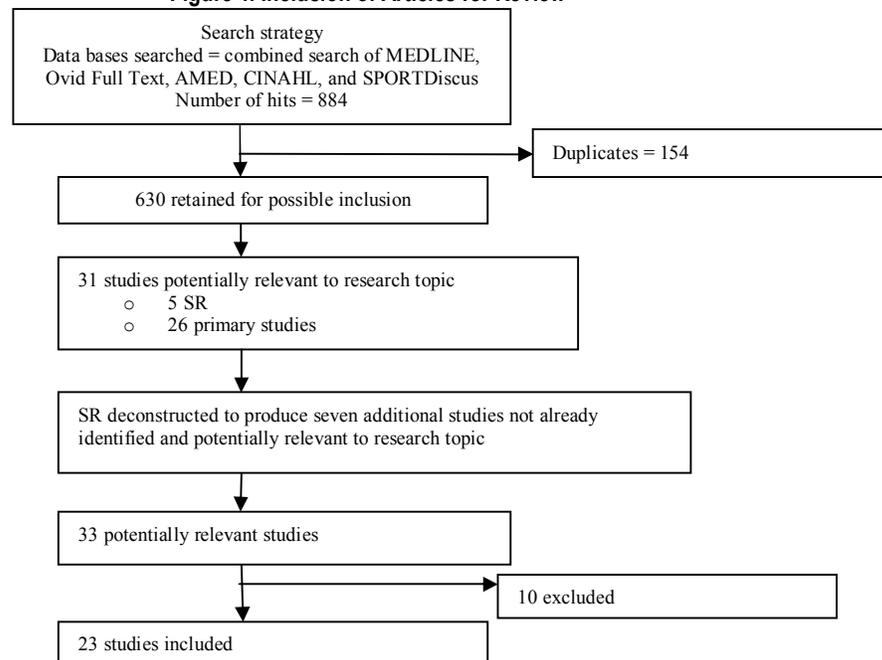
**Clinical relevance:** The clinical relevance was determined by a number of factors, including the way in which the clinical evidence was presented, the external and internal validity of the studies, the hierarchy, methodological quality of each study, number of significant outcomes, sample size, description of study population (age, gender, and country of origin). Clinical relevance decisions were also made on therapists' ability to replicate the intervention and its applicability to real life settings.

**Data extraction:** To assist evaluations of evidence dimensions, data was extracted from the included studies in a systematic manner, and entered onto a purpose-built MSEXcel spread sheet. Information included study population descriptors, year and country of origin of study publication, information on interventions, outcome measures, and control treatments as well as data related to the dimensions of evidence.

## Results

**Study identification and selection:** Figure 1 presents a flowchart of the search approach and decision-making regarding inclusion of articles for the review. Five systematic reviews and 26 primary experimental studies were identified. The systematic reviews produced 7 additional experimental studies from their reference lists (studies which had not already been identified from the search). Ten experimental studies were excluded as they were not considered to be relevant after detailed reading. They did not focus on ACL disorder, rather on muscle activity in CKC and OKC, or range of motion compared CKC and OKC, or electromyographic investigation. The excluded studies are listed in Appendix 2.

**Figure 1. Inclusion of Articles for Review**



**Hierarchy of evidence:** The 23 retained articles comprised seven randomized controlled trials (RCT) (hierarchy level 1b), one randomized trial (RT) and two controlled trials (CT) (hierarchy level 2a), and 13 trials (T) (hierarchy Level 2b) (see Table 1 for definitions). The frequency of study design is reported as part of Table 2.

**Methodological quality:** The two reviewers agreed 98% of the time on the quality score for the studies included in this review. Discrepancies were resolved in every case by discussion. Two studies had good methodological quality.<sup>15,21</sup> Twenty studies had moderate quality.<sup>3,5-7,14,16-20, 22-31</sup> One study had poor quality.<sup>32</sup> None of them fulfilled the criteria for excellent quality. All studies with good or moderate quality methodology were RCTs (outlined in Table 2). Appendix 3 provides the raw data from PEDro instrument scoring for each included study.

