A Systematic Review of Anterior Cruciate Ligament Reconstruction Rehabilitation

Part I: Continuous Passive Motion, Early Weight Bearing, Postoperative Bracing, and Home-Based Rehabilitation

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ABSTRACT: Anterior cruciate ligament (ACL) reconstruction is a common surgical knee procedure that requires intensive postoperative rehabilitation by the patient. A variety of randomized controlled trials have investigated aspects of ACL reconstruction rehabilitation. A systematic review of English language level 1 and 2 studies identified 54 appropriate randomized controlled trials of ACL rehabilitation. Topics discussed in this part of the article include continuous passive motion, early weight bearing in motion, postoperative bracing, and home-based rehabilitation.

[*J Knee Surg*. 2008;21:217-224.]

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. Although 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 (ie, bracing) and did not encompass many recently published studies.[19,22]

The goal of this systematic review was to assemble the available randomized controlled trials in ACL rehabilitation to facilitate the development of evidence-based rehabilitation protocols. This article is the first in a 2-part series systematically reviewing the level 1 and 2 evidence regarding ACL reconstruction rehabilitation.

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METHODS

PubMed 1966-2005, Embase 1980-2005, and the Cochrane Controlled Trials Register were searched for articles appropriate to this study. Bibliographies of identified studies also were searched, and a hand review of the past 6 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 methodologic quality with emphasis on identifying biases present in each study. All studies were level 1 or 2 evidence. Topics included in this review are continuous passive motion (CPM), rehabilitative bracing, neuromuscular electrical stimulation, early weight bearing, home versus supervised physical therapy, open versus closed chain kinetic exercise programs, and accelerated rehabilitation, as well as a variety of miscellaneous topics assessed by only 1 randomized trial.

CONTINUOUS PASSIVE MOTION

Six randomized controlled trials have been performed assessing the efficacy of CPM in the rehabilitation of ACL reconstructions. In a 1991 study, Richmond et al[17] compared short-term versus longer-term CPM use. Twenty patients were randomly divided into 2 groups. Group 1 used CPM 6 hours per day for 4 days during hospitalization. Group 2 used CPM 6 hours per day for the first 14 days postoperatively. Both groups underwent additional rehabilitative activities.

The study was prospective, but the randomization method was not discussed. Some selection bias was present by exclusion of patients whose insurance would not pay for a CPM machine. Otherwise, the 2 groups were similar. Reconstruction methods were identical for both groups.

Swelling, atrophy, range of motion, and instrumented laxity were assessed postoperatively. Swelling, atrophy, and range of motion were assessed at 2, 7, 14, 28, and 42 days. No significant difference was noted in any of these values at these time points. A statistically significant difference was noted on KT-1000 89 N testing at 42 days. The 14-day CPM group had statistically significant less anterior translation compared with the 4-day CPM group (0.4 mm versus 2.4 mm, $P = .04$). The authors concluded longer-term CPM use, given its higher cost, was not beneficial and also did not increase the risk of laxity in the knee.

Rosen et al,[20] in a 1992 study, compared early active motion versus CPM in patients undergoing autograft patellar tendon reconstruction. Seventy-five patients were randomly divided into 3 groups: group A patients underwent early active motion during hospitalization followed by outpatient physical therapy (PT) 3 times per week, group B patients used a CPM machine 20 hours per day during hospitalization (mean, 2.9 days) followed by CPM use 6 hours per day for 4 weeks and outpatient PT 3 times per week, and group C patients performed early active motion during hospitalization and followed the group B CPM protocol but did not participate in outpatient physical therapy for the first month. The study was prospective, and randomization was performed by a lottery. In general, there was minimal selection bias, with the groups equivalent except for gender. Group B had 42% women versus 24% and 20% in groups A and C, respectively. Exclusion criteria included extracapsular procedures and meniscal repairs.

