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ACL Reconstruction Rehabilitation: A Systematic Review Part II

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Introduction

Anterior cruciate ligament (ACL) reconstruction is a common procedure to allow patients to return to their former active lifestyle. Rehabilitation of the reconstructed knee is critical for the successful return to risky cutting and jumping activities. While many of the individual aspects of ACL rehabilitation have been evaluated using randomized trials few reviews have used an evidence based approach to create an overall protocol for ACL rehabilitation. Previous systematic reviews were not inclusive of all possible aspects of rehabilitation i.e. bracing and were old enough to exclude many recently published studies.[1, 2] The goal of this systematic review is to assemble the available randomized controlled trials (RCTs) in ACL rehabilitation to facilitate the development of evidence based rehabilitation protocols. This represents Part II of a two part systematic review.

Methods

Pubmed 1966 to 2005, Embase 1980 to 2005 and the Cochrane Controlled Trials Register were searched for papers appropriate to this study. Bibliographies of identified studies were also searched and a hand review of the last six months of appropriate journals was performed. For the database search terms included anterior cruciate ligament, ACL, rehabilitation, randomized trials, and clinical trials. This search identified 82 potential studies for inclusion. Inclusion criteria included English-language randomized clinical trials involving ACL reconstruction rehabilitation. Exclusion criteria included non-English language, no true randomization, and subject matter not pertaining to ACL reconstruction rehabilitation. This resulted in 54 studies included in this systematic review. Studies underwent worksheet appraisal for methodological quality with emphasis on identifying

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biases present in each study. All studies were level 1 or 2 evidence. Topics included by this review are continuous passive motion, rehabilitative bracing, neuromuscular electrical stimulation, early weight-bearing, home versus supervised physical therapy, open versus closed chain kinetic exercise programs, accelerated rehabilitation and a variety of miscellaneous topics assessed by only one randomized trial.

Open vs. Closed Kinetic Chain Exercises

Surprisingly, despite the significant amount of discussion that has occurred regarding the merits of open and closed kinetic chain exercises there have only been five studies prospectively randomized following ACL reconstruction to investigate these issues.

The first study published by Bynum et al in 1995 evaluated rehabilitation following BTB autograft ACL reconstruction using open versus closed chain exercises for a 24 week course.[3] One hundred patients were prospectively randomized using a computer generated number and envelope system. Examiners were blinded and performed exams at three-month intervals and yearly. Three patients were dropouts prior to completing the 24 week course leaving 47 in the open chain and 50 in the closed chain groups. Parameters assessed included Lysholm, Tegner, patient satisfaction, range of motion, patellofemoral pain, and KT 1000 instrumented laxity. Sixty-six percent returned for objective and subjective final follow up. An additional 22% were followed subjectively (88%). Final follow-up occurred on average at 19 months (range 12 to 36).

A statistically significant difference was noted in KT 1000 maximum values at final follow-up. Closed chain group was 1.6 mm versus 3.3 mm in the open chain group $p = 0.02$. At the nine-month evaluation patellofemoral pain was noted in 15% of the closed chain group versus 38% in the open chain group $p = 0.046$. Subjective patient assessment, Lysholm score and Tegner score was equivalent in both groups. Twenty-one patients in the closed chain group felt they returned to normal ADL's sooner than expected versus 10 in the open chain group $p = 0.007$. The authors concluded that closed chain exercises are safe and effective and may offer the advantages of less stress on the healing graft and less patellofemoral pain.

Mikkelsen et al in a 2000 study appraised the addition of open chain exercises at six weeks to a closed chain rehabilitation program.[4] Forty-four patients were randomized to either closed chain rehabilitation program for the entire rehabilitation period or to a closed chain program that had the addition of open chain exercises at the six-week postoperative point. At six weeks the open chain group added isokinetic concentric and eccentric quadriceps strengthening between 90° and 40° increasing over six weeks to 90° to 10°. The other group continued closed chain exercises during the entire 12 weeks. Randomization, blinding or independent assessors were not discussed. Surgical technique was endoscopic autograft BTB.

Parameters assessed included instrumented laxity (KT 1000 manual maximum), isokinetic strength testing, and patient satisfaction. KT 1000 values showed no significant difference in knee laxity at six months. The authors stated there was a significant increase in quadriceps strength in the open chain group at six months but no statistics were cited. Patient satisfaction evaluation at an average 31 months demonstrated subjectively that the open chain group returned to sports at the same level at a higher rate than the closed chain group ($p < 0.05$). The authors concluded that open chain exercises can be safely added at the six-week postoperative point without risk to increased knee laxity and with the added potential of improved quadriceps strength and better return to sports.

