Is Knee Laxity Change after Anterior Cruciate Ligament Injury and Surgery Related to Open Kinetic Chain Knee Extensor Training Load?

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ABSTRACT

The purpose of this study was to evaluate whether knee anterior laxity changes after ACL injury and surgery are related to aspects of thigh muscle resistance training during rehabilitation. One hundred and two subjects (22 females) diagnosed with an ACL deficient knee or who had undergone ACL reconstructive surgery participated in this study. The subjects trained their knee extensors in the open kinetic chain during a 6 week program and the relationship of aspects of training (for example, absolute resistance load) and other factors to anterior laxity change during this period were analysed using linear regression analysis. Results: The only factor found to be significantly related ($r = -0.347$) to anterior knee laxity change was average absolute load used in training the knee extensors. Conclusions: These results offer some early clinical support for increasing the strain on the ACL graft (in patients treated with reconstruction) or other passive restraints to anterior tibial displacement, during rehabilitation after ACL injury and reconstruction surgery in order to promote decreased knee anterior laxity.

BACKGROUND

The purpose of this study was to evaluate which thigh muscle resistance training factors, if any, are related to knee anterior laxity change during rehabilitation after ACL injury (ACL deficient – ACLD) and reconstruction (ACLR). The hypothesis to be tested is that some aspect of knee extensor open kinetic chain training (i.e. volume or absolute load) will have a significant ($p < 0.05$), positive correlation with laxity change in rehabilitation of ACLD and ACLR knees. That is, we propose that subjects trained with open kinematic chain (OKC) knee extensor resistance exercise will have greater increases in knee anterior laxity with increased training volume or load. This hypothesis is based on laboratory findings showing increasing strain on the ACL with increased loads in the open kinetic chain (5).

METHODS

Subjects

Forty nine subjects diagnosed with an ACLD knee or who had ACL reconstructive surgery participated in this study with their characteristics summarised in Table 1. Patients with an ACLD knee were recruited from three main sources: 1) orthopaedic surgeons who had diagnosed the patient as ACL-deficient through clinical testing, or through magnetic resonance imaging (MRI) or arthroscopic examination; 2) physiotherapists who had diagnosed the patient as ACL-deficient through clinical testing; and 3) ACL reconstruction surgery waiting lists. In all cases, the patients' lead clinician (usually an orthopaedic surgeon) had to give informed consent for the patient to be contacted and recruited to the study. Collaborating orthopaedic surgeons and physiotherapists were drawn from 11 National Health Service and private hospitals in the east and south London area of the United Kingdon. Subjects were deemed suitable for inclusion in the study if they had no prior history of pathology requiring medical attention in the contralateral lower extremity within the previous six months; they did not have a posterior cruciate ligament injury in the ACL deficient knee; they were aged 18-60; and their diagnosis had been made through arthroscopy, MRI or clinical testing. If their diagnosis was based on clinical testing (e.g. manual Lachman testing), a difference in anterior tibial displacement (ATD) of 3 mm between the injured and uninjured knees, as measured using the ligament arthrometer (see below), was necessary for inclusion in the study (6).

Potential subjects with an ACLR knee were identified for this study from in-patients recovering from ACL reconstruction at 11 National Health Service and private hospitals in the London area. Subjects were deemed suitable for inclusion in the study if they had no prior history of pathology requiring medical attention in the contralateral lower extremity within the previous six months, they did not have a posterior cruciate ligament injury in the operated knee, they were aged 18-60, and their surgeon had given consent for them to be approached. Twelve orthopaedic surgeons participated in the study. Surgeon A performed ACL reconstruction using the technique described by Kennedy et al.[7] This technique consists of combining the ligament augmentation device (3M, Minneapolis, MN) with a small film of the patellar tendon to act as the graft. The tendon graft remains anchored at the tip of the tibial tuberosity. It is threaded through a tibial bone tunnel and then passed through the joint with an over the top technique and fixed with a lateral screw. Surgeons B, C and D performed arthroscopically-assisted ACL reconstruction after harvesting a bone-patellar tendon-bone graft from the central third of the extensor mechanism via an anterior midline incision. The free graft is then inserted through tunnels in the tibia and femur with fixation using interference screws or staples. Surgeons E, F and G performed an open (non-arthroscopic) version of the above. Surgeons H, I, J, K and L performed arthroscopically-assisted ACL reconstruction using a graft harvested from the semitendinosus and/or gracilis muscles. Surgeon B also used this technique for some of his patients.

Twenty four (49%) had ACLR surgery (6 of these were hamstring grafts and 18 patellar tendon). For the subjects with an ACL-deficient knee, the average time from injury to pre-test was 31.9 months (SD = 47.5, minimum = 0.8, maximum = 164.2).

