Preoperative quadriceps strength is a significant predictor of knee function two years after anterior cruciate ligament reconstruction

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ABSTRACT

Objective: To identify preoperative predictive factors for knee function two years after reconstructive surgery of the anterior cruciate ligament (ACL). The main hypothesis was that preoperative quadriceps strength would be the most significant predictor for knee function two years after reconstructive surgery.
Design: Cohort study.
Setting: ACL injured individuals treated at a University Hospital and an outpatient clinic in Oslo, Norway.
Participants: Seventy-three individuals with complete unilateral rupture of the ACL scheduled for reconstruction with a bone-patellar-bone autograft were included in the study, from where 60 were available for two-year follow up and included in the final analyses.
Interventions: Not applicable.
Main outcome measurements: Identification of baseline independent variables that may predict knee function assessed with the Cincinnati Knee Score as dependent variable two years after ACL reconstruction.
Results: Quadriceps muscle strength, meniscus injury and the Short-Form-36 Bodily Pain sub score were identified as significant predictors for knee function assessed from the Cincinnati Knee Score two years after ACL reconstruction. Individuals with preoperative quadriceps strength deficits above 20% also had persistent significantly larger strength deficits two years after surgery.
Conclusions: Preoperative quadriceps muscle strength deficits and meniscus injuries have significant negative consequences for the long-term functional outcome after ACL reconstruction. From our findings we suggest that ACL reconstruction should not be performed before quadriceps muscle strength deficits of the injured limb is less than 20% of the uninjured limb.

Surgical reconstruction of the anterior cruciate ligament (ACL) is performed to re-establish the ligamentous stability of the knee joint.[1 2] However, even if the static stability of the joint is recuperated, reconstruction does not in itself restore knee function.[3–10] The main dysfunctions after ACL injury and subsequent reconstruction are dynamic instability and quadriceps muscle strength weakness.[11 12] Deficits in quadriceps strength are attributed both to activation failure and atrophy,[13] and may persist for several years after reconstructive surgery.[11 13–17] Preoperative quadriceps muscle strength deficits have previously been assessed from isokinetic measurements to be between 7 and 17%.[13 14 18 19] In a recent literature review, Palmieri-Smith *et al*[11] included 11 studies that assessed isokinetic quadriceps muscle strength deficits between the reconstructed and the non-injured knee joint six months after ACL reconstruction with bone-patellar-tendon-bone (BPTB) grafts. Quadriceps deficits varied from 24 to 40.5%. Ten studies evaluated quadriceps deficits one year after ACL reconstruction, and reported a range from 10 to 27.1%. Studies with follow-up time over five years after ACL reconstruction have shown that quadriceps asymmetry may persist, with quadriceps deficits between 6 and 10%.[18 20 21] Quadriceps weakness and its potential long-term negative influence on knee function should, hence, be a major concern after ACL injury and reconstruction.[22]

Identification of predictive factors for good knee function after ACL reconstruction is important to optimise pre- and postoperative rehabilitation programmes, both in general and more specifically for restoration of quadriceps muscle strength.[23–25] Therefore, the main aim of the present study was to identify preoperative predictive factors for knee function two years after reconstructive surgery using a BPTB autograft. We hypothesised that preoperative quadriceps strength would be the most significant predictor for knee function two years after ACL reconstruction.

METHODS

This is a prospective cohort of ACL injured subjects who have gone through ACL reconstruction with two years follow-up. However, the study was originally designed as a randomised controlled trial of two different six months postoperative rehabilitation programmes after ACL reconstruction.[22] The RCT has previously shown that there were no significant differences between the two intervention groups neither preoperatively nor two years after ACL reconstruction.[26] This study could therefore be assessed as a prospective cohort study with preoperative and two years follow-up data. The study was approved by the Regional Committee for Medical Research Ethics in Eastern Norway. All participants signed an informed consent prior to participation.