The next three studies involved the same cohort of patients although different numbers were involved in each trial. Each trial assessed different parameters but only after six weeks of rehabilitation. Patients were entered into the studies after two weeks of standard physical therapy. Thus, the authors evaluated the effect of four weeks of open chain versus closed chain exercises with no further follow-up.

The first study, by Morrissey et al in 2000 evaluated the effect of open chain exercises on instrumented knee laxity.[5] Thirty-six patients were randomized to one of two groups. The closed chain group performed predominately leg press exercises between weeks three and six following ACL reconstruction. The open chain group performed knee and hip extensor exercises using either ankle weights or machines. Randomization was performed using the block method. Observers blinded to subject allocation were used for assessment. A power analysis was performed prior to the study indicating 60 subjects were required. Why the authors only recruited 36 patients was not addressed in the manuscript.

The Knee Signature System was used to determine instrumented laxity at two weeks and six weeks. The open chain group was determined to be 9% looser but the 95% confidence interval ranged from −8% to +29%. Thus the authors could not conclude that open chain exercises increased knee laxity.

Hooper et al in a 2001 study evaluated the effect of open chain exercises using gait analysis on level walking, stair ascent and stair descent.[6] Once again the open chain group performed these exercises between weeks three and six while the closed chain group performed leg presses between weeks three and six

A Hughston clinical score VAS was used at two weeks and six weeks and was equivalent between both groups. Gait analysis demonstrated level walking was equivalent in both groups at both time points. The only difference between the two groups was a decreased knee angle at stair ascent in the closed chain group $p < 0.05$. The authors admit this is of questionable clinical significance. Both groups significantly improved their level walking gait analysis and their stair ascent and descent analysis between two and six weeks.

Morrissey et al in a 2002 study evaluated open versus closed chain exercises as discussed in the previous two studies and its effect upon postoperative pain.[7] Isometric and isokinetic testing was performed at two and six weeks and three questions from the Hughston clinical score were assessed including one question regarding pain with sitting. The authors felt this addressed patellofemoral pain. Isometric and isokinetic testing was equivalent in both groups and there was no difference in the pain scores.

The studies demonstrate the need for additional research in this area. Bynum et al showed increased knee laxity in the open chain group but no determination can be made regarding which exercises may contribute to this laxity.[3] Open chain exercises initiated six weeks postoperatively as in the Mikkelsen study may be safe and improve patient outcome.[4] The other three studies assessed final outcome at six weeks following four weeks of open chain versus closed chain exercises and this follow-up may be too short to make reasonable conclusions.[5, 6, 7] Also these three studies may suffer from lack of power to detect a difference.

Neuromuscular Electrical Stimulation

Fourteen RCTs have evaluated the use of electrical stimulation during the course of postoperative ACL reconstruction rehabilitation. In 1979 Eriksson and Häggmark published a study of eight patients undergoing reconstruction of the ACL using a modified Jones procedure.[8] All eight patients were casted and underwent isometric training. Four of the eight also had percutaneous electrical stimulation that was used to train for one hour five days a week during the four weeks after the first postoperative week. Randomization was not addressed. The electrical stimulation group noted less muscle atrophy and increased succinate dehydrogenase activity compared to the cast and isometric training only group.

Arvidsson et al in a 1986 study evaluated the effect of electrical stimulation during cast immobilization following ACL reconstruction.[9] Thirty-eight patients were randomized following ACL reconstruction using the medial one third of the patellar tendon. Randomization was not discussed. All patients were splinted for one week and then casted for five weeks at 45° flexion. All patients did isometric quad sets in the cast. Patients randomized to electrical stimulation did 30 minute sessions three times daily for the first six weeks (40 Hz, pulse width 300μsec, 20 sec. duration with a 35 sec. rest).

Parameters assessed included CT scan preoperatively and 40 to 45 days postoperatively, muscle biopsy for histology and muscle enzymes. Hamstring cross-sectional area decreased significantly in males in the electrical stimulation group $p < 0.05$. In females a significant difference was noted in quadriceps cross-sectional area which was decreased 31.4% in controls and 15.6% in the electrical stimulation group $p < 0.001$. On biopsy muscle fiber area minimally decreased in the electrically stimulated females (5.4%). In female controls and all males a 30 to 40% decrease in muscle fiber area was noted. The authors concluded electrical stimulation was found to decrease the amount of muscle wasting especially in females. They could not explain the differences seen by gender.

