PROPRIOCEPTION ENHANCEMENT FOR ANTERIOR CRUCIATE LIGAMENT DEFICIENCY

A PROSPECTIVE RANDOMISED TRIAL OF TWO PHYSIOTHERAPY REGIMES

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We performed a prospective, double-blind, randomised, clinical trial to investigate the efficacy of two regimes of rehabilitation for knees with anterior cruciate ligament deficiency (ACLD).

Fifty ACLD patients were randomly allocated to one of two treatment groups: a programme of muscle strengthening (T) or a programme designed to enhance proprioception and improve hamstring contraction reflexes (P). An indirect measure of proprioception, the reflex hamstring contraction latency (RHCL), and a functional scoring system were used to record the status of the knee before and after the 12-week course of physiotherapy. Sagittal knee laxity was also measured.

There was improvement in mean RHCL and in the mean functional score in both groups after treatment. The improvement in group P was significantly greater than that in group T. There was no significant change in joint laxity after treatment in either group. In both groups there was a positive correlation between improvement in RHCL and functional gain.

J Bone Joint Surg [Br] 1994; 76-B:654–9.
Received 20 September 1993; Accepted after revision 8 February 1994

Physiotherapy is widely used in the management of patients who have torn their anterior cruciate ligament (ACL) but the most effective regime is still in doubt.

Most treatments for anterior cruciate ligament deficiency (ACLD) are designed to strengthen the muscles, particularly the knee extensors (Blackburn 1985; Tegner et al 1986b; Beard and Fergusson 1992), but some biomechanical studies have suggested that the hamstring muscles can better simulate the function of the ACL (Walla et al 1985). This has led logically to the concept of intensive hamstring strengthening. Both these methods of rehabilitation assume a positive correlation between muscle strength and knee function for which we can find no substantial evidence.

The demonstration of nerve endings in the ligament (Schultz et al 1984; Haus and Halata 1990) suggests that the ACL has a neurophysiological as well as a mechanical role (Johansson, Sjölander and Sojka 1991) and decreased joint proprioception in the ACLD limb has been shown in several studies (Barrack, Skinner and Buckley 1989; Barrett 1991; Skinner and Barrack 1991; Corrigan, Cashman and Brady 1992; Beard et al 1993). It has been suggested that methods of rehabilitation which enhance proprioception in structures around the knee may be effective in compensating for loss of the ACL (Ihara and Nakayama 1986; Engle and Canner 1989).

We designed a double-blind, randomised trial to determine if a 'programme of proprioceptive enhancement' with emphasis on neuromuscular facilitation, rapid hamstring recruitment and dynamic stability would be more effective in improving function than a traditional muscle strengthening regime.

PATIENTS AND METHODS

Patients were eligible for inclusion if they were aged between 16 and 50 years and had an arthroscopically confirmed complete rupture of the ACL. We excluded those with complex meniscal tears, grade-III collateral ligament damage, significant chondral damage, symptoms in the other knee or in the hips, ankles, or feet. We also excluded those who had had previous formal rehabilitation or an operation for ACLD, those in whom the date of

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0301-620X/94/4821 $2.00

injury was more than 36 months previously and those with a history of any neurological disease.

A group of 50 patients, eight women and 42 men, was recruited from an arthroscopy day-surgery unit. Their mean age was 25 years (16 to 49) and the mean time from injury to arthroscopy was 13 months (SD 11).

Outcome measures

Knee function. We assessed subjective knee function by the validated functional scoring scale of Lysholm and Gillquist (1982). To ensure that the effects of the diagnostic arthroscopy did not bias the subjective score, patients were asked to answer some of the questions by reference to their status before the operation, such as the frequency of giving way. Any patient who thought that the level of instability and general function had changed substantially as a result of the arthroscopy was excluded at this time. The intra- and interobserver coefficients of variation for the Lysholm scoring system have been shown to be 3% and 4% respectively with a test-retest correlation coefficient of 0.97 (Tegner and Lysholm 1985).

