Exercise for Rehabilitation and Treatment: Summary of Research

Summarizing research findings to evaluate the effectiveness of exercise for rehabilitation and treatment of orthopedic conditions

Summary 5: Rehabilitation after ACL injury (I) February 2009

Q: Following ACL reconstruction or injury, does open or closed chain quadriceps strengthening, or the combination, result in reduced knee laxity and better functional outcomes?

To answer this question, we performed a comprehensive search of the PubMed database (September 2008) for randomized, controlled trials and systematic reviews that addressed this specific research question. 1

Of the seven publications that met the criteria for inclusion in this review, five compared open kinetic chain (OKC) vs closed kinetic chain (CKC) exercise (1,3,4,6,7); one evaluated the effect of adding OKC exercise to CKC exercise (5); and one compared early versus late OKC exercise (2).

The effect of open vs closed chain exercise on knee laxity was evaluated in five studies (1,3,5-7). Four of the studies found no significant differences in knee laxity (1,3,5,6), while one found slightly lower tibial translation after CKC training of uncertain clinical significance (7). A significantly greater tibial translation was also found with early vs late OKC exercise, but only among subjects receiving a hamstring tendon graft (2). The authors recommend that OKC exercise not be introduced early for these patients.

The objective (measurable) functional outcomes that were evaluated by at least two of the reviewed studies included quadriceps strength, range of motion, anterior knee pain, and single-leg jumps. Findings included significantly greater isokinetic quadriceps strength with OKC in two of three studies (1,5), but no differences in ROM (1,2), knee pain (2,4), or single leg jump tests (1,3).

The subjective (self-reported) functional outcomes that were commonly evaluated included Lysholm score (1,7) and the Tegner score/return to sport questionnaire (1,5,7). No differences were found except participants performing a combination of CKC and OKC exercises were significantly more likely to return to sport at their pre-injury levels compared to CKC alone (5).

Based on this review, it can be concluded that OKC and CKC exercise during ACL rehabilitation have a similar effect on knee laxity and functional outcomes. A 2005 review of open vs closed chain exercise concluded that an optimum program would likely include a mix of both types of exercise (8). Sample exercises from VHI PC-Kits have been provided based on examples from these studies.

Quad strength single-leg quarter squat from VHI PC-Kits: Closed Chain, Lower Extremity #12

Knee extension from VHI PC-Kits: Orthopedic, Hip/Knee #76
### Table 1: Overview of Research Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Overview</th>
<th>Description of Intervention</th>
<th>Results &amp; Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hypothesis/Aim:</strong></td>
<td>To compare OKC and CKC rehabilitation programs for increasing quadriceps strength, without increasing tibial translation, in patients with acute ACL deficiency</td>
<td>Both groups completed identical rehabilitation programs with exception of quadriceps strengthening mode (OKC or CKC).</td>
<td><strong>Outcome Measures:</strong></td>
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<td><strong>Subjects:</strong> 42 adults (24 male; 18 female) meeting the following criteria: 15-45 yrs; unilateral ACL rupture ≤14 wks old (verified by arthroscopy or MRI); and no previous LE injury or surgery except partial meniscal or minor collateral ligament injury in the injured knee, or partial meniscectomy in injured or contralateral knee</td>
<td></td>
<td>1. Primary outcome measures</td>
<td>a. Quadriceps strength: 1-RM squat test on one leg, isokinetic flexion and extension, and single leg vertical and horizontal jump. b. Tibial translation: Static translation using the CA-4000. Dynamic translation was measured during the stance phase of walking, single leg squat on one leg, and isokinetic knee flexion and extension at 60°/sec.</td>
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<td><strong>Groups:</strong></td>
<td>1. CKC (n=20) 2. OKC (n=22)</td>
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<td>2. Secondary outcome measures</td>
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<td><strong>Duration:</strong> The length of the intervention was 4 mos. Assessments were conducted at baseline and 4 mos.</td>
<td></td>
<td><strong>Results:</strong> <strong>Primary outcomes.</strong> After rehabilitation, the OKC group showed greater knee extension strength compared to the CKC group (p=0.009), expressed as a percentage of strength of the uninjured leg (96% vs 84%). No differences were seen in the other strength measures. There were also no differences in measures of static or dynamic tibial translation between the groups after rehabilitation. Both groups showed significant translation compared to the uninjured leg. <strong>Secondary outcomes.</strong> There was no difference between the groups in swelling, PROM, or muscle activation. There were also no differences in subjective measures of knee function or activity. However, the CKC group had a significantly greater increase in Lysholm score (p=0.044), attributed to a lower baseline score.</td>
<td><strong>Conclusions:</strong> The authors conclude that OKC exercises result in improved quadriceps strength</td>
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Hypothesis/Aim:
To compare early vs late initiation of OKC quadriceps strengthening exercises following ACL reconstruction using either patellar or hamstring tendon grafts