Sisk et al in a 1987 study examined the effect of electrical stimulation in casted patients on isometric quadriceps strength.[10] Twenty-two patients were randomized to cast for four weeks at 45° and then casted brace for two weeks with range motion of 45° to 90° with or without the addition of electrical stimulation (frequency 40 Hz, duration 300msec, on 10 seconds off 30 seconds for eight hours a day). Randomization method or use of an independent observer was not addressed in the manuscript. Isometric quadriceps strength was evaluated during the seventh, eighth, and ninth week postoperatively. No difference was noted in quadriceps strength between the two groups.

Wigerstad-Lossing et al in a 1988 study evaluated the effect of electrical stimulation in addition to voluntary muscle contraction.[11] Twenty-six patients were randomized following ACL reconstruction using the medial one third of the patellar tendon. Both groups had a full length cast for three weeks at 20 to 30° flexion followed by three weeks in a knee cast. The experimental group performed electrical stimulation with pulse width 300 ms with a two second rise followed by a six second stimulation followed by a 10 second pause for 10 minutes four times a day three times a week. Randomization, blinding and independent assessment was not addressed. Three patients in the control group were dropped for compliance issues. Isometric muscle strength preoperatively and at six weeks postoperatively along with CT scan and muscle biopsy was performed.

Isometric muscle strength decreased significantly more in the control group (58% versus 39%) $p < 0.01$. CT cross-sectional area decreased less in the electrical stimulation group (23% versus 29%) $p < 0.05$. Type I muscle fiber area in the controls decreased significantly $p < 0.025$.

Delitto et al in a 1988 study evaluated the addition of electrical stimulation co-contraction to voluntary isometric co-contractions following ACL reconstruction.[12] Twenty patients were randomized to either voluntary exercise or electrical stimulation trials five days a week for three weeks during the first six postoperative weeks. Randomization was not discussed, but assessment was performed by a blinded observer. Patients were evaluated by isometric testing at the six-week postoperative point. Electrical stimulation parameters included a 2500 hertz carrier wave, 50 pulses per second increased to patient's tolerance, 15 seconds on with a 50 second rest period. The amounts and number of repetitions was not discussed in this group. Isometric torque was significantly increased in the extensors and flexors in the electrical stimulation group ($p<0.05$).

Snyder-Mackler et al in a 1991 study evaluated 10 patients randomized to electrical stimulation during co-contraction versus co-contraction alone three times a week for the third through sixth week of rehabilitation.[13] Randomization and blinding was not discussed. Compliance was assessed by home exercise logs. There were no missed treatments in either group. Electrical stimulation delivered a 2500 hertz (pulse duration, 400 ms) triangular, alternating current at a 50% duty cycle of 75 burst per second.

Gait, isokinetic testing and KT 1000 instrumented laxity was used to assess outcome. Gait was determined to be better in the electrical stimulation group. KT 1000 testing was not significantly different in either group. Isokinetic testing was improved in the electrical stimulation group with peak torque normalized 69% versus 44% in the control group ($p<0.05$).

Draper and Ballard in a 1991 study evaluated the effect of electrical stimulation versus EMG biofeedback on quadriceps strength following ACL reconstruction.[14] 30 patients were randomized. Randomization was by a matching procedure controlling for age and gender. Compliance was assessed using log sheets. Fifteen patients used electrical stimulation in conjunction with their home exercise program for the first four weeks postoperatively 30 minutes three times a day. Electrical stimulation settings included amplitude 50mA and 35 pulses per second. The second group used EMG biofeedback in addition to the home exercise program to help achieve a voluntary maximum contraction. Isometric Cybex testing was performed at the sixth week postoperatively. The biofeedback group demonstrated improved recovery of quadriceps strength as compared to the nonoperative limb 46.4% versus electrical stimulation 37.9% $p = 0.044$.