**Interventions and comparators:** The treatment options in the intervention and control groups, and the outcome measures, are outlined in Table 2. The interventions comprised CKC exercises of some sort, and the controls consisted of OKC exercises, except for one study which considered a combination of CKC and OKC exercises.<sup>14</sup> Only nine of the 23 reviewed articles used a control group.<sup>5,7,14-16,21-23</sup> The remaining 14 studies used CKC or OKC or a combination of CKC and OKC exercises as their intervention. Three used "quasi control groups," described as control groups, but where the same subject-other leg was used, or the same intervention was applied to two or three different types of ACL disorders. The remaining 11 studies did not have a control group. The duration of treatment ranged from four weeks to three months, although dosage and progression of the treatment was generally not mentioned.

**Table 2** Intervention and control treatment in relation to outcome measures, and methodological quality categories

First author/year	Hierarchy	Quality	Sample size	Intervention	Control	Outcome measures
Bynum/1995	1b	good	100	CKC	OKC	Lysholm, Tegner, KT 1000
Mikkelsen/2000	1b	moderate	44	CKC	OKC & CKC	KT 1000, Kin Com dynamometer, functional questionnaire
Morrissey/2000	1b	moderate	46	CKC	OKC	arthrometer
Perry/2005	1b	moderate	49	CKC	OKC	arthrometer, function questionnaire
Morrissey/2002	1b	moderate	43	CKC	OKC	arthrometer, knee questionnaire, VAS
Hooper/2001	1b	moderate	47	CKC	OKC	gait/function
Heijne/2004	2b	poor	9	CKC		DVRT, electrogoniometer
Fleming/2003	2b	moderate	10	CKC		DVRT
Jenkins/1997	2a	moderate	19	CKC & OKC		KT 1000
Kvist/2001a	2b	moderate	12	CKC & OKC		computerized goniometer
Lutz/1993	2b	moderate	5	CKC & OKC		Cybox II isokinetic dynamometer
Wilk/1996	2b	moderate	10	CKC & OKC		External Load Measurement Devices
Stuart/1996	2b	moderate	6	CKC		force platform, video
Beynon/1995	2b	moderate	11	OKC		HEST
Beynon/1997	2b	moderate	8	CKC & OKC		DVRT
Fleming/1998	2b	moderate	8	CKC		DVRT
Yack/1993	2b	moderate	11	CKC & OKC		electropotentiometer
Brindle/2002	2b	moderate	15	CKC & OKC		Cybox Eagle Knee Extension
Kvist/2001b	2a	moderate	12	CKC		CA-4000 electrogoniometer
Toutoungi/2000	2b	moderate	16	CKC	OKC	dynamometer and force platform
Howell/1990	2a	moderate	42	CKC	OKC	KT 1000
Kirkley/2001	1b	good	103	CKC	OKC	KT 1000
Li/2004	2b	moderate	5	CKC		Computerized technique

**Outcome measures:** The most common outcome measures were reported in different ways, and related to strain / stress / elongation / anterior tibial displacement on healthy, deficient or reconstructed ACLs. Outcome measure instrumentation included the KT 1000 arthrometer, KIN-COM dynamometer, Knee Signature System arthrometer, Ligamentum arthrometer, differential variable reluctance transducer (DVRT), computerized

goniometer, Cybox II isokinetic dynamometer, Hall effect transducer (HEST), force platform, and potentiometer. In some studies, functional questionnaires were also used, for instance Lysholm knee function scoring scale, Tegner activity rating scale, functional questionnaire, Hughston Clinic knee self-assessment questionnaire, and jump test, with the intention of gaining information about resumption of daily function and satisfaction of

treatment.<sup>6,7,14,21,22,27</sup> Some studies additionally measured other outcomes such as pain, range of motion, and electromyographic activity of the muscles; however these were not included in this systematic review because they did not fit the inclusion criteria.

**Sample size:** All but two of the studies had limited statistical power due to small sample size. There were only two studies which demonstrated statistical power analyses calculations.<sup>7,15</sup> The subject numbers in the included studies are reported per study in Table 2.