Subjects: 68 adults (36 male; 32 female) meeting the following criteria: 16-50 yrs; no symptoms in contralateral knee, meniscus lesions suitable for fixation, or grafts harvested from contralateral limb

Groups:
1. Early (4 wk post-op) exercise with patellar tendon graft (P4, n=19)
2. Late (12 wk post-op) exercise with patellar tendon graft (P12, n=15)
3. Early exercise with hamstring tendon graft (H4, n=17)
4. Late exercise with hamstring tendon graft (H12, n=17)

Duration: The length of the intervention was individually determined for each subject by the treating physical therapist.

Outcome Measures:
1. Passive knee ROM for flexion and extension
2. Anterior knee laxity: KT-1000 arthometer
3. Pivot shift rotational instability
4. Postural sway during single-leg stance: Kinesthetic Ability Trainer 2000
5. Quadriceps and hamstring strength: 90°/sec within 10-90° of knee flexion using the Kin-Com dynamometer
6. Anterior knee pain: Questionnaire specifically for ACL injured patients

Results: There were no significant differences between the groups in knee ROM, postural sway, or reported knee pain. The H4 group had a significantly higher anterior knee laxity compared to all other groups (reported as difference from uninjured knee) at the 3 mos assessment. The H4 group also had a significantly higher rotational instability compared to the P4 group at mos 3 and 7. At 7 mos, P4 demonstrated a deficit in quadriceps strength from baseline (p=0.008), while H4 (p=0.002) and H12 (p=0.0005) showed a hamstring strength deficit.

Conclusions: The authors concluded that early start OKC exercises should not be undertaken when hamstring grafts are used in ACL reconstruction as it may result in greater anterior knee laxity. Otherwise, there were no substantial differences between early and late start for OKC exercises in the various outcomes tested. Of consideration, 20 different orthopedic surgeons were involved in the study with varying degrees of surgical skill and experience.
3) Perry, 2005

**Hypothesis/Aim:** To compare OKC and CKC training on knee joint laxity and function after ACL reconstruction

**Subjects:** 49 adults (37 male; 12 female) meeting the following criteria: 18-60 yrs; completed ACL reconstruction at participating hospital; and without prior pathology in contralateral extremity in previous 6 mos or PCL injury in operated knee

**Groups:**

1. OKC (n=24)
2. CKC (n=25)

**Duration:** Subjects were enrolled approximately 8 wks post-surgery. The length of the intervention was 6 wks. Assessments were completed at baseline and 14 wks.

**Outcome Measures:**

Both groups received 3 physical therapy sessions/wk and followed a common set of 14 activities (e.g., cycling, lunges, wobbleboard, inferential stimulation, ice therapy). The groups differed in the type of hip and knee extensor exercise performed (described below). Both groups performed 3 sets of 20 repetition maximums (RMs) of the prescribed hip/knee exercise during the first 4 wks, and 3 sets of 6 RMs during the last 2 wks. Load was increased when pain level was less than 5/10 with full ROM. Speed was controlled at 2 sec each for concentric and eccentric using a metronome. Absolute quadriceps load was not standardized between groups.