Subjects

Seventy-three ACL deficient subjects, 26 women with mean age 26.8 years (range 19.8 to 38.0 years) and 47 men with a mean age of 29.5 years (range 16.7 to 40.3 years), scheduled for ACL reconstruction with BPTB graft at the Orthopaedic Centre, Ulleval University Hospital, Oslo, Norway were recruited in the study. Subjects between 15 and 40 years of both genders were considered for enrolment if they had a unilateral complete rupture of the ACL with date of injury maximum three years before scheduled surgery. Because all subjects needed to go through two specific and well monitored rehabilitation programmes,[22] subjects had to be geographically located within the Oslo area. Potential candidates were excluded if they had any history of injury and/or surgical intervention in either the ACL-deficient or contralateral knee, meniscus injury that required repair or full depth cartilage defects affecting subchondral bone.

Self-assessment scores

Data collection involved self-assessment of knee function using the Cincinnati Knee Score.[24] Topics addressed in the Cincinnati Knee Score are pain, swelling, episodes of giving way, activity level in general and the specific activities walking, stair climbing, running, jumping and twisting. The score has been shown to be a valid and reliable tool for assessment of knee function.[24 27 28] Furthermore, two different visual analogue scales (VAS) were used; one related to pain and one to global knee function. VAS scores were collected by asking the subjects to draw a vertical line across a 100 mm horizontal line ranging from 0 to 100. For pain, 0 represented no pain at all and 100 the worst imaginable pain,[29 30] whereas for function, 0 represented normal knee function and 100 the worst possible function.[31]

In addition to these knee specific self assessment tools, subjects also reported general health-related quality of life from the Short-Form-36 (SF-36) questionnaire. The SF-36 consists of eight subscales each of which is scored from 0 to 100, where 100 represents excellent health status. The subscales included are physical function, role limitations-physical, role limitations-emotional, bodily pain, general health, vitality, social function and mental health. The reliability of the Norwegian version of the SF-36 has been reported to be in line with the set standards from the Cronbach α.[32]

Single-legged hop, muscle strength and knee joint laxity tests

Subjects performed three functional single-legged hop tests; the single leg hop for distance, the triple hop for distance and the stair hop tests. Single-legged hop tests are well established and have shown high reliability in ACL injured and reconstruction subjects,[33–36] and the three specific tests used in this study have previously reported high reliability.[37 38] The single and triple hop tests were performed as two trials for each leg where the best (longest in cm) trial was used for analyses. Results were calculated as the percentage of performance on the injured leg compared to the uninjured leg following the formula injured leg/uninjured leg ×100. The stair hop test involved hopping up and down 22 steps, each of 17.5 cm height, while time was measured in seconds. The test was conducted once for each leg. Results were calculated as the percentage of performance on the injured leg compared to the uninjured leg following the formula uninjured leg/injured leg×100.

Knee extension and flexion muscle strength was evaluated with a Cybex 6000 Isokinetic Dynamometer (Cybex, Division of Lumex, Inc., Ronkonkoma, NY, USA).[39] To address both maximal strength and endurance, the test protocol included five repetitions at 60°/second followed by 30 repetitions at 240°/second with a standardised one minute rest-period in between. In order to evaluate muscle performance throughout the movement cycle, total work was used as outcome measure.[39] Side-to-side differences were calculated from the formula injured leg/uninjured leg×100 and expressed as a percentage value. Isokinetic muscle strength tests have been established as a reliable method for assessment of muscle performance after ACL reconstruction.[40]

Static knee joint laxity defined as the anterior translation between tibia and femur was measured with a KT-1000 Arthrometer (MEDMetric, San Diego, CA, USA). The side-to-side difference between the injured and the uninjured knee was defined from the maximum manual test. Reliability of the KT-1000 measurements performed by experienced raters has previously shown to be satisfactory.[40 41]

Each data collection began with measurements of knee laxity using the KT-1000 followed by a standardised 10 minutes warm-up on a stationary ergometer cycle. Then subjects performed the single-legged hop tests and the isokinetic strength tests before they answered the questionnaires.

