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A RANDOMISED CONTROLLED TRIAL OF PROPRIOCEPTIVE AND BALANCE TRAINING AFTER SURGICAL RECONSTRUCTION OF THE ANTERIOR CRUCIATE LIGAMENT

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A randomised controlled trial (29 participants) was used to compare a 6-week proprioceptive and balance exercise program with a 6-week strengthening program in the early phases of rehabilitation after anterior cruciate ligament (ACL) reconstruction. Measurements of functional activity were taken by a blinded assessor before the intervention and at the end of the 6 weeks. Results demonstrated that there were no significant differences between groups on hop testing at 6 weeks. For several items in the Cincinnati knee rating system and the patient specific functional scale however, the strengthening group improved more than the proprioceptive and balance group ($p < .05$). The hypothesis that proprioceptive and balance training would improve functional activity more than strengthening exercises was not supported. There was either no difference between the two forms of exercise or strength training may be more beneficial than proprioceptive and balance training in the early phase of rehabilitation after ACL reconstructive surgery.

Keywords: rehabilitation, ACL injury, neuromuscular control

INTRODUCTION

There is evidence that injury to the ACL adversely affects knee joint proprioception, with several studies showing decreased knee joint proprioception in people with ACL deficiency (Barrack, Skinner, and Buckley

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1989; Corrigan, Cashman, and Brady 1992). It has been suggested that enhancement of the neuromuscular control of the knee following ACL injury or reconstruction through the prescription of balance and proprioceptive exercises may lead to better outcomes in terms of return to functional activities and a reduced rate of reinjury (Brukner and Khan 2001; Swanik, Lephart, Giannantonio, and Fu 1997).

In prospective randomised controlled studies that have investigated proprioceptive rehabilitation in persons with ACL deficiency, improvements in joint position sense (Ageberg, Zatterstrom, Moritz, and Friden 2001; Beard, Dodd, Trundle, and Simpson 1994), muscle strength (Fitzgerald, Axe, and Snyder Mackler 2000; Zatterstrom, Friden, Lindstrand, and Moritz 2000), perceived knee joint function (Fitzgerald et al. 2000; Zatterstrom et al. 2000), and hop testing (Ageberg et al. 2001; Zatterstrom et al. 2000) were reported following proprioceptive and balance exercise.

Only one prospective randomised controlled trial has compared proprioceptive exercise with strength exercise following ACL reconstructive surgery (Liu-Ambrose, Taunton, MacIntyre, McConkey, and Khan 2003). This study had a relatively small sample size (n = 5 in each group) and was conducted in the later phases of rehabilitation (>6 months following surgery). Some modest benefits were noted in the proprioceptive group for measures of muscle strength and proprioception; however, no benefits were noted for any measures of functional activity.

It was the aim of the current study to compare a proprioceptive and balance program with a traditional program based on strengthening exercises during the early phase of rehabilitation after ACL reconstructive surgery. It was hypothesised that a proprioceptive and balance program would lead to improved functional activity compared with a strengthening program.

MATERIALS AND METHODS

Participants

Twenty-nine people who had ACL reconstructive surgery and who fulfilled eligibility criteria were recruited to participate in the current study. Participants were recruited from three orthopaedic surgeons experienced in performing ACL reconstructive surgery. Participants were informed of the study and its requirements at the appointment with the surgeon 2 weeks after surgery.

All participants gave informed consent to participate in the current study, which had received ethics approval from the Faculty Human Ethics Committee. Participants were included in the study if they: (i) underwent surgical reconstruction of the ACL with one of the three participating

surgeons; (ii) were aged between 16 and 50 years; (iii) were willing to attend a centrally located sports medicine centre for physiotherapy treatment following surgery; and (iv) met the following physical requirements by 14 weeks following surgery:

(a) Walk without assistive devices;
(b) 0°–120° range of motion of the affected knee;
(c) straight leg raise with no quadriceps lag;
(d) minimal knee joint effusion.

Entry was excluded to participants who: (i) sustained significant concurrent injury to affected knee including posterior cruciate ligament injury, and/or Grade III collateral ligament injury, and/or patellar dislocation; (ii) had chondral changes of Noyes Grade 2B (Noyes and Stabler 1989) or greater at arthroscopy; (iii) meniscal pathology requiring repair or resection of >30% of meniscus; and (iv) radiographic evidence of arthritis.