**OKC training:** In addition to common exercises as described above, the OKC group performed unilateral resistance training of hip and knee extensors using ankle weights or a knee extension/hamstring curl machine.

**CKC training:** In addition to common exercises as described above, the CKC group performed unilateral resistance training of hip and knee extensors using a leg press machine.

**Results:** Overall, there were no significant differences found between the groups in any of the outcome measures (jump testing was terminated as a precautionary measure after a minor injury in one subject). The change in knee joint laxity from pre-testing to post-testing was 12±2 to 12±3 mm in the CKC group and 11±3 to 12±3 mm in the OKC group (p=0.10).

**Conclusions:** The authors conclude that OKC and CKC training do not differ in their effects on knee laxity or knee function during wks 8-14 after ACL reconstruction. However, they do not recommend replacing CKC training with OKC training until further research can evaluate the effect of greater training intensities, while also controlling for possible clinician or patient bias toward OKC exercise. Finally, it is worth noting that 60% of the subjects in the CKC group received a hamstring graft, while only 25% of the OKC group did. The potential influence of graft type was not investigated due to the limited sample size.
4) Morrisey, 2002

Both groups completed 3 physical therapy sessions/wk for 4 wks. Each session included 3 sets of 20 RM of CKC or OKC exercise at controlled velocities (1.5 sec concentric and 3 sec eccentric) in the range of 90-0°. Additional allowed exercises common to both groups included hip adduction, abduction, and knee flexion (excluding plantar flexion), and endurance training with a stationary cycle.

**OKC exercise**: Subjects performed unilateral OKC resistance training of hip and knee extensors using ankle weights or machines.

**CKC exercise**: Subjects performed unilateral CKC resistance training of hip and knee extensors on a leg press machine.

**Results**: At 6 wks post-surgery, there was a significant decrease in knee pain as assessed by the Hughston Clinic Questionnaire among participants in both groups (p<0.01-0.001 for the 3 selected questions), however there were no significant differences between groups (p=0.49-0.94). Similarly, there were no significant differences between the groups in the reduction of pain during isometric knee extension (p=0.67). The most common location of pain was the patellar ligament (39%).

**Conclusions**: The authors conclude that the knee pain did not differ between groups because the incurred strain on the patellar ligament is similar for both modes of exercise. Generalizability of findings is limited by duration (4 wks) and timing (2-6 wks post-op) of intervention.

**Hypothesis/Aim**: To compare the effects of CKC quadriceps strengthening vs a combination of CKC and OKC quadriceps strengthening following ACL reconstruction.

Subjects: 44 adults (34 male; 10 female) meeting the following criteria: diagnosis of first ACL injury; healthy contralateral leg; and without previous serious knee injury or concomitant injury that would preclude participation.

After ACL reconstruction with bone-patellar tendon-bone grafts, both groups started a 6 mo. PT supervised rehabilitation program that included exercises for range of motion, flexibility, proprioception and balance, hamstring strengthening, and quadriceps strengthening (CKC only).

**CKC+OKC exercises**: After 6 wks of the standard rehabilitation program, the CKC+OKC group continued with the rehabilitation

Outcome Measures:

1. Anterior knee laxity: KT-1000
2. Isokinetic quadriceps and hamstring strength at 30, 120, and 240°/sec
3. Knee function and satisfaction: rated with a 4-point questionnaire (31±9 mos post-surgery)
4. Return to sports participation: questionnaire

Results: After 6 mos, side-to-side differences in anterior knee laxity were not significantly different between groups (CKC+OKC, 1.2mm; OKC, 1.7mm). Isokinetic hamstring strength (injured vs healthy) was also not significantly different between the groups after 6 mos. Isokinetic quadriceps strength (injured vs healthy) was significantly greater (8-13%) in the CKC+OKC group (p<0.05) at 6 mos at all angular
that would preclude participation in the rehabilitation program

