Do early quadriceps exercises affect the outcome of ACL reconstruction? A randomised controlled trial

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A prospective, blinded, randomised controlled trial investigated the effectiveness of quadriceps exercises following anterior cruciate ligament reconstruction. A treatment group (Quadriceps exercise group) performed straight leg raises and isometric quadriceps contractions throughout the first two postoperative weeks, and a second group (No quadriceps exercise group) did not. A battery of outcome measures assessed subjects postoperatively at day one, two weeks, and one, three and six months. A total of 103 patients (Quadriceps exercise n = 48, No quadriceps exercise n = 55) commenced the study with 91 subjects available at final follow up (Quadriceps exercise n = 47, No quadriceps exercise n = 44). Performance of quadriceps exercises significantly improved a number of knee flexion and extension range of motion measurements (p = 0.01 to 0.04). No significant differences were found between the two groups at any postoperative period for quadriceps lag (p = 0.36), functional hop testing (p = 0.49 to 0.51), isokinetic quadriceps strength (p = 0.70 to 0.72), the majority of numerical analogue scores (p = 0.1 to 0.94) and Cincinnati scores (p = 0.10 to 0.84). Subjects performing quadriceps exercises reported significantly higher pain scores with exercise on the first postoperative day (p = 0.02). At six months postoperatively, the Quadriceps exercise subjects reported significantly more favourable Cincinnati scores for symptoms (p = 0.005) and problems with sport (p = 0.05). While average knee laxity was not significantly different between treatment groups over time (p = 0.27 to 0.94), quadriceps exercise performance was associated with a significantly lower incidence of abnormal knee laxity. Isometric quadriceps exercises and straight leg raises can be safely prescribed during the first two postoperative weeks and confer advantages for faster recovery of knee range of motion and stability. It remains to be proven whether the magnitude of differences between groups is clinically significant. **[Shaw T, Williams MT and Chipchase LS (2005): Do early quadriceps exercises affect the outcome of ACL reconstruction? A randomised controlled trial. *Australian Journal of Physiotherapy* 51: 9–17]**

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Introduction

Anterior cruciate ligament rupture is one of the most common debilitating knee injuries that can result in significant functional impairment (Baquie and Brukner 1997, Miyasaka et al 1991, Seward et al 1993). Surgical reconstruction of a ruptured ACL is advocated as the treatment of choice, particularly for individuals who intend to resume competitive sporting activities (Barrack et al 1990, Fetto and Marshall 1980, Frank and Jackson 1997). An integral element in producing a favourable outcome following anterior cruciate ligament reconstruction is participation in postoperative rehabilitation. This is reflected by the volume of literature generated each year relating to various techniques and treatment protocols employed during rehabilitation after anterior cruciate ligament reconstruction.

Rehabilitation following anterior cruciate ligament reconstruction typically commences during the acute in-patient period. Early objectives include restoration of knee range of motion, pain management, reduction of swelling, early ambulation and commencement of muscle strengthening (Chipchase and Brumby 2001, De Carlo et al 2000, Paessler and Shelbourne 1995, Podesta et al 2001, Shelbourne and Wilckens 1990, Wilk and Andrews 1992). A variety of treatment modalities have been used during this period including cryotherapy, gait education, range of motion exercises, continuous passive motion machines, strengthening exercises, electrical stimulation and bracing (De Carlo et al 2000, Podesta et al 2001). Studies investigating the efficacy of these treatments have been reported but few have specifically investigated the effectiveness of strengthening exercises during the in-patient period (Beynnon et al 1997, Cohn et al 1989, Dervin et al 1998, Drez et al 1991, Edwards et al 1996, Konrath et al 1996, Lessard et al 1997, McCarthy et al 1993, Noyes et al 1987, O'Meara et al 1992, Ohkoshi et al 1999, Risberg et al 1999a, Rosen et al 1992),

Quadriceps exercises are frequently advocated during the acute postoperative period, justifiable in terms of muscle strengthening or atrophy prevention and tissue-healing physiology, though concern has been expressed over the safety of performing quadriceps exercises during this early phase when the graft is thought to be weakest and susceptible to harm (Arms et al 1984, Beynnon et al 1992, Beynnon et al 1995). Despite this apprehension, a number of published protocols have advocated quadriceps exercises such as isometric quadriceps exercises and straight leg raises (Abercrombie 1992, Beard and Dodd 1998, De Carlo et al 1994, De Carlo et al 1997, De Carlo et al 2000, Manal and Snyder-Mackler 1996, Mangine and Kremchek 1997, Podesta and Podesta 1994, Podesta et al 2001, Risberg et al 1999b, Tovin et al 1994, Wilk and Andrews 1992, Wilk et al 1993).