All studies used subjects with healthy, deficient or reconstructed ACLs. Of the studies on reconstructed ACLs, all but one study reported on the use of the patellar tendon as graft, the remaining study only mentioning reconstructed ACL without additional explanation.<sup>16</sup> The subjects and reconstruction types

related to each study are presented in Table 3. Out of the 23 reviewed articles, three showed a statistically significant difference in all outcome measures when comparing the effect of CKC and OKC exercises, 11 studies showed some outcomes with significant differences, and nine demonstrated no outcomes with significant differences. Eleven authors recommended CKC in preference to OKC, two recommended a combination of CKC and OKC, none recommended OKC alone and the remaining ten presented equivocal evidence.<sup>3,5,14,15,17,18-20,22,25-27</sup> A summary of the frequency with which outcome measures showed significantly different findings when comparing interventions is provided in Table 3. Although information on ACL strain / forces was sought in this review, the way in which outcomes was reported differed between studies, constraining opportunities to compare findings directly.

**Table 3** Healthy, deficient and reconstructed subjects related to each study & the degree of significance of the outcome measures

First author/year	healthy	deficient	reconstructed (type of reconstruction)	Degree of significance of outcome measures
Bynum/1995			patellar tendon	fair
Mikkelsen/2000			bone patellar tendon bone graft	fair
Morrissey/2000			bone patellar tendon bone graft, patellar tendon	none
Perry/2005			bone patellar tendon bone graft, patellar tendon	none
Morrissey/2002			bone patellar tendon bone graft, patellar tendon	none
Hooper/2001			bone patellar tendon bone graft, patellar tendon	none
Heijne/2004	healthy			none
Fleming/2003	healthy			none
Jenkins/1997		deficient		good
Kvist/2001a	healthy	deficient		fair
Lutz/1993	healthy			fair
Wilk/1996	healthy			good
Stuart/1996	healthy			none
Beynon/1995	healthy			fair
Beynon/1997	healthy			none
Fleming/1998	healthy			none
Yack/1993	healthy	deficient		fair
Brindle/2002	healthy			fair
Kvist/2001b	healthy	deficient		fair
Toutoungi/2000	healthy			fair
Howell/1990	healthy	deficient	reconstructed	fair
Kirkley/2001	healthy	deficient	bone patellar tendon bone autograft	fair
Li/2004	healthy			good

**Effect size:** As only nine of the 23 studies used a control group, it was only possible within this subset of studies to consider the effect size of the difference in shear forces. None of these studies reported the effect size directly, thus effect size needed to be calculated from available data. Five studies did not provide sufficient data with which to calculate the effect size, mostly not reporting the standard deviation of the control group

difference.<sup>5,14,16,21,22</sup> The effect sizes in the remaining four studies where data was available were:

- 0.13 (knee extensor maximum peak torque)<sup>7</sup>
- 0.33 (anterior tibial displacement)<sup>6</sup>
- 0.38 (peak extensor moment during stair ascent after 2 weeks postoperative), 0.06 (peak extensor moment during stair ascent after 6

weeks postoperative), 0.05 (peak extensor moment during stair descent after 2 weeks postoperative), 0.07 (peak extensor moment during stair descent after 6 weeks postoperative)<sup>23</sup>

- 0.05 (anterior tibial translation for a normal knee), 0.07 (anterior tibial translation for a deficient knee), 0.21 (anterior tibial translation for a reconstructed knee)<sup>15</sup>

All the available effect sizes were poor, being less than 0.4.<sup>13</sup> This suggests that the study findings are generally unconvincing, and provide little support for a difference in effect of CKC or OKC exercises in minimising strain on the ACL.

#### **Clinical relevance**

Subjects' age ranged from 14 – 60 years, and gender proportions were biased towards males (overall studies 2 males: 1 female). The distribution of the country of origin of studies was 12 studies in the United States of America, six in the United Kingdom, and five in Sweden. The duration of treatment ranged from four weeks to three months, although dosage and progression of the treatment was rarely mentioned.