The choice of the graft (patellar tendon or hamstrings) was at the discretion of the treating orthopaedic surgeon based on clinical judgement and patient preference.

Experimental Design

This study employed a single-blinded, prospective randomised controlled trial design. When participants attained the physical requirements, between 4 and 14 weeks postsurgery, they were randomly allocated, using a concealed method, to either the proprioceptive and balance exercise group (Group A) or a traditional strengthening exercise group (Group B) after the baseline testing session. The baseline testing session consisted of baseline information (gender, age, weight, height, time since surgery, graft type and orthopaedic surgeon, and level of sporting ability); perceived measures of ability (Cincinnati knee rating system and patient specific functional scale); and range of motion (flexion and extension).

Randomisation

The sequence of random allocation was generated by pulling 30 standard sized pieces of paper out of a hat by the project supervisor (NT). Fifteen pieces of paper were marked with the letter A, and 15 with the letter B. Each piece of paper was sequentially placed into 30 sealed, opaque envelopes by the project supervisor. The sealed envelopes were numbered 1 to 30 and given to the clinical physiotherapist (RC). Participants were numbered 1 to 30 in order of when they commenced the baseline testing session and intervention period. When each participant attained the physical requirements,

and completed the baseline testing session, the clinical physiotherapist opened the corresponding sealed envelope to reveal their group allocation.

Interventions

Two physiotherapy sessions were conducted each week for the 6-week intervention period. For both groups, each physiotherapy session was 40 to 60 minutes in duration with up to 20 minutes being allocated to assessment, manual treatment, and advice from the clinical physiotherapist, with the remainder being allocated to exercise.

Participants in both groups were prescribed 1 hour of home exercise each day excluding physiotherapy days. The home exercise program closely matched the clinic based program for each group. Participants were required to fill in a simple exercise diary during the 6-week intervention, documenting how many minutes they spent each day on their rehabilitation exercises (including clinic based exercises).

The proprioceptive and balance training group (Group A) followed a rehabilitation program that aimed to challenge the proprioception and/or balance of the participant (Table 1). The exercises and activities in this program were based on and adapted from the proprioceptive and balance exercises used in previous ACL proprioceptive rehabilitation studies (Ageberg et al. 2001; Beard et al. 1994; Fitzgerald et al. 2000; Zatterstrom et al. 2000). The exercises were adapted to suit the range of equipment commonly used in physiotherapy clinics such as wobble boards, mini trampolines, inflatable balance discs, and exercise balls. The home program similarly was adapted to suit equipment and items commonly used in home programs such as a rolled towel and an exercise ball. The emphasis of the exercises was to practice maintenance of a stable, balanced position for periods of 20 seconds or greater. Progression of exercises was based on increasing the balance demands of the exercise by decreasing the base of support, for example, progressing from double leg exercises to single leg exercises.

The traditional strength training group (Group B) followed a rehabilitation program modified from the protocol of Brukner and Khan (2001), excluding exercises that aimed to improve balance or proprioception (Table 2). The exercises in this protocol would be expected to improve muscular strength and endurance. Most exercises used a set-repetition type structure, such as 3 to 4 sets of 10 to 15 repetitions, which aimed to improve the strength and endurance of major muscle groups of the lower limbs (American College of Sports Medicine [ACMS] 2002). The aim of the prescribed exercise dosage was to work the muscle group to the point of muscular fatigue. Progression of exercises in Group B was based on increasing the resistance of the exercise, when able to complete 3–4 sets

Table 1. Group A: Proprioceptive and Balance Exercise Program

Clinic exercise	Clinic progression A
Bike easy (no hands)	Bike moderate (no hands)
Double leg stance on mini tramp tapping balloon	Single leg stance on mini tramp tapping balloon
Double leg balance on wobble board	Double leg balance on wobble board eyes closed
Single leg stance on dura disc	Single leg stance on dura disc moving basketball
Double bridge on swiss ball (back on ball)	Single leg bridge on swiss ball
Swiss ball wall squats	Swiss ball single leg squats (with rear leg on swiss ball)
Beam walk	Multiequipment balance walk (mini tramp, dura disc, wobble board, etc.)
Home exercise	**Home progression A**
Walking easy 20–30 minutes	Walking moderate-hard 40 minutes
Double leg stance on pillow throwing ball against wall	Single leg stance on pillow throwing ball against wall
Double leg balance on two rolled towels	Single leg balance on rolled towel
Single leg stance on rolled towel	Single leg stance on rolled towel with eyes closed
Double bridge on swiss ball	Single bridge on swiss ball
Swiss ball wall squats	Swiss ball single leg squats (with rear legon swiss ball)
Heel-toe walk with eyes closed	Heel-toe walk with eyes closed