The effectiveness of performing quadriceps exercises during the early postoperative period appears, at the current time, to be unsubstantiated by prospective clinical outcome studies. Therefore, the aim of this study was to investigate whether specific quadriceps exercises in an acute postoperative rehabilitation program significantly altered postoperative outcome for anterior cruciate ligament reconstruction over six

Table 1. Exercises prescribed to each treatment group.

No quadriceps exercise group	Quadriceps exercise group
1. Foot and ankle exercises	1. Foot and ankle exercises
2. Active assisted knee flexion	2. Active assisted knee flexion
3. Calf stretches	3. Calf stretches
4. Passive knee extension	4. Passive knee extension
5. Standing posture	5. Standing posture
6. Gait education	6. Gait education
7. Passive knee extension with weight	7. Passive knee extension with weight
	8. Static quadriceps contraction*
	9. Straight leg raises*
	*10 repetitions, 3 times daily

months, relative to a program that excluded these exercises.

Method

The study used a randomised controlled, blinded, longitudinal design. Ethical approval was granted by the Human Research Ethics Committee of the University of South Australia. Subjects attending Sportsmed SA Hospital for elective anterior cruciate ligament reconstruction were eligible for inclusion if they were older than 18 years; underwent unilateral, arthroscopically-assisted anterior cruciate ligament reconstruction; received either a bone-patellar tendon-bone or semitendinosus-hamstring graft; and provided informed consent. Subjects were excluded if they had previous surgery on the reconstructed knee, excluding arthroscopy; a previous anterior cruciate ligament reconstruction on either knee; had sustained concurrent injury to the contralateral knee; received a concomitant collateral ligament repair; or resided in rural Australia, interstate, or overseas and were unlikely to be able to attend follow-up. Subjects who satisfied all involvement criteria were then asked to read and sign a consent form to confirm their commitment to being involved in the study. At this time, demographic details were recorded (gender, age, height, weight, and the date and cause of injury).

Subjects were allocated randomly to one of two treatment groups using a concealed allocation procedure. A member of the Sportsmed SA staff was responsible for subject allocation into treatment groups. After randomisation, the physiotherapist who administered the treatment was informed of which group the subject had been allocated to. The physiotherapist then administered the appropriate exercise regimen, but was not involved with any outcome measurements. The principal investigator performed all outcome measurements and was blinded to the group allocation for the duration of data collection.

The interventions performed by the Quadriceps exercise group and No quadriceps exercises group are listed in Table 1. The primary difference between the treatment groups was that subjects in the Quadriceps exercise group were instructed to perform specific quadriceps exercises (static quadriceps contraction and straight leg raises) daily throughout the first two postoperative weeks (10 repetitions, three times daily). Subjects were advised by the in-patient physiotherapist to perform the exercises until their first outpatient appointment, approximately 1 to 2 weeks postoperatively, at which time all subjects commenced a standard rehabilitation program. Individual exercise regimes were taught initially by the treating physiotherapist. Compliance was monitored with the Sports Injury Rehabilitation Adherence Score (SIRAS) and self-reported weekly logbooks (Brewer 2000).

Table 2. Outcome measures used in the study.

Measure	Day 1	2 weeks	1 month	3 months	6 months
Range of motion	✔	✔	✔	✔	✔
Quadriceps lag	✔	✔	✔	✔	✔
Limb circumference	✔	✔	✔	✔	✔
Pain	✔	✔	✔	✔	✔
Satisfaction	✔	✔	✔	✔	✔
Cincinnati Knee Rating System			✔	✔	✔
Knee laxity				✔	✔
Hop					✔
Isokinetic strength					✔

No single ‘gold standard’ outcome evaluation has been established for anterior cruciate ligament reconstruction (Shaw et al 2004). A combination of objective and subjective (patient reported) measures, which assessed disability and impairment, were used (Phillips et al 2000, Risberg 1999). The outcomes measures, and the times at which they were conducted, are presented in Table 2. An a priori estimation of time frames where differences would be expected could not be determined as previous literature had not reported outcome measures during the initial six months following anterior cruciate ligament reconstruction. Detailed description of these outcome measures including issues of reliability, sensitivity and validity has been reported previously (Shaw et al 2004).

A preliminary trial using intraclass correlation coefficients confirmed the principal investigator’s within-session (same day) or between-session (consecutive days) reliability for measurements of range of motion (0.91 to 0.97 within, 0.81 to 0.98 between), knee circumference (0.98 to 1.00 within, 0.98 to 1.00 between), arthrometer knee laxity testing (0.88 to

Table 3. Characteristics of subjects in each treatment group.