#### **Discussion**

There was no consensus in the literature included in this review regarding the differences in effect on the strain forces on the ACL of CKC and/or OKC exercises during a rehabilitation program. The lack of high quality studies, and the small number of studies demonstrating strong statistically significant findings across outcome measures, indicates that either treatment option on its own, or in combination, could be acceptable in current clinical practice.

#### **Clinical applicability**

##### **External validity**

All but one study reported information on the external generalisability of the study population (see scores for Pedro item 1 in appendix 3).

However, with respect to age, socioeconomic status and country, the studies included in this systematic review had good external validity. The countries of origin of the studies reflected similar socioeconomic status of patients, and a range of health care systems. As no study explicitly focused on a specific group of participants, and the study samples and subject ages in the included studies reflected the range of individuals commonly affected by ACL disorders, the findings reflect the general population without focusing on a specific age group or sport.

However there are some concerns regarding external validity for men and women, and the potential for bias in interpretation of findings. Murphy et al reported the epidemiology of incidence of ACL rupture as 67% female and 33% male. These proportions were not reflected in the reviewed studies.<sup>33</sup> This potentially decreases the generalisability of findings to all ACL injured individuals. Additionally the small sample size of all but two of the

studies suggest potential under-powering of many studies, which consequently may explain the lack of significant findings of the difference in ACL shear forces between CKC and OKC exercises.<sup>15,21</sup>

The CKC and OKC interventions in all studies were variably explained, and the interventions were not country-specific. They thus present interventions which could be adopted by physiotherapists around the world.

#### **Study quality**

No study was rated as having excellent quality. The only two good quality studies were RCTs, meaning that the findings from all other studies must be interpreted with caution, because there are potential risks for biasing in interpreting the outcomes.

A surprising finding of this systematic review was the rarity of good quality RCTs in this research area.<sup>15,21</sup> No meta-analysis had been undertaken within the time frame of the review (1990-2006) and there were only five systematic reviews on this research question. Most studies were lacking with respect to unbiased study design and quality of methodology. Only seven out of the 23 studies used a control group, and three used a quasi-control group (the contralateral healthy leg was the control).<sup>3,25,26</sup> No randomization therefore was possible and no homogeneity at baseline could be described. Because of this it was difficult to generalise the findings. Many studies were also lacking in providing adequate follow-up, blinding procedures, reporting drop outs, and not using sample size or power calculation. The significance of findings, standard deviations and effect size were rarely provided. Thus there is a need for higher hierarchy studies with greater methodological quality and more comprehensive reporting, in order to establish appropriate effect sizes and obtain a clearer idea of clinical relevance and transfer of findings to clinical practice. Additionally, the lack of evidence regarding advantages or disadvantages of OKC made it difficult to establish clinical relevance. Therefore most authors continued to recommend CKC exercises as a default position until a better understanding of the effects on ACL of OKC exercises is achieved.

The variability in the ways in which shear forces were measured in the included studies provided little opportunity to compare findings in a meaningful clinical manner. Coupled with the small effect sizes from the few studies which provided sufficient detail for calculation, it appears that the literature does not currently provide consistent evidence for the effectiveness of either intervention in reducing shear forces on the ACL. Thus there was little useful clinical information in the studies that supported immediate uptake of research findings into changed practice. This was reflected by a lack of detail related to application of the intervention (including time frames of interventions, dosage, and progression of intervention), which made it difficult for therapists to transfer the study interventions or findings into clinical practice. Studies infrequently addressed how often and how long the treatment/exercises should be performed

(the range being from four weeks to three months). Additionally it was not reported whether patients were compliant with a home program, whether they were employed or participating in sporting activities, or undertaking concurrent treatments. There was inadequate information about how long after surgery or injury the treatment commenced, and which operation technique had been used. While surgery techniques seemed similar, there were different rehabilitation protocols depending on which graft had been performed, and in which hospital setting. Information was however, lacking on post surgery plans (time of immobilization, weight bearing, movement restrictions or other additional injuries) which could influence the effect of strain on the ACL especially in short term outcomes.<sup>16</sup> As the relationship between ACL graft strain and its healing response is currently unknown, more studies are required to explore this area.<sup>28</sup>