Proprioception. We obtained a proprioceptive index for each limb by measuring the time required for the hamstring muscles to react to displacement using the Vicon Interfaced Knee Displacement Equipment (VIKDE; Beard et al 1993). The reflex hamstring contraction latency (RHCL) was defined as the time interval in milliseconds between the first recorded acceleration of the tibia (identified by accelerometry) and the first discernible reflex reaction of the hamstrings (identifiable by surface EMG). The difference between the RHCL of the normal limb (control) and that of the ACLD limb was then calculated for each subject and referred to as the 'between-limb RHCL'. The test-retest correlation coefficient for the equipment was 0.87 (n = 10) and the mean reading error for EMG traces was −1.1 ms (SD 4.2 ms; n = 50).

Knee laxity. We measured passive sagittal laxity with the KT1000 arthrometer (MEDmetric, California) with the knee flexed to 30°, using applied posteroanterior forces of 67 N, 89 N and the force required to obtain maximum manual displacement. The subject's normal knee was used as a control to obtain a between-limb difference. Although the reliability of the KT1000 device has been questioned (Forster, Warren-Smith and Tew 1989), it was considered adequate for measurement of mechanical sagittal laxity since it was used for paired differences and by a single examiner (Hanten and Pace 1987; Steiner et al 1990; Wroble et al 1990; Torzilli et al 1991).

Procedure. Patients were interviewed immediately after arthroscopy (by CAFD and DJB) and invited to enter the study. They were told that participation would require twice-weekly attendance for 12 weeks at one of two rehabilitation groups, each offering different exercises; the first attendance would be for measurement three weeks after the date of arthroscopy. During these three weeks all patients were asked to perform range-of-movement and gentle isometric/isotonic quadriceps and hamstrings exercises. Four different exercises were set with ten repetitions of each, twice daily.

Before attending for measurement, patients were assessed by the physiotherapy staff to ensure that any acute signs and symptoms resulting from the arthroscopy had settled. Those who did not have a full range of movement, who were unable to walk without aids or who had more than mild pain or a joint effusion were excluded at this time. All the variables mentioned above were measured by a single examiner.

The patients were then randomly allocated to one of the two treatment groups by a minimisation computer program. Stratification variables included gender, time since injury, frequency of sport and frequency of giving way. The examiner was blinded as to which group they had been allocated and the patients were unaware of the differences in exercise content between the two groups. Precautions were taken to avoid corruption of this situation.

Traditional regime (T). We had previously carried out a survey to establish the content of current physiotherapy programmes for ACLD in the UK (Beard and Fergusson 1992) and the results were used to formulate the content of the traditional treatment regime for this study. The objective of the exercises was to increase the strength of the lower-limb muscles; no attempt was made to increase the speed of contraction or to improve dynamic stability through proprioceptive enhancement techniques. Most exercises were of the open kinetic chain type; graduated weight-resisted exercises were included for most muscle groups with a slight emphasis on hamstring strengthening. Progression was achieved by increasing the weight resistance (see Appendix).

Proprioceptive regime (P). Exercises in this group were based on the rehabilitation protocols of Ihara and Nakayama (1986) and Engle and Canner (1989), with some new methods designed by the authors. The objective was to facilitate rapid contraction of the hamstring muscles and to improve dynamic stability through proprioceptive enhancement techniques. Progression, according to the type of exercise, was made by decreasing the stability of the starting position, by increasing the number of repetitions (and hence the rate of contraction), and finally by removing visual feedback. Most of the exercises were closed kinetic chain and were of the functional type (see Appendix).

In both groups the exercises were performed in a class format which had a circuit-training type design. Warm-up and warm-down periods, including stretching, were preceded and followed by the exercise circuit. Both groups were supervised by clinical physiotherapists who were not involved in the research but were aware of the existence of two groups. The 12 weeks of treatment consisted of twice-weekly intensive training for one hour at the physiotherapy department and a daily home-exercise programme which consisted of key exercises taken from each of the treatment regimes. The two classes

were held on separate days of the week. On completion of treatment, the same examiner repeated the measurements using the same instruments and methods.