	No quadriceps exercise group	Quadriceps exercise group	All subjects
Number of subjects	48	55	103
Average age (mean ± SD)	28.4 ± 8.1 years (range 18–58)	28.8 ± 9.3 years (range 18–52)	28.6 ± 8.8 years (range 18–58)
Height (mean ± SD)	175.0 ± 9.7 cm	177.9 ± 7.4 cm	176.5 ± 8.7 cm
Weight (mean ± SD)	76.5 ± 12.6 kg	80.7 ± 12.4 kg	78.7 ± 12.6kg
Females:Males	14:34	14:41	28:75
Patella-tendon graft	32	31	63
Hamstring graft	16	24	40
Left leg reconstructed	19	28	47
Right leg reconstructed	29	27	56
Time from injury to surgery*			
0–28 days	18	26	44
29 days+	20	35	55
Length of in-patient period (mean ± SD)	1.6 ± 0.6 days	1.6 ± 0.5 days	1.6 ± 0.6 days

*4 subjects could not specify when they injured their knee

0.95 within, 0.83 to 0.93 between) and functional hop tests (1.00 for both within and between). Within the main study, the principal investigator performed all tests and measurements (except for isokinetic muscle strength testing), using standardised protocols and the same instruments on each occasion. Isokinetic testing using a standardised testing procedure and a single Kin-Com machine was routinely performed by experienced outpatient physiotherapists as part of the postoperative rehabilitation program.

Statistical analyses For all statistical analyses, statistical significance was set at $p < 0.05$. Treatment group demographic data homogeneity was assessed with unpaired t-tests (interval data) or 2 x 2 chi-squared tests (nominal data). Repeated measures analysis of variance (ANOVA) was used as the primary statistical analysis for outcome measures generating interval data at multiple follow-up sessions. This analysis was used to compare No quadriceps exercise and Quadriceps exercise groups (main effect for treatment) over the follow-up period (group by time interaction) and interaction effects between treatment group and graft type over time (group by graft by time). Where repeated measures ANOVA revealed significant treatment group/graft type interaction effects over time, the relationship was investigated with two-way ANOVA analysis at each follow-up time point. Significant group by time interactions were further investigated by unpaired t-test analysis at each follow-up time point.

Where outcome measures were performed at one time point (e.g. isokinetic testing at six months) two-way ANOVAs were calculated to determine main effects for treatment groups and interaction effects between treatment groups and graft type. Between-group differences for outcome measures that generated ordinal data (e.g. Cincinatti Knee Rating System and Visual Analogue Scale scores) were analysed using Mann-Whitney U tests. Two-by-two chi-square analysis was performed to determine whether significant differences existed for the distribution of characteristics between treatment groups (e.g. the number of lax knees in each treatment group). When one or more cell had an expected count of less than 5, Fisher's exact test was applied. Correlation analysis was performed using Pearson correlation coefficients.

Results

During the eleven-month subject recruitment period, 394 patients with anterior cruciate ligament rupture were approached to be involved in the study. A total of 103 patients satisfied the inclusion criteria and consented to participate (Quadriceps exercise n = 48, No quadriceps exercise n = 55). The remaining 291 patients were excluded as 72 people declined participation, 119 people lived outside the Adelaide metropolitan area, and 100 people failed to meet the inclusion criteria. Ninety-one subjects were available at final follow-up. All subjects completed the study in the group to which they were originally allocated (intention to treat approach).

The descriptive demographic details of subjects in each treatment group are provided in Table 3. There was no statistically significant difference between treatment groups for age, height, weight, or duration of in-patient hospitalisation as calculated by unpaired t-tests. No differences were evident between groups for the distribution of gender, graft type, right or left limb involvement, or time from injury to surgery (chi-squared analysis). There was no difference between groups in terms of adherence to their exercise regimen (SIRAS) and self-reported weekly logbooks.

Range of motion Significant differences calculated by repeated measures ANOVA were found between the No quadriceps exercise and Quadriceps exercise groups over the six month follow-up for active knee flexion (Figure 1), active knee extension (Figure 2), and passive knee extension relative to neutral (Figure 3). Table 4 presents the mean and 95%

Table 4. Mean and 95% confidence intervals for outcome measures at each measurement session.