Range of motion and instrumented knee laxity were the most important determinants of outcome for the study. Range of motion was determined at hospital discharge, 1 week postoperatively, and then monthly for the first 6 months. No statistically significant differences were noted in any of the groups at any time. KT-1000 data were obtained at completion of the surgical procedure and at 2 and 6 months postoperatively. No difference in stability was noted between any group at any time point. In addition, no difference was noted in analgesic use, hemovac drainage, or length of hospital stay. The authors concluded the use of CPM in the first 30 days after ACL reconstruction resulted in similar results as early active motion. The CPM added an additional cost to treatment.

In another 1992 study, Yates et al[26] evaluated the effects of 2 weeks of CPM following patellar tendon autograft ACL reconstruction. Using random sampling, 30 patients were randomized to either CPM 16 hours per day for the first 3 postoperative days followed by 6 hours per day for a total of 14 days use or an identical rehabilitation protocol without CPM. The authors concluded there was decreased hemarthrosis, decreased narcotic use, and decreased swelling in the CPM group. Active and passive flexion was noted to be improved at days 3 and 7 in the CPM group.

McCarthy et al,[11] in a 1993 study, assessed the effects of CPM on anterior laxity following ACL reconstruction. Twenty patients who underwent patellar tendon autograft ACL reconstruction were randomized to either CPM 16 hours per day for the first 3 days followed by 6 hours per day until postoperative day 14 or an identical rehabilitation protocol without CPM. KT-1000 testing at 12 months

postoperatively demonstrated an identical average side-to-side difference of 0.4 mm in both groups, and all patients had side-to-side differences ⩽3 mm. The authors concluded CPM did not result in increased anterior laxity.

In another 1993 study, McCarthy et al[12] compared 3 days of CPM versus no CPM on pain and narcotic requirements. Thirty patients who underwent bone-patellar tendon-bone ACL reconstruction were randomized to 2 groups: group 1 began physical therapy on postoperative day 1 and group 2 began using a CPM machine immediately postoperatively and continued its use for 16 hours per day for 3 days in addition to routine physical therapy similar to group 1.

The randomization methods were not discussed. Patient-controlled analgesia use during the first 24 hours postoperatively, oral narcotic use on postoperative days 2 and 3, and graphic pain scales were used to assess results. The 2 groups were similar but no narcotic dose correction for patient body weight was performed to standardize results. Total narcotic dose and the number of times the patient-controlled analgesia button was pushed were significantly increased in the non-CPM group ($P < .05$). Oral narcotic use on postoperative days 2 and 3 was significantly increased in the non-CPM group. Graphic pain scales were similar in all groups at all time periods. The authors concluded CPM is beneficial following autogenous bone-patellar tendon-bone ACL reconstruction to decrease narcotic use.

Engström et al,[3] in a 1995 study, compared CPM versus active motion in the early postoperative period. Thirty-four patients were randomized to 2 groups: group 1 started active motion on postoperative day 1 following ACL reconstruction and group 2 started CPM 6 hours per day for 6 days in addition to active motion beginning on postoperative day 1. The method of randomization was not discussed. Parameters evaluated included swelling, range of motion, and atrophy at 6 weeks postoperatively. Selection bias was present in the fact that the active motion group had more acute ACL reconstructions (9 versus 3) and these patients had a much larger extension lag of 7.8° versus 0.8° in the CPM group. Otherwise, the groups were similar.

There was no statistically significant difference at 6 weeks in range of motion or atrophy between the 2 groups. Midpatellar and base of patella circumference was increased in the active motion group at 6 weeks ($P < .05$). The authors attributed this difference to the fact that the active motion group contained more acute ACL reconstructions and had increased swelling preoperatively. The authors concluded there were no benefits of CPM after ACL reconstruction.

All 6 of these studies included small numbers of patients. Every study had at least 1 parameter that was determined not to be statistically different between groups. Selection bias by randomization method potentially existed in all but the Rosen study.[20] Blinding of examiners was not addressed in any study. Dropouts and compliance were not addressed in any study. None of the studies presented power calculations to determine the size of group that would have been necessary to potentially demonstrate a difference if it did exist. Thus, these potentially have a type II error. Based on this review, there is no substantial advantage for CPM use except for a possible decrease in pain. Therefore, its use cannot be justified with its additional insurance and patient costs.