Statistical analysis. We performed a parametric two-sample Student's *t*-test on the normally distributed level data which included the RHCL and laxity, a non-parametric Mann-Whitney U-test on the ordinal level, Lysholm scores, and a non-parametric Spearman rank correlation test to find the relationship between the RHCL and function for the entire sample. Significance levels of $p < 0.05$ were chosen for all data.

RESULTS

Forty-three patients were analysed; 23 completed regime P and 20 completed regime T. Of the seven patients not included in the analysis, two (from group T) did not attend the class sufficiently often (< 6 sessions) but as outcome data were available, they were included in a separate 'intention to treat analysis'. Three patients did not return for remeasurement; one (from group P) had severe instability and underwent early reconstruction, another (from group P) had a flexion deformity and effusion, and one (from group T) had gone to prison. All the dropouts were men.

The mean number of attendances for patients was similar for the two groups, 14 for group P (SD 6) and 12 for group T (SD 4). The maximum possible number of attendances was 24. No patient achieved this but three attended for 23 sessions. No evaluation of compliance with the home programme was attempted.

Table I. Reflex hamstring contraction latency (RHCL) and functional score (mean ± SD) in the two groups before and after treatment

	Group P (n = 23)		Group T (n = 20)	
RHCL (ms)	**Before**	**After**	**Before**	**After**
Mean				
Control limb	49.6 (± 20.8)	42.2 (± 15.5)	44.8 (± 15.2)	42.9 (± 13.0)
ACLD limb	88.7 (± 35.7)	41.6 (± 19.2)*	83.7 (± 37.3)	70.1 (±31.1)
Lysholm score	56 (± 14)	85 (± 13)*	68 (± 16)	78 (± 22)*

* significant at $p < 0.05$

The mean RHCL and functional values before and after treatment are given in Table I. The pretreatment measures of RHCL were similar in the two groups but there was a difference in the measures for function. The relative changes in functional score were therefore used in the analysis rather than the absolute values.

After treatment, both groups had a reduction in RHCL and an increase in functional score (Table I). There were, however, some significant differences between the groups: the RHCL in group P (40 ms, SD 30) changed more than in group T (14 ms, SD 35; $p < 0.05$); and the functional score in group P was greater than in group T (29.4 SD 15, and 11.2 SD 15; $p < 0.005$; Fig. 1). The

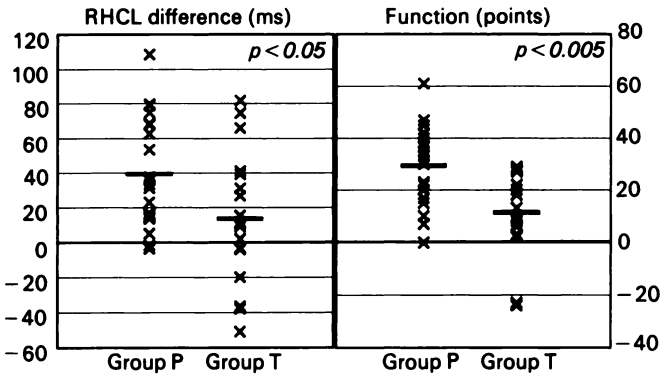

Fig. 1

Plot of all data points to compare changes in 'between-limb' RHCL difference (ms) and functional scores (points) in the two treatment groups. There is a significant difference between the groups in both cases (n = 43, mean indicated by horizontal bar).

inclusion of the two group-T patients who had attended less than six times in an 'intention to treat analysis' did not change the level of significance. A positive correlation ($r = 0.3$, $p < 0.05$) was found between the relative change in function and the relative change in RHCL for the entire sample (n = 43). There was no significant change in passive sagittal laxity in either group.

There was no identifiable relationship in either group between change in function or RHCL and the number of attendances for physiotherapy, time since injury, frequency of sport played or the level of preoperative instability.

DISCUSSION

The ACL assists in the maintenance of joint stability by resisting anterior movement of the tibia on the femur and is a key element in the mechanism which controls tibiofemoral articulation. A common manifestation of ACLD, the symptom of 'giving way' during activity, may result from loss of the mechanical and/or the neurophysiological function of the ACL.