	Day 1	2 Weeks	1 Month	3 Months	6 Months
Active knee flexion ROM (degrees)					
No quadriceps exercise (mean and SD)	77.1 (21.6)	101.8 (15)	122.3 (14.5)	139.9 (8)	142.6 (7.6)
Quadriceps exercise (mean and SD)	73.8 (20.3)	104.9 (15.3)	128.2 (12.7)	138.9 (8.1)	141.6 (6.9)
Difference (mean and 95% CI)	-3.3 (-11.5 to 4.9)	3.1 (-3.4 to 9.6)	5.9 (0.1 to 11.7)	-1 (-4.5 to 2.5)	-1 (-4.1 to 2.1)
Active knee extension ROM (degrees)					
No quadriceps exercise (mean and SD)	-22.4 (7.9)	-19.2 (6)	-14.8 (6.4)	-7.7 (4.5)	-4.9 (4.2)
Quadriceps exercise (mean and SD)	-22.5 (8)	-16.5 (6.1)	-12.1 (4.8)	-7.4 (4.4)	-5.7 (4.1)
Difference (mean and 95% CI)	-0.1 (-3.8 to 3.6)	2.7 (-0.1 to 5.5)	2.7 (0.1 to 5.3)	0.3 (-1.8 to 2.4)	-0.8 (-2.7 to 1.1)
Passive knee extension relative to neutral (degrees)					
No quadriceps exercise (mean and SD)	-11.8 (6.1)	-9 (5.6)	-7.7 (5)	-3.8 (3.1)	-2.3 (3.2)
Quadriceps exercise (mean and SD)	-12.7 (6.4)	-9 (5.4)	-6.5 (4.2)	-4.2 (3.7)	-3.1 (3.4)
Difference (mean and 95% CI)	-0.9 (-3.6 to 1.8)	0 (-2.4 to 2.4)	1.2 (-0.8 to 3.2)	-0.4 (-1.9 to 1.1)	-0.8 (-2.2 to 0.6)
Inferior knee circumference (LSI %)					
No quadriceps exercise (mean and SD)	105.8 (2.5)	106.6 (2.5)	104.2 (1.5)	102.4 (2.1)	101.5 (2)
Quadriceps exercise (mean and SD)	104.5 (3.9)	105.3 (2.5)	103.2 (2.5)	102.1 (2)	101.3 (2.2)
Difference (mean and 95% CI)	-1.3 (-3.2 to 0.6)	-1.3 (-2.7 to 0.1)	-1 (-2.2 to 0.2)	-0.3 (-1.5 to 0.9)	-0.2 (-1.4 to 1)
Pain at rest (cm on 10 cm VAS)					
No quadriceps exercise (mean and SD)	2.6 (2)	2.2 (1.9)	0.9 (1.1)	0.5 (0.7)	0.3 (0.6)
Quadriceps exercise (mean and SD)	3.1 (2.2)	2.5 (1.7)	0.9 (0.8)	0.4 (0.7)	0.3 (0.6)
Difference (mean and 95% CI)	0.5 (-0.3 to 1.3)	0.3 (-0.4 to 1)	0 (-0.4 to 0.4)	-0.1 (-0.4 to 0.2)	0 (-0.3 to 0.3)
Pain on performing exercise (cm on 10 cm VAS)					
No quadriceps exercise (mean and SD)	6 (2.1)	5.2 (2.1)	4 (2.3)	2.8 (2.1)	2.1 (1.8)
Quadriceps exercise (mean and SD)	6.9 (2)	5.9 (1.9)	3.5 (2)	3.1 (2)	2 (1.9)
Difference (mean and 95% CI)	0.9 (0.1 to 1.7)	0.7 (-0.1 to 1.5)	-0.5 (-1.4 to 0.4)	0.3 (-0.6 to 1.2)	-0.1 (-0.9 to 0.7)
Single hop (LSI%)					
No quadriceps exercise (mean and SD)					81.7 (12.7)
Quadriceps exercise (mean and SD)					83.8 (10.1)
Difference (mean and 95% CI)					2.1 (-2.8 to 7)
Triple hop (LSI%)					
No quadriceps exercise (mean and SD)					81.8 (13.6)
Quadriceps exercise (mean and SD)					83.7 (11.4)
Difference (mean and 95% CI)					1.9 (-3.5 to 7.3)
CKRS Symptoms					
No quadriceps exercise (mean and SD)			4.8 (1)	6.2 (1.2)	6.8 (1.1)
Quadriceps exercise (mean and SD)			4.9 (1)	6.1 (1.1)	7.5 (1.2)
Difference (mean and 95% CI)			0.1 (-0.3 to 0.5)	-0.1 (-0.6 to 0.4)	0.7 (0.2 to 1.2)
CKRS Patient grade					
No quadriceps exercise (mean and SD)			4.5 (0.8)	5.4 (1.3)	6.7 (1.4)
Quadriceps exercise (mean and SD)			4.5 (1.1)	5.6 (1.1)	7.1 (1.6)
Difference (mean and 95% CI)			0 (-0.4 to 0.4)	0.2 (-0.3 to 0.7)	0.4 (-0.2 to 1)
CKRS Sports activity score					
No quadriceps exercise (mean and SD)			55.1 (26.6)	72.1 (18.4)	75.8 (16)
Quadriceps exercise (mean and SD)			49.1 (21.3)	66 (21)	79.3 (13.4)
Difference (mean and 95% CI)			-6 (-15.9 to 3.9)	-6.1 (-14.4 to 2.2)	3.5 (-2.7 to 9.7)
CKRS ADL Function Score					
No quadriceps exercise (mean and SD)			23.6 (8.5)	30.2 (6.8)	33.9 (5.9)
Quadriceps exercise (mean and SD)			25.9 (6.3)	31.6 (6)	35.3 (3.7)
Difference (mean and 95% CI)			2.3 (-0.8 to 5.4)	1.4 (-1.3 to 4.1)	1.4 (-0.6 to 3.4)
CKRS Sports Function Score					
No quadriceps exercise (mean and SD)			40.7 (2.9)	55.3 (12.3)	73 (12.9)
Quadriceps exercise (mean and SD)			42.2 (6.2)	53.6 (11.7)	76.3 (14.6)
Difference (mean and 95% CI)			1.5 (-0.5 to 3.5)	-1.7 (-6.7 to 3.3)	3.3 (-2.5 to 9.1)