Snyder-Mackler et al in a 1995 study evaluated the effect of high-intensity electrical stimulation versus low intensity electrical stimulation and high-level volitional exercises.[15] One hundred and ten patients were randomized to four groups in a multicenter study utilizing all types of reconstruction. Randomization was performed centrally, but the method was not discussed. Thirty-one patients were randomized to high-intensity neuromuscular electrical stimulation with a 2500 hertz triangular alternating current at 75 burst per second for 15 contractions with 11 seconds on and 120 seconds off three times a week. The second group of 34 patients underwent high-level volitional exercises. The third group of 25 patients performed low intensity neuromuscular electrical stimulation with a duration of 300 microseconds at 55 pulses per second, 15 seconds on and 15 seconds off 15 minutes four times a day five days a week. Twenty patients in the fourth group combined the high and low neuromuscular electrical stimulation.

Gait and isometric strength were evaluated four weeks after initiating their treatment group. Gait and strength data was analyzed by an observer blinded to group allocation. High-intensity electrical stimulation either alone or in combination with low intensity electrical stimulation demonstrated increased recovery of the opposite limb quadriceps strength (70% versus 51% for the low intensity alone group, versus 57% for the volitional group) ($p = 0.001$). Gait analysis demonstrated increased flexion extension excursion with a more normalized gait in the high-intensity group. Patellar tendon autografts scored lower than other groups (allografts or hamstring) ($p <0.05$).

Snyder-Mackler et al in a separate paper from 1994 used the high and low intensity groups from the previous study and published this data separately with similar conclusions.[16]

Lieber et al in a 1996 study evaluated electrical stimulation and a matched intensity volitional exercise program.[17] Forty patients were randomized to two groups. Randomization method was not addressed. The first group used an electrical stimulator using an asymmetrical bipolar charged balance signal with maximum amplitude of 100 milli amps with a frequency of 50 and a stimulation pulse width of 250 microseconds. The second group performed volitional contractions matched to the intensity of the electrical stimulation with 15% of the injured leg's maximum voluntary contraction for the first week, 25% 2nd week, 35% 3rd week, and 45% the 4th week 30 minutes a day five days a week for four weeks. The two groups were evaluated using maximum voluntary contraction. There was no difference between the groups at 6, 8, 12, 24 and 52 weeks following surgery.

Paternostro-Sluga et al in a 1999 study evaluated 49 patients undergoing ACL repair or reconstruction.[18] Patients were randomized to three groups: the first group performed neuromuscular electrical stimulation one set at 30 hertz and one set at 50 hertz, 0.2ms one time a day seven days a week, group two used transcutaneous stimulation for analgesia and performed a home exercise program, group three performed exercises alone. Randomization method was not addressed, but the study was double blinded with regards to stimulation type. Isokinetic and isometric strength was tested at six, 12 and 52 weeks postoperatively. There were no significant differences in either group at any time point.

Michael Ross in a 2000 study evaluated the effect of neuromuscular electrical stimulation in conjunction with closed kinetic chain exercise following patellar tendon autograft ACL reconstruction.[19] Twenty patients were randomized using a posttest randomization design to one of two groups. No blinding or independent assessment was used. Group 1 performed closed kinetic chain exercises as part of their rehabilitation protocol. Group 2 performed an identical rehabilitation protocol with the addition of neuromuscular electrical stimulation during the closed kinetic chain exercise portion. The neuromuscular unit was a symmetrical biphasic square wave programmed at a frequency of 50 pulses/sec with a 200 ms phase duration. Each contraction lasted 15 seconds including a three second ramp on followed by a 35 second rest period.

Results were assessed using KT 1000, unilateral squat test, lateral step up test, and anterior reach test at six weeks postoperatively. The NMES group obtained 6.07° additional flexion during unilateral squat test and 3.3 additional reps during lateral step up test. These differences were statistically significant $p \leq 0.05$. KT 1000 instrumented laxity and the anterior reach test did not demonstrate a difference between the two groups. Ross concluded the addition of NMES to closed kinetic chain exercises produces a better lower extremity performance.

Rebai et al in a 2002 study evaluated 10 patients randomized to electrical stimulation with 80 hertz versus 20 hertz following ACL reconstruction.[20] The 20 hertz group had a pulse width of 300 microseconds on 15 seconds off 10 seconds for 60 minutes and the 80 hertz group had a pulse width of 300 microseconds with 15 seconds on and 75 seconds off for 54 minutes. This was performed 5 days a week for 12 weeks in addition to a standardized rehabilitation program. Randomization, blinding and independent assessment was not addressed in the study.

Isokinetic strength and muscle and fat volumes by MRI were evaluated 12 weeks postoperatively. The 20 hertz group recovered strength better when compared to the contralateral limb but did not recover better when compared to the ipsilateral limb preoperatively. Thus there were no significant strength differences in the two groups. There was less fat accumulation in the 20 hertz group (10% versus 20%) $p < 0.05$. Muscle volumes were equal in both groups.