of 10–15 repetitions. Increasing the resistance was achieved by adding body weight or by adding weight to the exercise. The protocol is also similar to the well-known accelerated rehabilitation program described by Shelbourne and Nitz (1990).

Outcome Measures

The baseline testing session, after surgery but just before the intervention, consisted of perceived measures of functional activity (Cincinnati knee rating system and the patient specific functional scale), knee range of motion testing (flexion and extension), as well as demographic data. The follow-up testing consisted of all of the above tests, as well as hop tests. Hop tests were considered unsafe at the baseline testing session, which could have been as early as 4 weeks after reconstructive surgery. Participants were measured by an experienced physiotherapist who was blind to group allocation.

Table 2. Group B: Strengthening Exercise Program

Clinic exercise	Clinic progression A
Bike easy hands on rails	Bike moderate-hard
Shuttle light resistance (leg press)	Single leg shuttle moderate-hard resistance
Double squat holding onto bar	Split squat holding onto bar
Double split squat holding onto bar	Forward lunge holding onto bar
Double bridge	Single bridge
Hip abduction side lying	Hip abduction side lying with light weight
Home exercise	**Home progression A**
Walking easy 20–30 minutes	Walking moderate 40 minutes
Double squat	Single squat holding onto bar if required
Step ups 20cm	Step ups 30cm+
Split squat holding onto bar	Single leg squat holding onto bar
Hamstring curl with theraband (red)	Hamstring curl with theraband (green)
Double bridge	Single bridge
Bilateral heel raise	Single heel raise flat surface
Hip abduction side lying	Hip abduction side lying with light weight
Abdominal crunches	Abdominal crunches

Cincinnati Knee Rating System

Perceived function and ability was measured to establish participant perceptions of improved activity. It was quantified using the Cincinnati knee rating system (Barber Westin, Noyes, and McCloskey 1999), as this questionnaire provides a validated rating scale for use with ACL-reconstructed knees with high test–retest reliability for each component (ICCs > 0.70; Barber Westin et al. 1999). Participants rated all scales on the system; however, only scores for pain, swelling, partial giving way, overall condition, walking, stairs, and squatting/kneeling were selected for comparison as the other scales such as sports scales were not relevant at the time of both assessments. For example, participants rated their ability to negotiate stairs on a 4-point ordinal scale: normal unlimited; normal some limitation; only 11–30 steps possible; or only 1–10 steps possible.

Patient Specific Functional Scale

Participants were asked to identify up to three important activities that they were unable to perform or were having difficultly with as a result of their knee problem on the day of assessment. Participants were asked to rate the degree of difficultly of their chosen activity on a 10-point scale, with 0 being "unable to perform the activity," and 10 being "able to perform the activity at the same level as before the problem." The scale has been shown to be reliable (ICC = .97) and responsive, with the minimum detectable change (90% confidence interval) of 3 points for single activity scores (Stratford, Gill, Westaway, and Binkley 1995).

Hop Testing

Participants were tested on three hop tests: the single leg hop test for distance, the timed single leg hop test over 6 m, and the single leg cross-over triple hop for distance. Each hop test was completed three times on each leg. The first trial was a familiarisation trial, with the mean of the second and third trials being calculated. A limb symmetry index was then calculated by dividing the mean distance, or time of the involved limb by the mean distance of the noninvolved limb, and multiplying by 100. Hop tests have good specificity (>90%) in ACL-injured people (Barber, Noyes, Mangine, McCloskey, and Hartman 1990; Noyes, Barber Westin, and Mangine 1991) and correlate well with strength and stability function ($r > 0.8$), although not with daily life function (Risberg and Ekeland 1994).