CKRS Problems with Sport Score			
No quadriceps exercise (mean and SD)	41.6 (11.9)	51.2 (12.4)	61.6 (15.2)
Quadriceps exercise (mean and SD)	40.2 (11.6)	55.2 (12.5)	66.4 (14.4)
Difference (mean and 95% CI)	-1.4 (-6.2 to 3.4)	4 (-1.2 to 9.2)	4.8 (-1.4 to 11)
CKRS Occupation Rating Score			
No quadriceps exercise (mean and SD)	21.6 (12.6)	29.0 (16.2)	31.1 (17.6)
Quadriceps exercise (mean and SD)	26.4 (15.5)	32.4 (16.4)	32.0 (16.9)
Difference (mean and 95% CI)	4.8 (-2.2 to 11.8)	3.4 (-3.5 to 10.3)	0.9 (-6.4 to 8.2)
Isokinetic concentric quads 60 deg/sec (LSI% difference)			
No quadriceps exercise (mean and SD)			-10.7 (15.5)
Quadriceps exercise (mean and SD)			-12.8 (16.7)
Difference (mean and 95% CI)			2.1 (-6.8 to 11.0)
Isokinetic eccentric quads 60 deg/sec (LSI% difference)			
No quadriceps exercise (mean and SD)			2.3 (21.6)
Quadriceps exercise (mean and SD)			-0.9 (21.5)
Difference (mean and 95% CI)			3.2 (-8.7 to 15.1)

CKRS, Cincinatti Knee Rating System. LSI%, Limb Symmetry Index of the reconstructed leg relative to the non-operative leg expressed as a percentage (reconstructed value divided by non-reconstructed value; values less than 100 indicate reconstructed leg performance deficits). LSI% difference, the reconstructed leg strength expressed as a percentage difference relative to the non-operative leg (LSI% subtracted from 100%; negative values indicate reconstructed leg performance deficits).

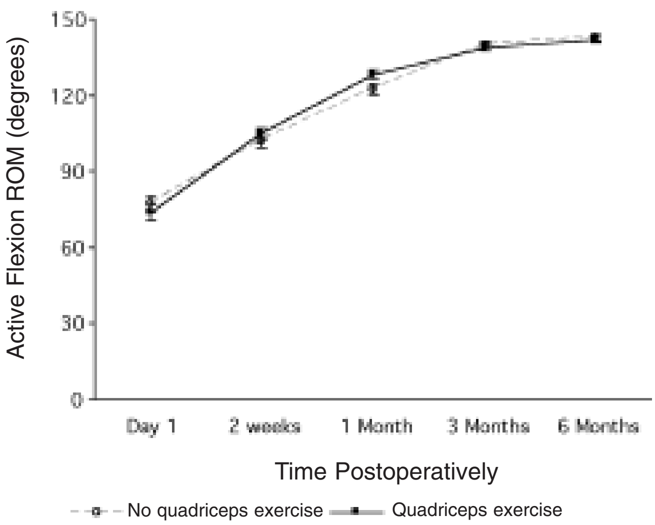

Figure 1. Estimated marginal means between treatment groups for active knee flexion (mean ± SEM).

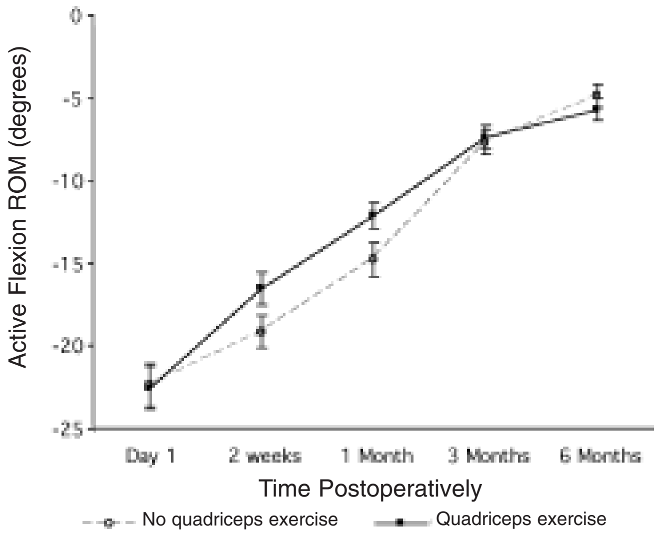

Figure 2. Estimated marginal means between treatment groups for active knee extension (mean ± SEM).