It is now widely accepted that in flexion the ACLD knee can utilise a net increase in the posteriorly directed forces acting on the tibial plateau to reduce anterior drawer and pivot shift. This may be achieved by increased activity (longer firing duration) or by increased stiffness of the hamstring muscles (Branch, Hunter and Donath 1989; Draganich, Jaeger and Kralj 1989; Kalund et al 1990; Lass et al 1991; McNair, Wood and Marshall 1992). Alternatively, it is thought that the effect may be obtained by inhibition of the agonist muscle group (quadriceps) (Dvir et al 1989; Berchuk et al 1990; Andriacchi and Birac 1993) although deliberate inhibition of any muscle group around an ACLD knee would seem to contradict the philosophy of conservative stabilising regimes.

It is therefore desirable for the ACLD limb to exhibit not only sufficient force in the hamstrings (muscle power) to prevent joint subluxation but also to deploy rapidly this

protective action. Proprioceptors are responsible for providing afferent information regarding change in position and angular velocity of the normal joint. When this information is processed via specific reflex arcs, it facilitates and adjusts motor activity in various muscle groups (Matthews 1988). If the change in position is threatening to the joint and likely to exceed the limits of normal movement, then the muscle groups activated by this reflex system will be those capable of counteracting the applied external force. When the tibia subluxes anteriorly, the hamstrings contract. In the ACLD knee with impaired proprioception, reduced facilitation of protective musculature might be expected and instability would result. The reflex arcs are complex and, although there has been some research, they are not yet fully understood (Solomonow et al 1987; Krauspe, Schmidt and Schaible 1992; Konradsen, Ravn and Sørenson 1993).

It was postulated that the proprioceptive deficit demonstrated in a clinically symptomatic chronic ACLD knee could be reduced by specific training methods and hence improve dynamic knee stability. Exercises were designed and employed which utilised functional, closed kinetic chain positions, facilitated rapid recruitment of the hamstring muscles and emphasised balance and proprioceptive feedback from around the knee, the objective being to reinforce existing proprioceptive pathways, to engage redundant pathways or to forge new ones.

The between-limb RHCL difference decreased in both groups but significantly more in patients treated by proprioceptive enhancement; the improvement in function was also better in this group. No difference was found between the groups in knee laxity measurements, although the between-limb laxity slightly increased after treatment in both. This finding agrees with the work of Skinner et al (1986) and Steiner et al (1986) who showed that exercise can increase anteroposterior passive knee laxity. It also further demonstrates the lack of a correlation between passive sagittal laxity and functional ability.

Apart from Ihara's work, based on only four subjects, we have found only one clinical study in which rehabilitation regimes for ACLD have been compared. Zätterström et al (1992) prospectively compared a method aimed at strengthening the knee extensor apparatus with one aimed at training of the lower limb in functional weight-bearing patterns, effectively a programme of dynamic stability training. They found improvement in the functional score of both groups but no significant difference between the two. The patients trained functionally tended to perform better with the hop test of Tegner et al (1986a) while those trained by extensor strengthening had a significantly higher isometric gain. Measures to enhance proprioception were not used, however, and there was no randomisation of the sample for patient allocation. It could be suggested that, in view of the ACL-emulating properties of the hamstrings, the strengthening regime should have been focused on those muscles rather than on the quadriceps.

For ethical reasons a 'no treatment group' was not included in our study and it is not therefore possible to infer from the improvements recorded in both our groups of patients that physiotherapy is beneficial. The changes seen in both groups may have been due to placebo effect. As to motivation, the patients in group P found the exercises interesting and enjoyed attending while those in the traditional group found them somewhat dreary. Although the attendance record was similar in the two groups this observation needs to be considered when evaluating the study.

Any clinical study comparing the efficacy of different treatments must also consider the issue of compliance. While the content of the classes attended can be controlled, compliance with the home programme is difficult to evaluate. The importance of the home component was stressed equally to both groups, but the frequency and intensity of the home exercises may have varied particularly since one group found the exercises more tedious than did the other.