### Conclusion

Not surprisingly, a recommendation from this review is that further research into this topic is required. Future studies should aim to use higher order experimental design (higher hierarchy level) and have better methodological quality, including at a minimum, single blinding, larger sample size, use of control groups, and reporting of statistical data such as effect size, confidence intervals and standard deviations. Furthermore it is recommended that functional test

outcomes are reported, as well as isokinetic or laboratory tests, because of questionable conclusions regarding to functional stability, activity or strain on ACL during daily activities in the current studies. Prospective RCTs should be performed with reconstructed ACL ligaments and healthy ACLs to determine optimal rehabilitation programs; however, it would still be problematic to extrapolate findings from studies on reconstructed ACLs to healthy knees, or vice versa. This concern is underlined by Kirkley et al regarding differences in response to strain or stress between healthy and reconstructed ACLs.<sup>15</sup> Furthermore, the effect of OKC exercises on ACL strain requires clarification, as do the effects of a combination of CKC and OKC exercises.<sup>14,19</sup>

The lack of high evidence level and good quality studies constrains the formulation of clear clinical recommendations regarding the effect of closed versus open kinetic chain exercises on ACL strain. Thus the findings of this review must be interpreted with caution. Nevertheless the findings support the conclusion that CKC exercises generally produce less stress/strain on ACL and have a greater functional impact than OKC exercises. There are no studies which support the effectiveness of OKC exercises. Thus the cautious clinical recommendation of this systematic review would be to use CKC exercises or a combination of CKC and OKC exercises rather than OKC exercises alone.

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## Appendix 1. Terminology and definitions

### *Definition of terms*

Effect is defined as the clinical findings within the stated inclusion/exclusion criteria for this systematic review.

Open kinetic chain exercises are defined as movement in a mobile foot and independent motion at the hip and ankle joint.

Closed kinetic chain exercises are defined as the foot is in a fixed position and motion at the knee joint is accompanied with motion in the hip and ankle joints.

The anterior cruciate ligament (ACL) is the most important structure in the knee joint to prevent an anterior tibial displacement (ATD) and stabilizes the knee joint during active and passive activities. In this systematic review conditions of healthy, ruptured, deficient and reconstructed ACLs were included.

### *Inclusion criteria*

#### Study design

Any study reflected in the following was included: randomized controlled trials, controlled trials, randomized trials, trials, clinical trials, case studies, single and double blind studies, and experimental studies.

#### Population

- Subjects aged between 14 – 60
- All kind of ACL conditions (healthy, ruptured, deficient and reconstructed) and also combined with meniscus lesion, articular cartilage lesion, medial or lateral collateral disorders
- Male and female population

### *Exclusion criteria and limitations*

#### Population

- Subjects aged under 14 and above 60
- Other conditions within the knee joint than ACL disorders

#### Limitations

- English language
- Humans
- Publication years from 1990 - 2006
- Removing of duplicates
- Articles, which were not available in full text within Adelaide or as electronic resources, were excluded.

### *Search terms used regarding:*

#### Population

- Anterior cruciate ligament, anterior cruciate ligament reconstruction, bone patellar tendon bone graft, hamstring graft, patellar tendon graft, anterior cruciate ligament repair, anterior cruciate ligament injur\$, anterior cruciate ligament deficiency

#### Intervention and comparison

- Open kinetic chain, closed kinetic chain, distally fixated, nondistally fixated, exercise, management, rehabilitation, physical therapy, physiotherapy, resistance training
- Randomized controlled trial, controlled trial, randomized trial, trial, clinical trial, random allocation, case study, double blind, single blind, experimental, study

#### Outcomes

- Tibiofemoral joint force, anterior tibial displacement, elongation, instability, stability, isometric, knee laxity, strength, load, stress, strain, arthrometer, function

### Appendix 2 (excluded studies)

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