EARLY WEIGHT BEARING AND MOTION

One randomized trial has been performed evaluating the efficacy of immediate weight bearing versus delayed weight bearing following ACL reconstruction. Tyler et al,[24] in a 1998 study, compared immediate weight bearing as tolerated versus a delay of 2 weeks. Forty-nine patients were prospectively randomized following endoscopic autograft bone-patellar tendon-bone reconstructions. The randomization technique was not discussed. Independent examiners assessed the results, but blinding was not discussed. Group 1 was instructed to discard their crutches as soon as possible and to bear as much weight as possible. Compliance with weight bearing was not determined. Group 2 was instructed to remain nonweight bearing for the first 2 weeks following reconstruction. They were instructed to not wear a shoe to improve compliance. Two patients in each group were lost to follow-up.

Parameters evaluated included range of motion, stability, vastus medialis oblique electromyogram, Lysholm and Tegner scores, and anterior knee pain. KT-1000 testing demonstrated no difference at final follow-up, which ranged from 6 to 14 months. Range of motion showed no statistical difference at 2 weeks or final follow-up of 6 to 14 months (mean, 7.3 months). Vastus medialis oblique activity was significantly increased in the weight-bearing group at 2 weeks ($P = .002$); however, at final follow-up, vastus medialis oblique activity was equal in both groups.

At final follow-up, a statistically significant difference in anterior knee pain was noted. Seven of 20 nonweight-bearing patients (35%) and 2 of 25 weight-bearing patients (8%) reported pain ($P = .03$). Anterior knee pain was evaluated using questions from the Lysholm scale that described pain with routine exertion, stair climbing, or squatting. Lysholm scores demonstrated a significantly greater improvement from preoperatively in the weight-bearing group ($P = .03$).

The authors concluded there were no deleterious effects of early weight bearing on stability or function and anterior knee pain may be decreased by earlier recruit-

TABLE 1

PUBLISHED STUDIES ON POSTOPERATIVE BRACING FOLLOWING ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION[a]

Study	No. Patients/ Groups	Group Differences	Randomization	Parameters Assessed	Significant Findings	ACL Reconstruction Method	Bias
Brandsson et al[2] (2001)	50/2	Brace 3 weeks versus no brace		Lysholm, Tegner, laxity, isokinetic, 1-leg hop, ROM, early complications	No difference at 2-year follow-up, early complications increased no brace	BTB	Selection
Feller et al[4] (1997)	40/2	Hinged passive extension brace versus no brace		ROM, KT-1000, isokinetic	No differences at 4 months	BTB	Exclusion, selection
Haggmark & Eriksson[7] (1979)	16/2	Cylinder cast versus cast brace		Thigh atrophy, ROM, muscle biopsy	No data	Jones PT	Selection
Harilainen et al[8] (1997)	60/2	Brace 12 weeks versus no brace	Birth year	Lysholm, Tegner, laxity, isokinetic	No differences at 1 and 2 years	BTB	Selection
Henriksson et al[9] (2002)	50/2	Plaster versus brace		ROM, isokinetic, laxity, Lysholm, Tegner	Brace decreased strength by Biodex at 24 months	BTB	Selection
Kartus et al[10] (1997)	78/39	Brace 4 weeks (range, 3-6 weeks)	Consecutive not random	Lysholm, Tegner, laxity, IKDC 1991, 1-leg hop	No differences at 2 years	BTB	Selection
Melegati et al[13] (2003)	36/2	Brace at 0°×7 days then 0°-120° versus brace 0°-120°×2 weeks	Alternating groups	Heel height difference, laxity	Brace in extension better at 4 and 8 weeks	BTB	Selection
Moller et al[14] (2001)	62/2	Brace 6 weeks versus no brace		Lysholm, Tegner, laxity, isokinetic, 1-leg hop, ROM, swelling, VAS	No brace increased Tegner 6 months and decreased swelling 2 weeks	BTB	Selection
Muellner et al[15] (1998)	40/2	Hinged brace 0°, increased progressively versus Neoprene sleeve 6 weeks		Tegner, OAK, ROM, Cybex, KT-1000, 1-leg hop	6 and 12 weeks ROM, 24 week 1-leg hop improved in sleeve group	BTB	Selection
Risberg et al[18] (1999)	60/2	Rehabilitative brace 2 weeks, functional 10 weeks versus no brace	Block	ROM, Cincinnati, CT thigh, isokinetic, VAS, laxity, 3 functional tests	Brace increased Cincinnati and increased thigh atrophy 3 months	BTB	Exclusion
Timm[23] (1997)	60/2	Protonics brace versus brace		Isokinetic, laxity, 1-leg hop	80% strength achieved 3.3 weeks earlier in Protonics	BTB	Selection