Rehabilitation protocol

All subjects included in the study participated in either one of two rehabilitation protocols that were included in a randomised controlled trial.[22] The first rehabilitation protocol emphasised neuromuscular training beginning the second week after ACL reconstruction. The programme was conducted for six months with two to three sessions per week. Key elements of the programme were exercises for balance and dynamic stability, agility, plyometrics and finally sport-specific activities. The second rehabilitation protocol emphasised muscle strength training of the lower extremities. The protocol progressed from functional exercises with focus on controlled weight-bearing to

Table 1 Selection of relevant independent variables for the stepwise forward regression model

Independent variable	p Value	Included	Reason for inclusion/exclusion
Meniscus injury	0.036	Yes	Additional injuries have previously shown to influence functional outcome.
SF-36 BP sub score	0.074	Yes	Self-assessed pain has previously shown to influence functional outcome.
VAS Global function	0.118	Yes	Self-assessed knee function during activity has previously shown to influence functional outcome.
Triple hop test (injured in percent of uninjured side)	0.218	Yes	Performance on functional hop tests has previously shown to correlate with knee function.
Quadriceps strength 60°/sec (injured in percent of uninjured side)	0.235	Yes	Quadriceps strength has previously shown to influence knee function.
Stair hop test (injured in percent of uninjured side)	0.258	Yes	Performance on functional hop tests has previously shown to correlate with knee function.
Hamstrings strength uninjured side 240°/sec	0.128	No	Hamstrings strength has previously shown to have less impact on knee function than quadriceps strength.
Hamstrings strength injured side 60°/sec	0.249	No	Hamstrings strength has previously shown to have less impact on knee function than quadriceps strength.
Tegner activity scale	0.221	No	Preoperative activity level has not shown to be strongly correlated to long-term function after reconstructive surgery.
KT-1000 manual max side-to-side difference	0.237	No	Static laxity has previously shown to have low correlation to knee function.

SF-36 BP, Short Form-36 bodily pain.

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Table 2 Independent baseline variables identified as significant predictors for the Cincinnati Knee Score two years after ACL reconstruction

Independent variables	β (95% CI of β)	Constant (95% CI of constant)	p Value	R^2
Preoperative quadriceps strength	0.296 (0.09 to 0.50)	63.03 (45.94 to 80.12)	0.005	0.156
Preoperative quadriceps strength	0.273 (0.08 to 0.47)		0.007	
Meniscus injury	6.598 (0.71 to 12.49)	55.09 (37.23 to 72.96)	0.029	0.240
Preoperative quadriceps strength	0.212 (0.01 to 0.41)		0.036	0.307
Meniscus injury	6.814 (1.12 to 12.51)		0.020	
Preoperative SF-36 BP sub score	0.167 (0.01 to 0.33)	48.72 (30.40 to 67.04)	0.042	

SF-36 BP, Short Form-36 bodily pain.

more specific strength training of the quadriceps, hamstrings and gastrocnemius muscles, and finally more sport specific exercises. Both rehabilitation protocols have been described in detail by Risberg *et al*.[22] As previously reported, there were no significant differences between the two rehabilitation groups preoperatively or two years after ACL reconstruction.[26]

STATISTICAL ANALYSIS

SPSS V.16.0 was used to analyse the data. Predictive factors for knee function were investigated using a stepwise forward linear regression analysis with the Cincinnati Knee Score two years after ACL reconstruction as the dependent variable. The first step in building the model consisted of simple linear regression analyses of all baseline variables. Threshold for inclusion in the stepwise forward regression model was set to 0.30. Out of 52 variables, 10 satisfied this criterion. Following the "1 in 10" rule for linear models,[42 43] the six most relevant variables were selected (table 1). The selection of variables was based on previous literature. Hence; the final model included one candidate predictor for every 10 subjects involved in the two year follow-up (n = 60).