Testing

The target date for pre-testing in the ACLR group was 8 weeks after reconstruction surgery and there was no target date for pre-testing in the ACLD group. Post-testing occurred after a six week training period. A detailed description of the test protocol can be found in one of our previous studies (3) as the present paper has evolved from an investigation of a different purpose. For the purposes of the analysis performed in this study, only those tests used in the analysis are described.
The Hughston Clinic questionnaire was used to evaluate the patient's self-assessment of their knee condition (8). The final score was calculated by aggregating the scores of the 28 questions that comprise this questionnaire and converted to a percentage of maximum possible score. A perfect knee would score 0 % and the worst possible score was 100%.
Body height and weight were measured with the patient in bare feet for both tests. Body height was measured first. Limits of active knee motion were measured with the subject lying supine, and using a manual goniometer as used in the clinic. Knee circumference was also measured with the patient in the supine position. Measurements of knee girth were taken at the mid-point of the patella and the superior border of the patella using a cloth tape. Both knees were measured in this way with the uninjured knee measured first.
One of three physical therapists, at all times blinded to subject group assignment, performed knee anterior laxity testing using the Knee Signature System (9) arthrometer (Orthopedic Systems, Inc., Union City, CA) with the knee in 25° of flexion and a force of 178N applied. The same examiner was used for pre- and post-testing of each patient in order to avoid error due to inter-observer variability. In reliability testing, we have found that our examiners least significant difference values in test-retests of ten uninjured subjects ranged from 3.8 to 4.8 mm, which compares favorably to published data (10).

Training

After initial testing, subjects were asked to attend physical therapy sessions three times per week for the six-week training period of the study, starting as soon as possible after the pre-test. Sessions occurred in the outpatient physiotherapy departments at one of four National Health Service hospitals in the London area [Mile End Hospital (MEH), St Thomas's Hospital (STH), The Whittington Hospital (TWH) or Whipps Cross University Hospital (WCUH)].

A detailed description of the training program used in this investigation appears in our previous work (3,4). All of the training sites had identical equipment for the key knee extensor and flexor training. For both muscle groups, training was performed from 0° to 90° knee flexion with 3 sets of 20 repetition maximum (RM) used at the beginning progressing to 3 sets of 6 RM in week 4. Open kinetic chain exercises were performed with both ankle weights and the knee extensor machine. Ankle weights were used for some subjects as they were initially unable to lift the unloaded lever arm of the knee extensor machine. The weight of the knee extensor machine lever arm at the shin pad (5kg) was added to that of any additional weights placed on the lever arm when recording absolute loads lifted with the knee extensor machine. The lever arm weight was measured by a standard balance placed under the resistance pad of the machine when the resistance arm of the machine was in the horizontal position and the centre of the pad was 34 cm from the centre of the machine's axis of rotation, which was the distance setting used by most of the study group. Our calculations showed that the small variations in lever arm length from 34 cm used by some subjects would make a negligible difference to the additional load of the lever arm.

Knee flexor exercise was also carried out with both ankle weights and a prone knee extension machine, for the same reasons. When using the knee flexor machine 5 kg was again added to that of any additional weights placed on the lever arm when recording absolute loads, to allow for the weight of the lever arm.

Data analysis

Anterior laxity change in the injured knee, the dependent variable, was calculated by subtracting the pre-training anterior knee laxity in the Lachman position measured with a knee arthrometer using a 178N posterior-anterior force from the same test performed after 6 weeks of training. Diagnosis (ACLD vs ACLR) was included as an independent variable in the analysis. In order to select the other independent variables for the regression analysis (necessary to give a fuller picture of the associations of the different training variables with laxity change), Pearson's correlation coefficients were calculated for the relationships between injured knee laxity change during the training period and all the independent variables in Table 2. Using the regression analysis rule of including no more than 1 independent variable per 10 subjects the number of variables had to be limited to four (in addition to the diagnosis variable). The independent variables were rank-ordered by the p-values of their correlation to injured knee laxity change and, generally, the variables with the four lowest p-values were used in the regression analysis.

In evaluating which independent variables to use, the rule of not including variables that are related to each other was followed. Due to the likely association between the different training parameters, only one of these variables per muscle group was used and average absolute load per rep was chosen for the quadriceps training because it had the lowest p-value. Likewise, only one Hughston score was used and again the selection was based on the lowest p-value. Change in uninjured knee laxity was selected over pre-test injured knee laxity and the pre-test laxity differences between the injured and uninjured knees. We chose change in uninjured laxity because we have already found laxity change in the injured knee to be related to baseline injured knee laxity (11) and because we found it appealing that inclusion of uninjured laxity would take into account general changes in the patient (e.g. body temperature), the examiner and the test environment from pre- to post-test.