Abbreviations: ROM, range of motion; IKDC, International Knee Documentation Committee; CT, computed tomography; VAS, visual analog scale; OAK, Orthopadische Arbeitsgemeinschaft Knie scoring system; BTB, bone-patellar tendon-bone; PT, physical therapy.

[a] Adapted with permission from Wolters Kluwer for English language only.[25]

ment of the vastus medialis oblique when weight bearing. A trend was noted in their study that patients who reported anterior knee pain at final follow-up had decreased vastus medialis oblique activity at 2 weeks. Potential selection or observer bias existed, but early weight bearing following reconstruction is probably justified. Any future studies need to document compliance with weight bearing in the assigned groups.

Noyes et al,[16] in a 1987 study, evaluated the effect of early motion following open and arthroscopic ACL reconstruction. Following ACL reconstruction or ACL repair with graft augmentation, 18 patients were randomly divided into 2 groups. Group 1 began CPM motion on postoperative day 2, whereas group 2 remained in a hinged brace at 10° of flexion for the first postoperative week and the began CPM use on day 7. Randomization method and blinding were not addressed.

The authors noted a weak trend toward earlier extension and flexion gains between postoperative days 14 and 21 in the early motion group, but these were not significantly different ($P = .20$). There was no difference in the 2 groups regarding knee laxity as measured by KT-1000 testing. Currently, most ACL rehabilitation protocols institute early motion within the first postoperative week, supporting the trend noted in this study.

POSTOPERATIVE BRACING

One of the authors (R.W.W.) recently published a systematic review of postoperative rehabilitative bracing.[25] These braces are designed to limit range of motion to predetermined settings and protect the knee against excessive varus and valgus stresses. Eleven articles[2,4,7-10,13-15,18,23] evaluating the results of ACL reconstruction rehabilitation using these braces were included in this systematic review (Table 1).

Outcomes evaluated included ease and speed of obtaining range of motion, especially extension; swelling control; wound drainage; knee laxity; pain; and protection from injury. All of the included studies contained biases that attracted from their conclusions. Only 1 study[18] determined the power to detect a statistically significant difference; therefore, many studies were potentially underpowered. Independent examiners were used in only 3 studies.[2,8,10] Blinding was only described by 3 studies.[10,14,18] Several studies had potential selection bias due to lack of description of randomization techniques. The only study that demonstrated a potentially clinically significant finding was by Melegati et al,[13] who reported improved extension following locking the brace in full extension during the first postoperative week.

No study demonstrated a potentially worse outcome when bracing was not used. Importantly, no increase in postoperative injuries, increased pain, decreased range of motion, or increased knee laxity was found in the control groups that were not braced following surgery. On the basis of the studies included, we determined postoperative bracing was not necessary following ACL reconstruction.

HOME-BASED REHABILITATION

Four available randomized controlled trials[1,5,6,21] have been performed to evaluate standard clinic-based physical therapy rehabilitation versus minimally supervised home-based rehabilitation following ACL reconstruction (Table 2). Schenck et al,[21] in a 1997 study, randomized 37 patients by lottery following 2-incision autograft bone-patellar tendon-bone ACL reconstruction to home-based or clinic-based physical therapy. Exclusion criteria included age <18 years. Patients were monitored by an independent observer; blinding of the independent observer was not discussed.