confidence intervals for outcome measures at each measurement period. Statistically significant differences between the treatment groups were identified at one month postoperatively for active flexion (No quadriceps exercise 122.3 degrees ± 14.5 versus Quadriceps exercise 128.2 degrees ± 12.7, $p = 0.05$) and active extension range of motion (No quadriceps exercise -14.8 degrees ± 6.4 versus Quadriceps exercise -12.1 degrees ± 4.8, $p = 0.05$). While significant differences over time were calculated for passive knee extension relative to neutral using repeated measures ANOVA, when unpaired t-tests were applied at each time point, no significant differences were found ($p = 0.23$ to 0.97). No statistically significant difference was detected for quadriceps lag (the difference between active and passive knee extension) over time between the two groups.

Knee circumference Repeated measure ANOVA demonstrated no significant differences between the Quadriceps exercise and No quadriceps exercise groups over time for any knee circumference measurements ($p = 0.22$ to 0.86). Table 4 presents the mean and 95% confidence intervals for outcome measures at each measurement period. However, a significant treatment group by graft type by time interaction was found for circumference measurement at the inferior patella pole ($p = 0.02$). Subsequent two-way ANOVA for inferior patella pole data revealed that a graft type by treatment group interaction was present at the three-month postoperative evaluation ($p < 0.01$). Post hoc unpaired t-tests were performed to compare inferior pole knee circumference between treatment groups, for each graft type. Thus, subjects who underwent anterior cruciate ligament reconstruction with

Table 5. Six month postoperative chi-squared analysis of subjects who displayed abnormal laxity, defined as an anterior-posterior side-to-side difference of greater than 3 mm or greater than 5 mm on testing with the KT-1000 arthrometer. Data are numbers of subjects with laxity and, in brackets, total numbers of subjects.

KT-1000 test force	AP laxity 'cut off'	No quadriceps exercise	Quadriceps exercise	*p*
15 lb	3 mm	12 (44)	3 (47)	0.01*
15 lb	5 mm	2 (44)	0 (47)	-
20 lb	3 mm	13 (44)	10 (47)	0.36
20 lb	5 mm	7 (44)	1 (47)	-
Maximum manual	3 mm	16 (44)	17 (47)	0.99
Maximum manual	5 mm	9 (44)	1 (47)	-

*$p < 0.05$

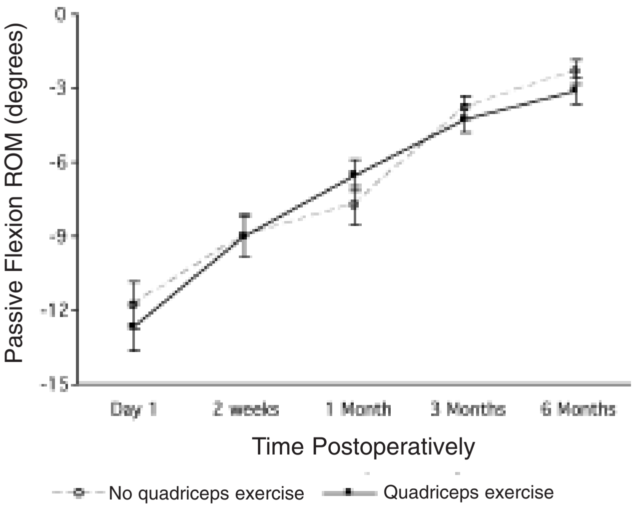

Figure 3. Estimated marginal means between treatment groups for passive knee extension (mean ± SEM).

the bone-patellar tendon-bone graft and who had not performed quadriceps exercises during the acute postoperative period were found to exhibit significantly greater knee circumference (bone-patellar tendon-bone graft No quadriceps exercise 103.7 ± 1.6 cm versus bone-patellar tendon-bone graft Quadriceps exercise 101.5 ± 1.5, $p < 0.01$). No statistically significant difference was noted between Quadriceps exercise and No quadriceps exercise groups who had received the hamstring graft.