Range of Motion

Passive knee joint extension was measured using a prone hang test as described by Sachs, Daniel, Stone, and Garfein (1989). This involves measurement of heel height difference with the patient in the prone position. Schlegel, Boublik, Hawkins, and Steadman (2002) found this method to be a valid way of documenting subtle knee flexion contractures. Active knee joint flexion was measured because large flexion deficits impair performance in active functional tasks such as running and hopping. A standard goniometer was used to measure active knee flexion. Watkins, Riddle, Lamb, and Personius (1991) found this measurement procedure to be highly reliable, with retest reliability of intraclass correlation coefficient (ICC) = 0.99 and intertester reliability of ICC = 0.90.

Data Analysis

Participant numbers were based on a power analysis using hop test data. Assuming the effect size of 1.08 reported by Fitzgerald et al. (2000), at least 13 participants would be required in each group, 26 in total for a power of 80%.

Baseline data were compared after surgery but prior to the intervention period using an independent *t* test, chi-squared test, or Fisher's exact probability test, as appropriate.

To test whether one group improved more than the other, change in scores from baseline to follow-up for the Cincinnati scale, the patient specific functional scale, and range of motion were compared with independent *t* tests, or Mann-Whitney U tests when parametric assumptions were not fulfilled. A *t* test on change scores is equivalent to the interaction effect in a two-way analysis of variance (Streiner and Norman 1995). Since the hop tests were only assessed at follow up, these variables were compared

with independent *t* tests of the follow-up scores. The level of significance for all tests was set at $p < .05$.

RESULTS

Participant characteristics can be viewed in Table 3. There were no drop outs or any adverse events reported or observed during the study. Twenty-two participants were referred by Surgeon 1 (Group A = 11, Group B = 11), 6 participants were referred by Surgeon 2 (Group A = 3, Group B = 3), and 1 by Surgeon 3 (Group B). There was no significant difference in allocation to groups between surgeons [χ^2 (df 2) = 0.97, $p = .62$]. There was no significant difference in the number of physiotherapy consultations during the intervention period [t (27) = 0.18, $p = .86$] between Group A (mean = 10.5, SD 1.3) and Group B (mean 10.6, SD 1.7). Both groups attended on average at least 10 of their 12 scheduled appointments over the intervention period, indicating adherence to appointments. Of the 20 participants who returned their exercise diaries, there was no significant difference in the minutes of average daily exercise performed by Group A (mean 42.3 minutes, SD 17.5) and Group B (mean 57.3 minutes, SD 21.2) [t (18) = 1.65, $p = .12$].

Baseline Assessment

Baseline data were compared with test data for differences between the groups before the treatment. There were baseline differences for age [t (27) = 2.72, $p = .01$], flexion range of motion [t (27) = 3.15, $p < .01$], and Cincinnati knee rating system pain [Mann Whitney U = 57.0, z = 2.34, $p = 0.02$] and squatting/kneeling [Mann Whitney U = 57.5, z = 2.25, $p = 0.03$]

Table 3. Participant Characteristics

	6 weeks	
	Balance (*n*=14)	**Strengthening (*n*=15)**
Age (years)	31.3 (7.8)*	24.7 (5.1)
Height (cm)	177.6 (6.5)	173.3 (9.8)
Weight (kg)	79.9 (11.5)	73.7 (13.4)
Gender	12 males, 2 females	8 males, 7 females
Time since surgery (days)	51.6 (21.8)	45.3 (11.3)
Graft type	13 hamstring, 1 patellar tendon	13 hamstring, 2 patellar tendon

Notes: Difference in characteristic between groups *$p < .05$.

Table 4. Results of Cincinnati Knee Rating Scale, Patient Specific Functional Scale, and Range of Motion