Twenty-two patients in the home rehabilitation program had an average of 2.85 visits (range, 0-6 visits) with a physical therapist in the clinic to supervise a home-based program. Fifteen patients in the clinic-based group had an average of 14.2 visits (range, 6-40 visits) in the physical therapy clinic. There was a significant difference between the groups in the number of visits required ($P < .05$). The prescribed exercises were the same for both groups, with the only difference the amount of clinic-supervised therapy.

Parameters assessed to determine outcome included range of motion, Lysholm score, pain visual analog scale, 1-legged hop, KT-1000 testing, and the Sickness Impact Profile. These were measured preoperatively and at 3 months and 12 months postoperatively. There was no difference in any measured evaluation between the 2 groups at any point in the study. No patient in either group required additional surgery. The authors concluded minimal supervision for rehabilitation could result in equivalent outcome following ACL reconstruction. The authors excluded patients <18 years because they think these patients are too immature to control their own rehabilitation.

Beard and Dodd,[1] in a 1998 study, assessed a home versus group exercise program following 4 to 6 weeks of standardized supervised physical therapy after ACL reconstruction. Thirty-one patients were randomized, and 5 were lost to follow-up. Randomization was by a computer program. An independent examiner was blinded to patient allocation.

Both groups performed supervised physical therapy 2 times per week for the first 2 weeks and once per week for the next 2 to 4 weeks following surgery. At that point, the 13 patients in the home-based group continued their reha-

TABLE 2

PUBLISHED STUDIES ON HOME-BASED REHABILITATION FOLLOWING ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION

Study	No. Patients/ Groups	Group Differences	Randomization	Parameters Assessed	Significant Findings	ACL Reconstruction Method	Bias
Schenck et al[21] (1997)	37/2	Home versus clinic, 2.85 versus 14.2 visits	Lottery	ROM, Lysholm, VAS, 1-leg hop, instrumented laxity, sickness profile	None	BTB	Selection
Beard & Dodd[1] (1998)	31/2	Group exercise class after 6 weeks supervised	Computer	Lysholm, Tegner, IKDC, VAS, 1-leg hop, instrumented laxity, isokinetic	None	BTB	Not obvious
Fischer et al[5] (1998)	54/2	6 visits versus 24 visits		Lysholm, 1-leg hop, ROM, instrumented laxity, thigh atrophy, subjective health	None	Allograft or autograft BTB	Selection
Grant et al[6] (2005)	145/2	4 sessions versus 17 sessions	Stratified block	ROM, instrumented laxity, strength	ROM improved in home group	BTB	Performance

Abbreviations: ROM, range of motion; VAS, visual analog scale; BTB, bone-patellar tendon-bone; IKDC, International Knee Documentation Committee.

bilitation without supervision. The 13 patients in the supervised group then continued twice per week attendance to a group knee exercise class, with the goal of 12 weeks of continued supervision. An attempt to determine compliance of the home group was made, but the home-based patients did not complete the compliance forms. In the supervised group, the median number of sessions attended was 16 (range, 10-22 sessions). The maximum number of sessions that could be attended was 32 (16 weeks).

Outcome was assessed by Lysholm, Tegner, and International Knee Documentation Committee scores; visual analog scale for sports and activities of daily living; instrumented laxity; and isokinetic testing. These were all assessed preoperatively and at 3 and 6 months postoperatively. No difference was noted in any assessment at any time point. The authors concluded a home-based regimen of rehabilitation following a short course of supervised therapy is equivalent to further supervised therapy.

Fischer et al,[5] in a 1998 study, evaluated a group of patients prospectively randomized to a home-based or clinic-based physical therapy program following autograft or allograft bone-patellar tendon-bone ACL reconstruction. Fifty-four patients were randomized to the 2 groups. One patient in the clinic-based group was lost to follow-up because of subsequent foot surgery. Randomization technique, blinding, and independent assessment were not discussed. Compliance was assessed in the home group using a training log. Exclusion criteria included patients $<$15 years. The patients in the home-based group were prescribed 6 physical therapy visits in the first 6 months postoperatively. The clinic-based group was prescribed 24 visits in the first 6 months. The home-based group averaged 5 visits (range, 3-7 visits). The clinic-based patients averaged 19.9 visits (range, 10-28 visits).