Pain and satisfaction scores Pain perception at rest, with movement, and while performing exercises, and satisfaction with overall knee function were assessed at each time point using individual numerical analogue scales (ordinal data). Table 4 presents the mean and 95% confidence intervals for pain at rest and during exercise at each measurement period. Using Mann-Whitney U tests, no statistically significant differences were found between the No quadriceps exercise and Quadriceps exercise groups for pain perception or overall satisfaction at any follow-up period with a single exception. Subjects performing Quadriceps exercises on the first postoperative day reported significantly greater pain with exercises than subjects not performing Quadriceps exercise (Quadriceps exercise 6.9 ± 2.0 vs No quadriceps exercise 6.0 ± 2.1, $p = 0.02$).

Cincinnati Knee Rating System (CKRS) Seven individual numerical subjective rating scores are incorporated in the self-report Cincinnati Knee Rating System questionnaires: Symptoms, Patient Grade, Sports Activity Score, ADL Function Score, Sports Function Score, Problems with Sport Score, and Occupation Rating Score. Table 4 presents the mean and 95% confidence intervals for CKRS at one, three, and six months. At six months postoperatively, Mann-Whitney U test demonstrated statistically significant differences between the treatment groups for both the Symptom scores (Quadriceps exercise 7.5 ± 1.2 vs No quadriceps exercise 6.8 ± 1.1, $p = 0.005$) and the Problems with Sport Score (Quadriceps exercise 66.4 ± 14.4 vs No quadriceps exercise 61.6 ± 15.2, $p = 0.05$). Subjects who had performed acute postoperative quadriceps exercises reported significantly higher (more favourable) Symptom and Problems with Sport scores. Post hoc Mann-Whitney U tests were calculated for each of the individual factors that had been summed to produce the overall symptom score (pain, swelling, partial giving way and full giving way). The Quadriceps exercise group reported significantly higher (more favourable) results for pain (Quadriceps exercise 7.1 ± 1.5 vs No quadriceps exercise 6.5 ± 1.4, $p = 0.03$), partial giving way (Quadriceps exercise 7.9 ± 1.2 vs No quadriceps exercise 7.1 ± 1.7, $p = 0.03$) and full giving way (Quadriceps exercise 8.0 ± 1.3 vs No quadriceps exercise 7.4 ± 1.2, $p = 0.03$). No other CKRS scores achieved statistical significance between treatment groups, at one, three, or six months postoperatively.

Knee laxity No significant differences over time were found between the Quadriceps exercise and No quadriceps exercise group means for KT-1000 arthrometric knee laxity testing using repeated measures ANOVA. This was regardless of whether a 15 or 20 pound test force, or maximum manual testing, was applied. However, analysis with chi-squared and Fisher's exact tests revealed a significant difference between the Quadriceps exercise and No quadriceps exercise groups for the proportion of abnormally lax knees within each treatment group at six months (Table 5). A significantly greater proportion of subjects in the No quadriceps exercise group demonstrated laxity at each test force (Table 5). No significant differences were found at three months postoperatively between the proportion of subjects in the Quadriceps exercise and No quadriceps exercise groups who exhibited knee laxity.

Functional hop testing As functional hop testing was performed only at six months postoperatively, two-way ANOVA was conducted to compare group means for main effects (treatment group and graft type main effects) and for interaction effects between the treatment group and graft type. No significant interaction effects were found between treatment group and graft type ($p = 0.45$ to 0.82) for either the single hop, triple hop, or when the two hop tests were averaged. No statistically significant treatment group main effects were found for any hop test performance between the two groups (single hop $p = 0.51$, triple hop $p = 0.51$, combined $p = 0.49$). Table 4 presents the mean and 95% confidence intervals for single and triple hop tests results at each measurement period.

Isokinetic quadriceps strength Isokinetic muscle strength evaluation was performed only at six months postoperatively. Therefore, two-way ANOVA was performed to compare group means for main effects (treatment group and graft type) and for interaction effects between treatment group and graft type. No significant main effects were found between groups for quadriceps muscle strength deficit at six months (concentric quads 60 degrees/sec No quadriceps exercise 10.7 ± 15.5 vs Quadriceps exercise 12.8 ± 16.7, $p = 0.72$; eccentric quad 60 degrees/sec No quadriceps exercise 2.3 ± 21.6 vs Quadriceps exercise 0.9 ± 21.5, $p = 0.70$). Table 4 presents the mean and 95% confidence intervals for concentric and eccentric quadriceps measures at six months. No statistically significant interaction effects between treatment group and graft type were calculated.

Discussion

Quadriceps exercises, such as isometric quadriceps contractions and straight leg raises, are frequently prescribed by physiotherapists during the acute postoperative period following anterior cruciate ligament reconstruction (Shaw et al 2002). However, the rationale for the prescription of quadriceps exercises during postoperative recovery is often based on anecdotal rather than higher level evidence.