Some other deficiencies of the study should be taken into consideration. The follow-up period was short and no objective measure of muscle strength was used. Future studies should use objective measures of muscle strength and consider function in relation to the level of activity rather than independently as we did. Although most patients improved, few returned to their preinjury level of sport or activity. Finally, the design of the study, being a clinical trial, provides no explanation of the changes observed; the physiological mechanisms involved and their complex interaction with knee mechanics require further experimental investigation.

Conclusions. Proprioception and function improved in ACLD patients treated by physiotherapy. Proprioceptive enhancement techniques were more effective in improving function and RHCL than were traditional strengthening exercises. There was a positive correlation between function and proprioception.

APPENDIX

Both exercise programmes have a circuit-training format with eight separate stations, two different exercises at each station (unless it is a combined activity). The participants complete the circuit in pairs, barefoot, each exercise being timed by a supervising physiotherapist for 90 seconds. Suggested modifications for progression are shown in brackets.

Proprioceptive programme

1) a) 'Wobble'-board exercises (2 leg, 1 leg, eyes closed)
b) Stand single leg. Pass ball under opposite leg (on toes, eyes closed)

2) a) Sit, PNF patterns (hamstrings) on Westminster pulley (↑weight resistance, ↑speed)
b) Long sit. Weight-resisted SLR and inner-range quadriceps exercises (↑weight resistance)

3) a) Stand. Single-leg dynamic stability using wheeled stool; movement provided by partner to facilitate hamstring contraction (reduce support, eyes closed)
b) As 3a but changeover with partner

4) a) Static bicycle (↑speed)
b) Medicine ball. Stand with 2° activity, e.g., bouncing a ball (single leg, ↑knee flexion angle)

5) a) Stand. Hamstring recruitment at 90° hip and knee flexion (subject foot on gym ball); movement provided by partner
b) As 4a but changeover with partner

6) a) Stand. Ballistic hamstring 'catches' (knee flexed) (↑resistance, ↑speed, eyes closed)
b) Pair lying. Ballistic hamstring SLR (↑weight resistance, ↑speed)

7) a) Mini-trampet exercises, diagonal and cross patterns (single leg, ↑flexion angle, eyes closed)
b) Pro-fitter exercise (Fitter UK, Banbury, UK) (single leg, ↑speed, ↑resistance)

8) a) Skipping (single leg)
b) Arching using large gymnastic ball (single leg, ↑speed)

Traditional programme

1) a) Prone lying. Weight-resisted SLR (hamstrings) (↑weight resistance)
b) Supine lying. Weight-resisted SLR (quadriceps) (↑weight resistance)

2) a) Step-ups
b) Stand. Single leg. Floor touch from bench

3) a) Long sit. Weight-resisted inner-range quadriceps exercises (↑weight resistance)
b) Pair lying. Weight-resisted knee flexion (hamstrings) (↑weight resistance)

4) a) Static bicycle (↑resistance)
b) Sit to stand with medicine ball

5) a) Sit. Westminster pulley flexion (hamstrings) exercises in single plane (↑weight resistance)
b) Stand. Slow weight-resisted hamstring curls (knee flexion) (↑weight resistance)

6) a) Supine lying. Bridging over gymnastic ball
b) Sit. Isotonic weight-resisted extension (quadriceps) (↑weight resistance)

7) a) Side lying. Weight-resisted hip abduction
b) Side lying. Weight-resisted hip adduction

8) a) Sit. Body pull along bench (hamstrings)
b) Supine lying. Sit-ups (abdominals/trunk/hip flexors)

Financial support for this research was provided by the Arthritis and Rheumatism Council for Research and the Oxford Health Authority Locally Organised Research Scheme. The study was completed with the assistance and co-operation of the physiotherapy staff, Nuffield Orthopaedic Centre NHS Trust. Gratitude is expressed to Dr J. J. O'Connor, Mr R. Gill, Ms J. Moser and Ms C. Crawford for their help in the preparation of the manuscript.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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