Fitzgerald et al in a 2003 study evaluated neuromuscular electrical stimulation in conjunction with their rehabilitation.[21] Forty-eight patients were randomly assigned to either the electrical stimulation group or control group. Five patients dropped out prior to final data analysis. Randomization method, blinding and independent observation was not addressed in the study. The difference in this study was that electrical stimulation was performed with the knee in full extension. Amplitude was used such that a full tetanic contraction was elicited and increased as tolerated with a 2500 hertz alternating current 75 burst per second two times a week for 12 weeks.

Outcome was assessed by evaluating isokinetic quadriceps strength at 12 and 16 weeks postoperatively, knee outcome survey regarding ADLs, and a zero to 10 knee pain rating. The electrical stimulation group was better with quadriceps strength at 12 weeks $p<0.05$. The time to begin agility training was better in the electrical stimulation group. Reaching functional parameters to begin crutch and treadmill training was equal in both groups. Activity of daily living score was increased in the electrical stimulation group. Knee pain ratings were equal in both groups.

Based on the variety of parameters used in these studies it is difficult to make generalized conclusions regarding the use of neuromuscular electrical stimulation following ACL reconstruction. The quality of the studies varied, but in general most studies did not address randomization, were not blinded and did not use independent observers to assess the results. Many of the early studies evaluated the use of electrical stimulation in casted patients which is rarely performed today. Even though some studies demonstrated improved isokinetic strength this was not correlated with patient based outcome measures or other functional testing. In addition patient satisfaction with the treatment was rarely assessed. Despite these shortcomings some general conclusions can be made. It appears that if neuromuscular electrical stimulation is to be successful it must be applied in a high intensity setting early in the postoperative period. High intensity stimulation is typically administered in an outpatient physical therapy setting thus precluding home units. This is borne out by the studies in this series. Neuromuscular electrical stimulation may help achieve improved quadriceps strength but does not appear to be a requirement for successful ACL reconstruction rehabilitation.

Accelerated Rehabilitation

Based upon anecdotal success ACL rehabilitation protocols slowly evolved from twelve months time frame for return to sports to a generally accepted six month time for return. Currently some orthopaedists are advocating even shorter rehabilitation protocols. Evidence for these shorter intervals will be helpful for orthopaedists justifying return to play decisions. Minimal current evidence exists in this area regarding safe time intervals for return to play. Two RCTs have been published to evaluate the effects of accelerated ACL reconstruction rehabilitation. Ekstrand in a 1990 study randomized twenty soccer players to two different rehabilitation protocols with the goal of returning to sports at six vs. eight months following ACL reconstruction using an autologous fascia lata graft.[22] Randomization method, power study or confidence intervals for outcome measures were not presented. All patients were male soccer players. The rehabilitation protocols were similar for both groups except the eight month group delayed jogging and isokinetic strengthening an additional four weeks beyond the four to five month time point when the six month group initiated these activities. Both groups delayed full weight bearing until three months postoperatively. Outcome was assessed by Lysholm, instrumented laxity, isokinetic strength, one leg hop, figure 8 running, and return to sports. The six month group performed better at eight months for running and strength testing. No differences existed at twelve months. Two patients in the eight month group did not return to sports due to early arthrosis. Based on this study no significant conclusions can be made on a difference in six vs. eight month rehabilitation.

Beynnon et al in a 2005 study performed a prospective, randomized, double-blind comparison of ACL rehabilitation programs administered over two different time intervals.[23] A power analysis was performed to determine the number of patients required to detect a 2.5 mm difference in knee laxity between treatments. Twenty-five patients were randomized to an identical ACL rehabilitation program with the only difference the timeframe during which it was administered. One group (accelerated) performed the protocol over 19 weeks while the second group (nonaccelerated) performed the same protocol over 32 weeks. Exclusion criteria included meniscal repair, grade four chondral lesions and significant concomitant ligamentous injuries. Randomization was performed by a random number generation program. Three patients were lost to follow-up leaving 10 in the accelerated group and 12 in the nonaccelerated group. Compliance with the program differed between the two groups. While it was equal at 16 weeks in both groups, by completion of the program it differed. In the accelerated group 68% were compliant to the end of the 19 week program while only 40% of the nonaccelerated group was compliant through the end of the 32 week program.