	Baseline		6 weeks	
	Balance (*n*=14)	**Strengthening (*n*=15)**	**Balance (*n*=14)**	**Strengthening (*n*=15)**
Activities				
CKRS				
Pain	6.0 (2.0)	4.0 (0)#	6.5 (2.3)	6.0 (1.0)
Swelling	6.0 (2.0)	4.0 (4.0)	7.5 (2.0)*	8.0 (2.0)
Overall condition	5.0 (1.0)	4.0 (1.0)	6.5 (1.3)	7.0 (2.0)
Walking	30.0 (10.0)	30.0 (0)	40.0 (10.0)*	40.0 (0)
Stairs	30.0 (2.5)	30.0 (0)	40.0 (10.0)	40 (10.0)
Squatting/kneeling	30.0 (10.0)	20.0(30.0)#	30.0 (0)*	30.0 (0)
PSFS				
Activity 1	4.3 (2.1)	2.9 (2.1)	6.9 (1.4	6.1 (2.7)
Activity 2	4.8 (2.1)	3.3 (2.1)	7.1 (2.4)*	7.3 (1.5)
Activity 3	5.0 (2.1)	3.7 (2.8)	7.2 (1.3)*	7.5 (1.8)
Impairment				
Range of motion				
Knee flexion (°)	132.1 (7.1)	125.1 (2.6)#	133.9 (7.0)	129.4 (5.0)
Knee extension deficit (cm)	0.71 (1.76)	0.58 (1.11)	0.1 (1.7)	–0.1 (1.7)

Notes: Means and standard deviations denoted in parentheses except for CKRS where medians and interquartile ranges are denoted in parentheses. CKRS: Cincinnati knee rating system. PSFS: Patient specific functional scale. *$p < .05$ for comparison of change between groups between baseline and 6 weeks. #$p < .05$ for comparison between groups at baseline.

(Table 4). No significant differences were observed for the 13 other measurements and characteristics at baseline.

Change From Baseline to 6 Weeks

Significant differences in change scores of the Cincinnati knee rating system were observed for swelling [Mann Whitney U = 61.0, z = 1.98, $p = 0.047$], walking [Mann Whitney U = 65.0, z = 2.02, $p = 0.04$], and squatting/kneeling [Mann Whitney U = 53.0, z = 2.49, $p = 0.01$] with Group B (strengthening) improving more than Group A (proprioceptive and balance exercise; Table 4). There were no significant differences between groups for pain, overall condition, or stairs.

There was no significant difference in change scores of the patient specific functional scale between groups for activity 1[t (27) = 0.88, $p = .38$].

Table 5. Hop Test Results at 6 Weeks

	6 weeks	
	Balance (*n*=14)	**Strengthening (*n*=15)**
Activities		
Hop tests		
Single hop (cm)	125.6 (22.9)	118.8 (18.9)
Single hop symmetry (%)	99.1 (10.0)	93.4 (8.6)
Timed 6m hop (sec)	2.49 (0.66)	2.82 (0.83)
Timed 6m hop symmetry (%)	83.4 (12.6)	79.6 (11.8)
Triple crossover hop (cm)	307.0 (132.6)	381.0 (131.1)
Triple crossover hop symmetry (%)	79.3 (15.2)	80.0 (17.3)

Notes: means and standard deviations denoted in parentheses. No significant differences between the two training groups.

Significant differences were seen, however, in Activity 2 [t (27) = 2.84, p = .01] and Activity 3 [t (27) = 2.71, p = .01]. Group B improved more than Group A in both Activity 2 and Activity 3. The most nominated activities included running, squatting and kneeling, stairs, and getting in and out of a car.

There were no significant differences in change scores between Group A and Group B for active knee flexion range of motion [t (27) = 1.56, p = .13] or extension deficit [t (27) = 2.01, p = 0.06].

Comparisons at 6 Weeks

Hop Tests

There was no significant difference between Group A and Group B for the single leg hop test (scores [t (27) = 1.65, p = 0.11] or limb symmetry index percentage [t (27) = 1.65, p = 0.11]), single leg timed hop test (scores [t (26) = 0.82, p = .42] or limb symmetry index percentage [t (26) = 0.82, p = .42]), or single leg crossover triple hop test (scores [t (27) = 0.27, p = .79] or limb symmetry index percentage [t (27) = 0.27, p = .79]); (Table 5).

Age Differences

Due to participants being older in Group A (Group A mean: 31.3 years, Group B mean: 24.7 years), Pearson product moment correlations between age and outcomes were performed. There was no significant correlation between age and any outcome measure.

DISCUSSION

The current study is only the second randomised clinical trial to investigate proprioceptive and balance training following ACL reconstruction, and the first trial to investigate this in the early phases of rehabilitation. The results of the current study suggest that there is no advantage to function in doing proprioceptive and balance exercises in the early phases of rehabilitation following ACL reconstruction when compared with a traditional strengthening program.