Groups:

1. CKC quadriceps exercises (n=22)
2. CKC+OKC quadriceps exercises (n=22)

Duration: The length of the intervention was 6 mos. Assessments were completed before surgery, 6 mos after surgery, and about 1 yr (questionnaires only) after surgery.

program but performed additional isokinetic concentric and eccentric quadriceps exercises. The exercises progressed from 90-40° of knee flexion at wk 6 to 90-10° at wk 12. Subjects performed 50-80 repetitions per set and one (wk 6) to four (wk 12) sets/wk. Angular velocities ranged from 30-240°/sec.

CKC exercises: The CKC group continued with the same rehabilitation program performed by the CKC+OKC group, without the additional isokinetic quadriceps exercises.

velocities except concentric at 240°/sec. The subjects’ ratings of their knee function and satisfaction were not different between the groups, however the return to sport questionnaire found a significantly greater proportion of the CKC+OKC participants returning to sport at their pre-injury level (12/22 vs 5/22, p<0.05). The median time to return to sport at the pre-injury level was 7.5±1 mos for CKC+OKC and 9.5±3 mos for CKC.

Conclusions: The authors concluded that the addition of OKC exercises to ACL rehabilitation, compared to CKC exercises alone, leads to improved quadriceps strength and earlier return to pre-injury levels of sport. Of note, the CKC+OKC group underwent a greater volume of exercise compared to the CKC only group. Thus the between group differences may simply be due to the addition of exercises that resulted in improvements, not necessarily OKC exercises.

Hypothesis/Aim:
To compare CKC and OKC training on knee laxity during the early period after ACL reconstruction

Subjects: 36 adults (29 male; 7 female) meeting the following criteria: As described in Morrissey, 2002 with the exception of the minimum number of completed treatment sessions being 9 rather than 8

Groups:

1. OKC exercise (n=18)
2. CKC exercise (n=18)

Duration: Morrissey, 2002

Outcome Measures:

1. Anterior knee laxity: Knee Signature System

Results: There were no significant differences in knee laxity between the groups, with pre- and post-values of 9.87 and 9.98 mm for the CKC group, and 9.46 and 10.25 mm for the OKC group (p=0.32).

Conclusions: Generalizability of findings is limited by duration (4 wks) and timing (2-6 wks post-op) of intervention. The authors concluded that the concern “about the safety of OKC knee extensor training in the early periods after ACLR [anterior cruciate ligament reconstruction] surgery may not be well founded.”
Hypothesis/Aim:
To compare the effects of CKC and OKC exercises during accelerated rehabilitation following ACL reconstruction.

Subjects: 97 adults (88 male; 9 female) meeting the following criteria: >18 yrs; isolated ACL tear; normal contralateral knee; and rigid graft fixation.

Groups:
1. OKC exercises (n=47)
2. CKC exercises (n=50)

Duration: The length of the intervention was 1 yr. Assessments were completed pre- and post-operatively at 3 mo intervals for 1 yr.

Examples of exercises from both groups are provided below (not complete list). Details on frequency, duration, or intensity were not provided.

OKC exercises: 0-3wk: Co contraction isometric
3wk: 30° flexion SLR
6wk: Quadriceps isotonic, cycling, proprioception
8wk: Isokinetic hamstring
12wk: Quadriceps isotonic
16wk: Jogging, knee bends
24wk: Quadriceps isokinetic, progressive resistance training
7-8mos: Noncutting, jumping sports
12mos: Unrestricted sports

CKC exercises: 0-8wk: Knee bends, leg press
6wk: Cycling, proprioception
8wk: Single leg knee bend, walking against sport cord, slow jog against cord
12wk: Side-to-side jumping against sport cord
16wk: Sport specific exercises with sport cord
24wk: Progressive running and sport-specific
9mos: Noncutting, jumping sports
12mos: Unrestricted sports

Outcome Measures:
1. Subjective assessments included Lysholm knee function scale, Tegner activity scale (modified), overall patient assessment rating, and a satisfaction survey.
2. Objective assessments included knee ROM, patellofemoral tenderness, and knee laxity using KT-1000 arthometer.