Results were assessed using KT 1000, KOOS and IKDC outcome measures, Tegner activity level, one legged hop, and the biochemical markers of articular cartilage metabolism in synovial fluid. Follow-up was performed through 24 months. There was no statistically significant difference between the two groups of any results measured at any time point. The authors concluded that compliance with any ACL rehabilitation program is difficult past 12 weeks, but that in this study accelerated rehabilitation over 19 weeks did not result in deleterious effects compared to a 32 week program.

Miscellaneous

Ten RCTs have dealt with more discreet issues in single studies regarding ACL reconstruction rehabilitation. Draper in a 1990 study evaluated the effect of EMG biofeedback on recovery of the quadriceps muscle following ACL reconstruction.[24] Twenty-two patients were randomized either to routine protocol or routine protocol plus biofeedback performed during straight leg raises and quadriceps sets during the first 12 weeks of rehabilitation. Randomization method was not reviewed. Results were assessed using isometric strength of 12 weeks and the time to full knee extension. A significant treatment effect was noted in the biofeedback group for quadriceps isometric strength return $p < 0.01$. The time to obtain full extension was 63 days in the biofeedback group versus 78 days in the routine group. This was significant $p = 0.033$.

One study has been performed to evaluate the effects of performing rehabilitation exercises in water as compared to traditional land training by Tovin et al from 1994.[25] Twenty patients were randomized following bone tendon bone autograft ACL reconstruction using a block, coin toss, alternating randomization technique. The land group performed traditional rehabilitation exercises with a closed chain emphasis for the first eight weeks. The water group performed a similar exercise program in the pool with water resistance and some modification of the rehabilitation program for weeks two through eight.

Thigh girth, knee effusion, and knee passive range of motion was evaluated at two-week intervals during the eight weeks. Isokinetic and isometric peak torque, instrumented knee laxity and Lysholm scores were obtained at eight weeks. Knee laxity was equivalent in both groups. Range of motion was equivalent in both groups. Isokinetic peak flexion torque was increased in the land group $p = 0.01$. The water group demonstrated a smaller knee effusion at eight weeks. Lysholm score was greater in the water group at eight weeks 92.2 versus 82.4 $p = 0.03$.

Blanpied et al[26] in a 2000 study assessed the effectiveness of adding a slide board home exercise program two times a week to a standard physical therapy regimen. Fourteen patients were randomized to two groups eight weeks following ACL reconstruction using a BTB autograft. The intervention group used a lateral slide board three times a week in addition to a standard physical therapy regimen during weeks eight through 14. The intervention group gradually increased their time on the slide board to three 12 minute sessions with a three-minute rest between sets during week six. The control group continued with standard physical therapy. Randomization, blinding and the use of independent observers was not discussed.

Parameters assessed included isometric peak extension and flexion torque, maximum lateral step height, and lateral step up repetitions to fatigue. The authors did not normalize their data to the opposite extremity. Thus their analysis and conclusions may be flawed. The slide group demonstrated increased peak extension torque from pretest values. Peak flexion differences were not significant. Lateral step height significantly increased from pre to posttest in the slide group. Both groups demonstrated significant improvement from pre to posttest on lateral step up repetitions to fatigue. The authors concluded that the lateral slide board exercises improve knee extension strength.

Cupal and Brewer in a 2001 study examined the effects of relaxation and guided imagery on the strength, reinjury anxiety, and pain following ACL reconstruction.[27] Thirty patients were randomized to one of three groups: treatment, placebo, and control. Randomization was performed by random block assignment procedures to ensure equal group sizes. The treatment group received 10 individual sessions of relaxation and guided imagery in addition to normal physical therapy during the first six months of rehabilitation or. Treatment sessions were scripted, audiotaped and identical for all participants. Participants were asked to listen to the audiotapes at least once daily. The placebo group received attention, encouragement and support in addition to their normal physical therapy. Each placebo participant was asked to devote 10 to 15 minutes per day visualizing a peaceful scene. The control group underwent a normal physical therapy course.

Results were evaluated using isokinetic knee strength testing, a 0 to 10 reinjury anxiety score and pain score at 24 weeks. The treatment group demonstrated a significant strength increase in isokinetic testing at 24 weeks $p < 0.05$. Reinjury anxiety and pain decreased more significantly in the treatment group $p < 0.05$. Compliance with daily audiotape listening averaged 4.4 times per week. The authors concluded a relaxation and imagery based psychological intervention program may facilitate recovery from ACL reconstruction.