The average age of subjects in the current study (28.6 ± 8.8 years) is consistent with the ages reported in many previous studies of international populations of ACLR subjects (De Carlo et al 1992, De Carlo and Sell 1997, Shelbourne and Gray 1997). The two most popular graft types currently used for anterior cruciate ligament reconstruction are the bone-patellar tendon-bone and semitendinosus-hamstring grafts (Brown et al 1993, Corry et al 1999, Frank and Jackson 1997, Mologne and Friedman 2000, Roos and Karlsson 1998). In the current study, given the small sample size (relative to the number of anterior cruciate ligament reconstructions performed nationally) and the selection bias (i.e. receiving bone-patellar tendon-bone or semitendinosus-hamstring grafts was a recruitment criterion), inferences cannot be made regarding the frequency of use of these two grafts in clinical practice. However, the findings of the current study may be generalised with caution to patients who are recipients of either of these two graft types who present with anterior cruciate ligament rupture in the absence of major damage to other knee structures.

This investigation produced little evidence to support the belief that performance of specific quadriceps exercises during the initial two postoperative weeks results in improved outcomes following anterior cruciate ligament reconstruction. This is particularly the case if acute postoperative quadriceps exercises are prescribed with the solitary aim of improving or restoring muscle strength postoperatively. The degree of quadriceps lag throughout the six-month follow-up was not significantly affected by performing quadriceps exercises during the acute postoperative period. Additionally, muscle strength and function, evaluated by functional isokinetic testing and hop testing at six months, was not adversely affected by the omission of quadriceps specific exercises during the first two postoperative weeks. Functional quadriceps use during the initial two postoperative weeks (e.g. with ambulation) followed by intensive outpatient rehabilitation (commenced by two weeks postoperatively and including quadriceps exercises) appeared to be sufficient to produce a comparable strength and functional outcome, when compared with a program in which quadriceps specific exercises were initiated immediately postoperatively.

However, performing quadriceps exercises during the first two postoperative weeks offered a number of benefits not specifically related to long-term improvements in quadriceps strength. With restoration of knee range of motion being a major objective during the acute postoperative period, early implementation of quadriceps exercises resulted in a more rapid restoration of knee flexion and extension range of motion. This benefit, however, was limited to the one-month postoperative period, where patients who had performed acute postoperative quadriceps exercises displayed significantly greater range of motion restoration, relative to subjects who had not performed acute postoperative quadriceps exercises. Whether this statistical finding is clinically relevant remains to be considered, as to date little information exists which determines the relationship between improvements in range of motion and functional or clinical significance.

A more notable finding was the incidence of abnormal anterior-posterior knee laxity for the reconstructed knee six months postoperatively. The performance of quadriceps exercises during the acute postoperative period resulted in a lower prevalence of abnormal anterior-posterior knee laxity at six months. Again, the clinical importance of this finding is uncertain. In the current study, no statistically significant relationship was found between the degree of arthrometric instability and the reporting of giving way by subjects. Pearson's correlation analysis between arthrometric knee laxity and CKRS subjective scores for giving way resulted in poor correlations (r = -0.29 to 0.07). Nor was there a significant relationship between laxity and functional hop test performance and the six-month laxity measured at all arthrometer test forces (r = -0.07 to 0.09). These findings suggest that, although performance of acute postoperative quadriceps exercises may decrease the incidence of abnormal laxity in a small proportion of patients, this improvement may not necessarily produce greater patient satisfaction or functional performance. Moreover, although significantly more No quadriceps exercise subjects exhibited abnormal laxity at six months, the relative proportion of abnormally lax knees in both groups compared favourably to figures reported in previous literature (Aglietti et al 1994, Barber-Westin and Noyes 1993, DeCarlo et al 1997).

It is important to acknowledge that the potential long-term sequelae of not performing acute postoperative quadriceps exercises has yet to be determined. This is particularly important in light of a greater incidence of abnormal instability among subjects who had not performed quadriceps exercises during the first two postoperative weeks. Whilst excessive instability is believed to be associated with re-injury, revision surgery or the onset of degenerative conditions, no direct extrapolations can be made from the findings of this study.

Conclusion

Quadriceps exercises are a simple, economical intervention taking minimal time to provide. While this study did not find that acute postoperative quadriceps exercises resulted in significant improvements in muscle strength or lower limb function, subjects performing acute postoperative quadriceps exercises had faster recovery in range of motion and some more CKRS scores. Additionally, for a small proportion of anterior cruciate ligament reconstruction patients, quadriceps exercises resulted in a lower incidence of abnormal knee laxity. Therefore, this prospective, randomised controlled study has confirmed that isometric quadriceps exercises and straight leg raises can be safely prescribed during the first two postoperative weeks, and inclusion of such a regimen results in small but statistically significant improvements in recovery of range of motion and the frequency of knee stability. Whether the improvements associated with the inclusion of acute postoperative quadriceps exercises are of clinical significance remains to be seen.

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