Parameters assessed included range of motion, thigh atrophy, anterior drawer compliance, hopping test, Lysholm score, and a subjective health status score. There was no significant difference between the 2 groups for any assessment at any time point. The authors concluded a home-based program is understandable, convenient, and reliable and can be used for many patients undergoing ACL reconstruction.

Grant et al,[6] in a 2005 study, randomized 145 patients to a minimally supervised home-based rehabilitation program versus a traditional physical therapy-supervised protocol. Assessment was blinded, and randomization was performed using a stratified blocked procedure. Home-based patients attended 4 physical therapy sessions within the first 3 postoperative months. Physical therapy-based patients attended 2 sessions per week for weeks 2 through 7 and once per week for weeks 8 through 12, for a total of 17 sessions within the first 3 postoperative months. Compliance was assessed by therapy attendance. Patients

were assessed preoperatively for baseline measurements and at 6 and 12 weeks postoperatively. Range of motion, instrumented laxity, and strength were assessed at these time points. Three patients dropped out after randomization, and 129 patients were assessed at the 12-week final follow-up.

Results were determined as acceptable outcomes. A significant difference was noted in flexion and extension range of motion. The home-based group had an acceptable rate of 96.8% for extension versus 83.3% for the physical therapy-based group ($P = .02$). The home-based group had an acceptable flexion rate of 66.7% versus 47% for the physical therapy-based group ($P = .03$). Knee laxity and strength demonstrated no significant differences. A potential performance bias existed because all home-based patients saw the same physical therapist at the sports medicine center, whereas the physical therapy-based group was allowed to choose any physical therapist.

These studies each potentially have some form of bias. Each study except the study by Grant et al[6] lacked either a discussion of randomization methods, blinding, independent observation, or measure of compliance. Despite these potential shortcomings, it is reasonable to conclude a minimally supervised physical therapy program can result in successful ACL rehabilitation.

CONCLUSION

Many issues regarding ACL reconstruction rehabilitation have been evaluated using randomized controlled trials. The methodologic quality of the studies reviewed is mixed. Most of the studies have 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 conclusions 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. Continuous passive motion 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. Postoperative rehabilitative bracing either in extension or with the hinges opened for range of motion does not offer significant advantages over no bracing.