Meyers et al in a 2002 study compared stair climber versus cycle ergometry in ACL reconstruction rehabilitation.[28] At the four-week postoperative point 46 patients were randomized to three sessions a week using a stair climber or cycle equalized for workload. Randomization was not discussed.

Parameters assessed included isokinetic strength testing at 4 and 12 weeks, leg girth, KT 1000, and subjective evaluation. The only outcome for which a difference was noted was increased gastrocnemius circumference in the stair stepper group. The authors concluded a stair climber is a viable and safe alternative to cycle use for postoperative ACL reconstruction rehabilitation.

Liu-Ambrose et al[29] in a 2003 study evaluated proprioceptive or strength training six months after ACL reconstruction. Ten patients were randomly allocated to strength training by a method of increased loading versus a proprioceptive training program that was progressed by decreasing the support base, decreasing surface stability, increasing repetition number, removing visual feedback, and increasing the complexity and speed of the training. Both programs lasted 12 weeks with three times a week sessions. Patients were randomized if they were more than six months following ST hamstring autograft reconstruction. (Range 6–27 mos., 9/10 6 – 10 mos). The strength group consisted of three males and two females. The proprioception group consisted of one male and four females. On average the strength group was 12.2 months out from ACL reconstruction versus 6.7 months for the proprioception group. Randomization, blinding and independent assessment was not addressed in the manuscript. Compliance was assessed by use of a training log.

Outcome measures were Lysholm, Tegner, average isokinetic torque, functional hop tests, and hamstring peak torque time. Patients were assessed six and 12 weeks after beginning the training programs. Lysholm and Tegner scores increased significantly in both groups but there was no difference between the two groups. The proprioception group demonstrated a greater change in isokinetic torque compared to the strength group after 12 weeks of training. (Hamstring $p = 0.04$, quadriceps $p = 0.005$). Both groups showed statistically significant increases in their functional hop tests but there was no difference in the increase between groups. Peak torque time decreased in the proprioception group at six weeks and then returned to baseline at 12 weeks. The strength training group peak torque time actually increased at six weeks and then returned to baseline at 12 weeks. The authors hypothesize this may be caused by the strength training program which emphasized slow muscle training versus the peak torque time which emphasized fast recruitment testing.

The authors performed a power analysis prior to the study to detect a 10 to 12% difference in peak torque time. Their study did not detect a difference this large and thus may have been underpowered. The authors concluded that proprioceptive training and strength training both are beneficial for improving functional ability and subjective scores. The limitations of the study included selection bias by choosing groups dissimilar with regards to gender and time from surgery.

Ohta et al. in a 2003 study evaluated low load resistance muscle training with moderate restriction of blood flow following ACL reconstruction using a quintupled semitendinosis autograft.[30] Forty-four patients were randomized to two groups using odd or even identification numbers. Starting at week two the restricted blood flow group placed a tourniquet on the proximal thigh of the operated side and inflated it to 180 mm Hg while performing their rehabilitation exercises. The tourniquet was inflated for a maximum of 15 minutes followed by a 15 to 20 minute rest period and then resumption of exercises with the tourniquet. An exercise log was kept to determine exercise achievements. Two patients from the tourniquet group dropped out due to discomfort.

Results were measured using isokinetic testing, cross-sectional thigh area and muscle fiber diameter by biopsy preoperatively and at 16 weeks postoperatively. Isokinetic preoperative ratios of injured to healthy strength were equal. Postoperatively at 16 weeks in the extensor muscle strength the restricted blood flow group was stronger for all measurements at $p \leq 0.004$. Flexor muscle strength measurements were also significantly improved in the restricted blood flow group all at a level of $p \leq 0.05$ or better. Cross-sectional area by MRI was increased in the extensor muscles in the restricted blood flow group $p = 0.04$. No significant difference was noted in the cross-sectional area of the knee flexor group. No significant difference was noted in muscle fiber biopsies.

Decker et al. in a 2004 study evaluated gate retraining following patellar tendon ACL reconstruction.[31] Sixteen subjects were randomized into two groups. Randomization, blinding and use of independent observers were not addressed. Both groups performed identical rehabilitation protocols until the six-week mark. At that point one group began a walking program with the aid of the metronome set at a stride frequency calculated by a modified force driven harmonic oscillator. The second group began a walking program at a preferred stride frequency without use of a metronome. Both groups were asked to walk three times a week for 20 to 30 minutes and both groups kept an exercise log. Compliance with the program was similar in both groups.