RESULTS

Table 1 contains information about subject characteristics and the summary data for the independent variables used in the regression analysis. Backward stepwise linear regression was performed with no interactions between independent variables considered. None of the independent variables displayed statistically significant ($p < 0,05$) interactions with the injured knee laxity change in the regression analysis except the average absolute load per repetition in knee extensor OKC training ($r = -0,344$, $p = 0,016$). This relationship is illustrated in Figure 1. The negative correlation is indicative of a relationship whereby *greater* knee extensor OKC absolute training *loads* are associated with *smaller changes* in knee *laxity* over the training period. This result led the authors to investigate whether there was also an inverse relationship between average absolute training load and number of repetitions performed, i.e. whether the lower intensity training subjects had a greater training volume and the results of this analysis are presented in Figure 2. In addition to including diagnosis (ACLD or ACLR) in this regression analysis, the Pearson's correlation coefficients for the relationship between injured knee laxity change and knee extensor average absolute training load were calculated for both diagnosis groups and r-values of -0,341 and –0,350, respectively, were found.

Table 1. Subject characteristics and summary data for the independent variables (N = 49)*.

Variable	Mean ± SD	Minimum	Maximum
Gender		13 females, 36 males	
Diagnosis		25 ACLD, 24 ACLR	
Age (years)	31 ± 7	20	56
Body mass (kg)	76 ± 15	53	111
Body height (cm)	173 ± 8	157	191
Number of training sessions attended	11± 4	1	18
Period between tests (days)	45 ± 5	37	60
Injured knee anterior laxity change (mm)	0 ± 3	-10	4
Uninjured knee anterior laxity change (mm)	*0 ± 3	-10	7
Injured knee flexion PROM at test 2 (°)	138 ± 10	118	160
Average knee extensor training load (kg)	*8,1 ± 2,8	3,4	16,7
Average knee flexor training load (kg)	*7,6 ± 2,9	3,4	16,6
Change in Inj – Uninj girth (cm)	-0,1 ± 1,2	-3	4
$Height^2$ (m^2)	3,0 ± 0,3	2,4	3,6
Hughston test 2 (scale is 0-100 with 0 = normal knee)	*14 ± 17	0	58
Uninj laxity test 2 (mm)	9,7 ± 2,1	5,6	14,5

ACLD = anterior cruciate ligament deficient
ACLR = anterior cruciate ligament reconstruction

Finally, in order to allow clinicians and researchers to standardise the absolute OKC knee extensor training loads used in this study to their work, the average absolute load per height^2 was calculated. A mean of 2,7 kg/m^2 (SD = 0,8) with minimum and maximum values of 1,1 kg/m^2 and 4,8 kg/m^2, respectively, were found.

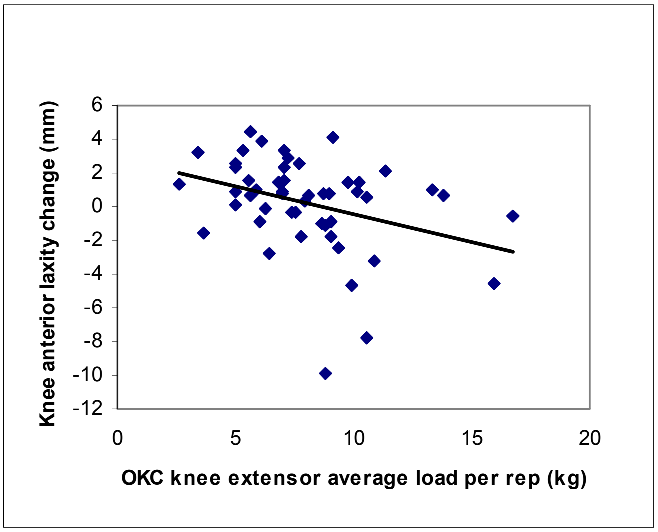

Figure 1. Scatter plot of the relationship between the average load (kg) used in knee extensor OKC training and the injured knee anterior laxity change (mm) (N = 50, r = -0,347, p = 0,014).