When change scores were compared the strengthening program improved more than the proprioceptive and balance exercise program in some measures of activity. There are at least two possible explanations for this result. First, the traditional strengthening program may have performed better. It may be the case that strength training is the best type of training in the early phases of rehabilitation following ACL reconstruction. Alternatively, due to baseline differences with the strengthening group having lower scores than the proprioceptive and balance group, a regression to the mean effect could have occurred for the strengthening group (Vickers and Altman 2001). Given that better outcomes after ACL reconstructive surgery have been observed in participants under the age of 30 years (Pizzari, Taylor, McBurney, and Feller 2005) this regression to the mean effect could have been amplified since the participants in the strengthening group were younger than those in the proprioceptive and balance exercise group. In our sample, however, there was no relationship between age and outcome.

The only other located study that has compared proprioceptive and balance training with strength training following ACL reconstruction was that of Liu-Ambrose et al. (2003). That study investigated 10 participants over a 12-week training program. The results of the current study were similar to those of Liu-Ambrose et al. (2003), in that there appeared to be no additional benefit in performing proprioceptive and balance training following ACL reconstruction with regards to patient functional activity. The results of the current study complement those of Liu-Ambrose et al. (2003) in that the intervention was carried out in the early phases of rehabilitation, while Liu-Ambrose et al. (2003) study investigated the effects of balance and proprioceptive exercises in the later phases of rehabilitation.

There may be various reasons why proprioceptive and balance training does not provide added benefits in early stage rehabilitation after ACL reconstructive surgery. The major theoretical benefit of proprioceptive and balance training is to improve the nervous system's ability to synchronise muscular activity around the knee, aiding dynamic knee joint stability. Dynamic knee joint stability is not sufficiently challenged until patients return to sports that require quick change of direction or rotation through the knee. The current study was conducted and assessed in the early

phases of rehabilitation, with no participants reaching this functional level at the time of assessment (3 months following surgery). Very few patients following ACL reconstruction are advised to return to sports before 6 months following surgery, approximately 50% of patients are advised to return to sports between 6 and 9 months, and a further 20% are advised to wait until 12 months following surgery (Feller, Cooper, and Webster 2002). Elsewhere, it has been reported that patients generally return to sports between 20 and 32 weeks postsurgery (Lai and Ng 1997). Proprioceptive and balance training may be more appropriate at a later stage in rehabilitation; however, this requires further experimental investigation.

The results of the current study suggest either no difference between the groups or that strength training may be more relevant than proprioceptive and balance training in the early phases of rehabilitation. It has been well documented that muscle strength decreases following ACL reconstruction (Chapman, Chamberlain, Railton, Boyle, and Strauss 1995; Kramer, Nusca, Fowler, and Webster-Bogaert 1993; Yasuda, Ohkoshi, Tanabe, and Kaneda 1992), and that improvement in muscle strength increases functional activity following ACL reconstruction (Liu-Ambrose et al. 2003). A rationale exists, therefore, for an intervention focussed on improving muscle strength in the early stages of rehabilitation after ACL reconstructive surgery.

Limitations

The current study had several limitations. First, despite participants being allocated to their respective treatment group via concealed random allocation, there were some baseline differences between the groups. This made interpretation of statistical comparisons between the two groups more difficult. Second, measures of strength and proprioception/neuromuscular function were not assessed in the current study. The outcome measures in the current study assessed participants' perceived functional activity and their function using hop tests. Although information has been provided that the strength group performed better in some measures of activity, no information has been provided as to why this occurred. Finally, the current study did not assess whether people returned to participate in their desired activities following rehabilitation. Whether people have reinjured or have returned to participate in their sport or desired societal roles must be assessed to determine whether rehabilitation interventions ultimately have been successful.

CONCLUSION

In the early phases of rehabilitation following ACL reconstruction there appears to be no additional benefit in performing balance and proprioceptive exercises compared with strength training; there is either no difference

between the functional outcomes for these two forms of training or there may be some additional benefit in strength training. Due to only a short intervention period and follow-up assessment relatively early in the rehabilitation process, it may be that any benefits of the proprioceptive and balance program were not fully realised at the time of assessment. Follow-up assessment of the participants in the current study when returning to participate in sport would provide valuable information on any longer term benefits of either rehabilitation program.

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