Results: At final follow up, 66% of subjects completed objective testing and 88% completed subjective testing at a mean of 19 mos post-surgery (range 12-36 mos). Among the subjective assessments, there were no significant differences between the groups in the Lysholm score, Tegner scale, or patient assessment. The satisfaction survey showed that more CKC subjects reported returning to normal daily activities “sooner than expected” (72% vs 33%, p=0.01). Patellofemoral tenderness was significantly less at 9 mos in the CKC group (15% vs 38%, p=0.05) but it was not significant at final follow up (18% vs 24%, p=0.48). Among the objective assessments, there were no differences in flexion or extension deficit, Lachman pivot shift. The CKC group had a significantly lower side-to-side difference in tibial translation at the maximum applied force (1.6 vs 3.3mm, p=0.02), but the difference at 20 lbs of force did not meet significance (1.1 vs. 2.2, p=0.06).

Conclusions: The authors concluded that CKC exercises as part of an accelerate program are safe, effective, and may offer advantages over OKC exercises. Of note, the amount of applied resistance and rate of progression were not standardized between the two groups. Thus, the faster return to sport may be attributed to these rehabilitation protocol differences.

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Table 2: Additional Exercises from VHI Exercise Kits

The exercises included in this newsletter are intended only as a sampling of exercises from the different VHI exercise collections that might be relevant to the topic discussed. Their inclusion in this newsletter does not represent any rehabilitation protocol or any suggested exercise progression that could be used with patients. Using the order of the exercises to create a rehabilitation program for patients is inappropriate and could result in serious injury.
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Table 2: Additional Exercises from VHI Exercise Kits (cont.)

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<td>Kit</td>
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<td>Orthopedic</td>
<td>Hip/Knee</td>
</tr>
</tbody>
</table>
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References


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1 PubMed database was used to identify peer-reviewed research publications that addressed the specific clinical question (population, diagnosis, treatment, and outcome). For inclusion, studies must be a randomized controlled trial (RCTs) and published in English. A maximum of 10 RCTs were reviewed, with strength of design and publication year determining which studies to include.

2 No study footnotes needed.

3 Statistical definitions: 1) *P*-value (*p*) denotes the level of significance, where *p*<0.05 indicates a statistically significant result. 2) *95% Confidence Interval (95% CI)*: a range that contains the true population estimate 95% of the time. A smaller range indicates an estimate that is more precise. 3) *Relative Risk (RR)* is a ratio of proportions (ProportionTreatment / ProportionControl). RR less than 1.0 indicates the treatment group has a decreased risk of developing the condition/disease compared to the control group, while RR greater than 1.0 indicates the treatment group has an increased risk. 4) *Incidence Risk Ratio (IRR)* is the ratio of two incidence rates; the incidence rate among the treatment group divided by the incidence rate in the control group. IRR gives a relative measure of the effect of a given treatment with values less than 1.0 favoring the treatment. 5) *Hazard Ratio (HR)* is the relative likelihood of experiencing a particular event; an HR of 0.5 indicates that one group has half the risk of the other group. HR is broadly equivalent to RR, but is useful when the risk is not constant with respect to time as it uses information collected at different times. 6) *Odds Ratio (OR)* is the odds of an event happening in the treatment group expressed as a proportion of the odds of an event happening in the control group and can be interpreted similar to the RR. 7) *Likelihood Ratio (LR)* is the likelihood that a given test result would be expected in a patient with the target disorder compared to the likelihood that the same result would be expected in a patient without that disorder. The LR is used to assess how good a diagnostic test is and to help in selecting an appropriate diagnostic test(s) or sequence of tests.