Results were assessed by gait analysis at the six and 12 week postoperative point. At six weeks both groups noted decreased stride frequency and velocity. At 12 weeks the metronome group had an improved mid stance knee range of motion and improved extension at ground contact $p < 0.05$. The authors believe that gait changes may contribute to prolonged quadriceps weakness.

Tyler et al. in a 2004 study evaluated the effect of creatine supplementation on strength recovery following ACL reconstruction.[32] The study was a randomized, placebo-controlled, double-blind trial involving 60 subjects following endoscopic BTB autograft ACL reconstruction. Method of randomization was not reviewed in the manuscript. Patients were given 20 g a day for seven days beginning the first postoperative day followed by 5 g a day for 11 weeks.

Results were assessed using isokinetic testing at 6, 12, and 24 weeks postoperatively, knee outcome score and a single leg top test preoperatively and at six months postoperatively. No significant differences were noted in either group with any of the parameters tested at any time point. Attrition bias may have affected the study. Thirty-eight patients (17 creatine, 21 placebo) were available at six-month follow-up. Patients were lost to follow-up due to a variety of reasons including noncompliance, surgical complications, and gastrointestinal distress. The authors concluded that creatine supplementation did not demonstrate a beneficial effect during the first 12 weeks following ACL reconstruction.

Shaw et al in a 2005 study evaluated the effect of early quadriceps exercises following ACL reconstruction.[33] One hundred three patients were randomized using concealed allocation methods to one of two groups. Both groups performed range of motion, active knee flexion, passive knee extension, gait education, and foot ankle and calf exercises. The quadriceps exercise group added quadriceps sets and straight leg raises with 10 repetitions three times daily.

Results were determined using KT 1000 testing at three and six months, isokinetic testing and top test at six months, range of motion, quadriceps lag, limb circumference, pain, and satisfaction at one day two weeks 1, 3 and 6 months. The Cincinnati knee rating scale was used at 1, 3 and six months. Significant differences were noted in active flexion and extension at one month with the quadriceps exercise group improved ($p = 0.05$). No differences were noted in quadriceps lag or limb circumference at any time point. No difference in pain was noted except at one day when the quadriceps exercise group noted pain while performing the exercises. The symptoms and problems with sports subscores of the Cincinnati scale were significantly improved in the quadriceps exercise group at six months. KT 1000 testing was similar in both groups at all time points. The authors concluded early quadriceps exercises are not deleterious and may improve some facets of ACL rehabilitation.

Conclusions

As can be seen in this systematic review many issues regarding ACL reconstruction rehabilitation have been evaluated using randomized controlled trials. The methodological quality of the studies reviewed is mixed. Most of the studies suffer from some form of potential bias. This is especially true of the studies published prior to 2000 when many of the study quality issues were not yet recognized. Despite this some reasonable conclusion can be made from the studies and used in developing an ACL reconstruction rehabilitation protocol.

Early weight-bearing appears beneficial and may decrease patellofemoral pain. Early motion is safe and may help avoid problems with later arthrofibrosis. CPM usage is not warranted to improve rehabilitation outcome in patients and can avoid the increased costs associated with CPM. Minimally supervised physical therapy in selected motivated patients appears safe without significant risk of complications. Until further studies are performed protocols should use closed kinetic chain exercises in the first six weeks. Postoperative rehabilitative bracing either in extension or with the hinges opened for ROM does not offer significant advantages over no bracing. Neuromuscular electrical stimulation if deemed necessary for the patient should be instituted early in the postoperative timeframe and should be of high intensity to achieve meaningful results. Accelerated rehabilitation appears safe at least in the five to six month time frame as demonstrated by the studies by Beynnon and Ekstrand.[23] Further studies will be necessary to determine if even shorter time frames are safe.

As seen in the miscellaneous section water-based therapy, stair climber, and slide board exercise programs appears safe and may add variety if available for the patient. Gait, proprioception and psychological training may be of some benefit. Creatine at least in the dosage and timeframe used by Tyler et al offered no benefit. Restricting blood flow during rehabilitation sessions will require further studies before it becomes regularly prescribed by most clinicians. Despite greater than 50 RCTs in the field many questions remain and further studies are warranted to continue to add evidence to our ACL reconstruction rehabilitation protocols.

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