REFERENCES

1. Beard DJ, Dodd CA. Home or supervised rehabilitation following anterior cruciate ligament reconstruction: A randomized controlled trial. *J Orthop Sports Phys Ther*. 1998;27:134-143.
2. Brandsson S, Faxen E, Kartus J, Eriksson BI, Karlsson J. Is a knee brace advantageous after anterior cruciate ligament surgery? A prospective, randomised study with a two-year follow-up. *Scand J Med Sci Sports*. 2001;11:110-114.
3. Engström B, Sperber A, Wredmark T. Continuous passive motion in rehabilitation after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1995;3:18-20.
4. Feller J, Bartlett J, Chapman S, Delahunt M. Use of an extension-assisting brace following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1997;5:6-9.
5. Fischer DA, Tewes DP, Boyd JL, Smith JP, Quick DC. Home based rehabilitation for anterior cruciate ligament reconstruction. *Clin Orthop*. 1998;(347):194-199.
6. Grant JA, Mohtadi NG, Maitland ME, Zernicke RF. Comparison of home versus physical therapy-supervised rehabilitation programs after anterior cruciate ligament reconstruction: A randomized controlled trial. *Am J Sports Med*. 2005;33:1288-1297.
7. Haggmark T, Eriksson E. Cylinder or mobile cast brace after knee ligament surgery: A clinical analysis and morphologic and enzymatic studies of changes in the quadriceps muscle. *Am J Sports Med*. 1979;7:48-56.
8. Harilainen A, Sandelin J, Vanhanen I, Kivinen A. Knee brace after bone-tendon-bone anterior cruciate ligament reconstruction. Randomized, prospective study with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 1997;5:10-13.
9. Henriksson M, Rockborn P, Good L. Range of motion training in brace vs. plaster immobilization after anterior cruciate ligament reconstruction: A prospective randomized comparison with a 2-year follow-up. *Scand J Med Sci Sports*. 2002;12:73-80.
10. Kartus J, Stener S, Kohler K, Sernert N, Eriksson BI, Karlsson J. Is bracing after anterior cruciate ligament reconstruction necessary? A 2-year follow-up of 78 consecutive patients rehabilitated with or without a brace. *Knee Surg Sports Traumatol Arthrosc*. 1997;5:157-161.
11. McCarthy MR, Buxton BP, Yates CK. Effects of continuous passive motion on anterior laxity following ACL reconstruction with autogenous patellar tendon grafts. *J Sport Rehabil*. 1993;2:171-178.
12. McCarthy MR, Yates CK, Anderson MA, Yates-McCarthy JL. The effects of immediate continuous passive motion on pain during the inflammatory phase of soft tissue healing following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 1993;17:96-101.
13. Melegati G, Tornese D, Bandi M, Volpi P, Schonhuber H, Denti M. The role of the rehabilitation brace in restoring knee extension after anterior cruciate ligament reconstruction: A prospective controlled study. *Knee Surg Sports Traumatol Arthrosc*. 2003;11:322-326.
14. Moller E, Forssblad M, Hansson L, Wange P, Weidenhielm L. Bracing versus nonbracing in rehabilitation after anterior cruciate ligament reconstruction: A randomized prospective study with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2001;9:102-108.
15. Muellner T, Alacamlioglu Y, Nikolic A, Schabus R. No benefit of bracing on the early outcome after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 1998;6:88-92.
16. Noyes FR, Mangine RE, Barber S. Early knee motion after open and arthroscopic anterior cruciate ligament reconstruction. *Am J Sports Med*. 1987;15:149-160.

17. Richmond JC, Gladstone J, MacGillivray J. Continuous passive motion after arthroscopically assisted anterior cruciate ligament reconstruction: Comparison of short- versus long-term use [published correction appears in *Arthroscopy*. 1991;7:256]. *Arthroscopy*. 1991;7:39-44.
18. Risberg MA, Holm I, Steen H, Eriksson J, Ekeland A. The effect of knee bracing after anterior cruciate ligament reconstruction: A prospective, randomized study with two years' follow-up. *Am J Sports Med*. 1999;27:76-83.
19. Risberg MA, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: How much and what type. *Phys Ther Sport*. 2004;5:125-145.
20. Rosen MA, Jackson DW, Atwell EA. The efficacy of continuous passive motion in the rehabilitation of anterior cruciate ligament reconstructions. *Am J Sports Med*. 1992;20:122-127.
21. Schenck RC Jr, Blaschak MJ, Lance ED, Turturro TC, Holmes CF. A prospective outcome study of rehabilitation programs and anterior cruciate ligament reconstruction. *Arthroscopy*. 1997;13:285-290.
22. Thomson LC, Handoll HH, Cunningham A, Shaw PC. Physiotherapist-led programmes and interventions for rehabilitation of anterior cruciate ligament, medial collateral ligament and meniscal injuries of the knee in adults. *Cochrane Database Syst Rev*. 2002;1:CD001354.
23. Timm KE. The clinical and cost-effectiveness of two different programs for rehabilitation following ACL reconstruction. *J Orthop Sports Phys Ther*. 1997;25:43-48.
24. Tyler TF, McHugh MP, Gleim GW, Nicholas SJ. The effect of immediate weightbearing after anterior cruciate ligament reconstruction. *Clin Orthop*. 1998;(357):141-148.
25. Wright RW, Fetzer GB. Bracing after ACL reconstruction: A systematic review. *Clin Orthop*. 2007;455:162-168.
26. Yates CK, McCarthy MR, Hirsch HS, Pascale MS. Effects of continuous passive motion following ACL reconstruction with autogenous patellar tendon grafts. *J Sport Rehabil*. 1992;1:121-131.