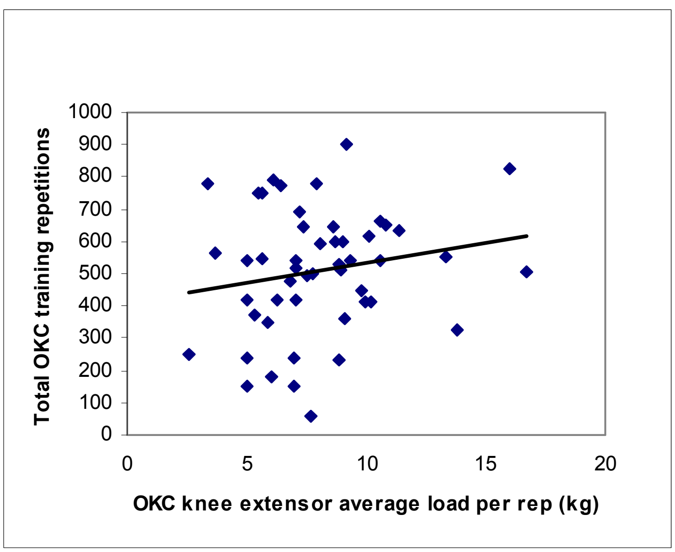

Figure 2. Scatter plot of the relationship between total knee extensor OKC training reps performed and the average load (kg) used in this training (N = 50, r = 0,181, p = 0,207).

Table 2. Variables considered for regression analysis.

Variable	Pearson's correlation r- (and p-) values for relationships to injured knee anterior laxity change.
Age (years)	0,018 (0,902)
Quads average load per rep (kg)	**-0,344 (0,016)**+**
Body mass (kg)	-0,020 (0,893)
Body mass index (kg/m^2)	0,035 (0,812)
Change in (Inf flexion + inj extension PROM) (°)	0,104 (0,496)
Change in Hughston	-0,030 (0,838)
Change in Inj – Uninj girth (cm)*	0,081 (0,559)
Change in uninj laxity (mm)	0,191 (0,189)**
Height (m)	-0,120 (0,412)
Height^2 (m^2)	-0,116 (0,425)
Hughston average for tests 1 & 2	0,220 (0,129)
Hughston test 1	0,191 (0,188)
Hughston test 2	0,246 (0,088)**
Inf flexion + inj extension PROM test 1 (°)	-0,151 (0,322)
Inf flexion + inj extension PROM test 2 (°)	-0,114 (0,455)
Inj – Uninj girth test 1 (cm)*	-0,043 (0,770)
Inj – Uninj girth test 2 (cm)*	-0,150 (0,303)
Inj – uninj laxity test 1	-0,187 (0,198)
Inj extension PROM test 1 (°)	<0,001 (0,999)
Inj extension PROM test 2 (°)	0,068 (0,655)
Inj flexion PROM test 1 (°)	-0,162 (0,286)
Inj flexion PROM test 2 (°)	-0,146 (0,338)
Inj laxity test 1 (mm)	-0,191 (0,188)
Period between tests (days)	-0,022 (0,879)
Maximum Quads load (kg)	-0,292 (0,042)
Quads reps performed	-0,010 (0,945)
Quads sessions	-0,012 (0,933)
Quads Sets X Reps X Load	-0,261 (0,069)
Hams reps performed	0,140 (0,338)
Hams sessions	0,012 (0,936)
Hams Sets X Reps X Load	-0,115 (0,430)
Hams average load per rep (kg)	-0,281 (0,050)**
Maximum Hams Load (kg)	-0,188 (0,196)
Uninj laxity test 1 (mm)	0,007 (0,963)
Uninj laxity test 2 (mm)	-0,121 (0,407)

Inj = injured knee
Uninj = uninjured knee
*Girth at mid-patella
PROM = passive range of motion
Hughston = Hughston Clinic knee self-assessment questionnaire
Quads = knee extensor muscle group
Hams = knee flexor muscle group
** Variable used in model building.
+ Variable that showed a statistically significant relationship ($p < 0,05$) to injured knee change in the stepwise regression analysis.

DISCUSSION

The main finding of this study, that laxity change is related to the training load used, agrees with earlier laboratory findings where the magnitude of ACL strain is related to absolute load in OKC exercise (5). The average absolute training load for the knee extensors was negatively related to knee laxity change. That is, knee laxity change decreased as knee extensor average absolute training load increased. Assuming this relationship is indicative of a causative effect of knee extensor exercise intensity on knee anterior laxity changes, this finding appears to contradict what is expected (and to what we suspect is the view of most clinicians). The fact that the relationship was negative leads to the rejection of our hypothesis that a significant positive relationship would be found.

The results of this study give support to previous findings that knee extensor OKC training, at the loads used in this investigation, is safe in patients with ACLD or ACLR knees (1,2). More importantly, these results indicate that training of this type using proper loads (mean in this study was 2,7 kg per height squared (m^2)) applied at a similar time after injury/surgery as used in this study may be beneficial to knee stability and should be encouraged instead of discouraged in these individuals. Future studies are required to confirm these findings and to offer more specific training recommendations relative to different stages in the healing process after injury and surgery. Since this study, our team has commenced two new, related studies, one with normals and that other with ACLD patients, where knee extensor OKC training load is randomly assigned. The preliminary results of these studies will be presented in Dr Morrissey's Ljubljana lecture.

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