Spearman Correlation Coefficient was used to control for strong intercorrelations within the independent variables, with a cut-off at $r_s = \pm 0.70$. No variables had to be eliminated. The explanatory power of the regression (R^2), the regression coefficient (β), the constant, the p values and the confidence intervals for the constants and the regression coefficients were computed. Significance level was set to 5%. In order to further examine to what extent larger quadriceps deficits and meniscus injuries at baseline affected knee function two years after ACL reconstruction, subjects were classified into two sets of subgroups: Those with "strength deficit ≤ 20%" or "strength deficit > 20%" at baseline, and those with "injury" or "no injury" of the meniscus at baseline. Cut-off between the quadriceps strength subgroups was set to less or equal than 20% side-to-side strength deficit, based on knowledge that uninjured individuals normally have quadriceps asymmetry within 10%[44] and that previous studies also have used a 20% cut-off level for good or poor quadriceps strength after ACL injury and ACL reconstruction.[14 45–48] For both sets of subgroups (quadriceps strength and meniscus injury) outcome scores two years after ACL reconstruction for the Cincinnati Knee Score, quadriceps strength and SF-36 BP sub score were assessed. Mean differences between the subgroups were tested with independent Student t tests with a probability level of $p<0.05$.

Table 3 Mean, standard deviation (SD) and range for the baseline and two years outcome scores for the identified predictors quadriceps muscle strength deficit and bodily pain sub score of the Short-Form-36 sub score from the regression model (n = 60)

Outcome variables	Baseline			Two years after ACL reconstruction		
	Mean	*Range*	*SD*	*Mean*	*Range*	*SD*
Cincinnati Knee Score	65.8	18–87	15.3	88.1	58–100	10.9
Quadriceps strength (index)	80.7	38.3–112.2	17.3	92.3	50.3–119.0	12.9
SF-36 BP sub score	64.9	22–100	19.8	84.0	41–100	19.7

ACL, anterior cruciate ligament; SF-36 BP, Short Form-36 bodily pain sub score.

RESULTS

Data were collected preoperatively (on average 43 weeks from injury to baseline test, range 7 to 153 weeks) and two years after surgery (on average 111 weeks from surgery to follow-up, range 80 to 157 weeks). ACL reconstruction was performed shortly after the baseline test; on average 45 weeks (range 8 to 154 weeks) after injury. Of the 73 subjects included in the study at baseline 60 subjects (83%) were available for the follow-up two years after ACL reconstruction (21 women and 39 men). Reasons for subjects being considered lost to follow-up were one subject with low back pain, three who withdrew from the study and nine that did not respond to contact or did not arrive for scheduled testing. There were no significant differences at baseline between those who participated in the two year follow-up (n = 60) and those who were lost to follow-up (n = 13), except for percentage side-to-side difference for isokinetic muscle strength at 240°/sec. Those lost to follow-up had significantly lower quadriceps strength at 240°/sec compared to those that participated in the two year follow-up (p = 0.007).

Predictors for knee function

Preoperative quadriceps strength, calculated as the percentage difference between the injured and uninjured side, meniscus injury and the SF-36 BP sub score were significant predictors for the Cincinnati Knee Score two years after ACL reconstruction (table 2). Preoperative quadriceps strength alone explained 15.6% of the regression, combined with meniscus injury it increased to 24.0% and the SF-36 BP sub score revealed a further increase to 30.7% of the explained variation.

Comparisons among subgroups

Baseline and two year follow-up scores for the Cincinnati Knee Score and the two of the three identified predictors that were continuous; quadriceps strength deficits and SF-36 BP sub score, are shown in table 3.

ACL individuals with quadriceps strength deficits larger than 20% had a significantly lower (p = 0.008) Cincinnati Knee Score two years after surgery (table 4). The mean difference in score was 7.5 points. Quadriceps strength was still significantly lower (p = 0.001) two years after surgery among those who had deficits >20% at baseline. The mean quadriceps muscle strength difference between the subgroups was 11%. There were no significant differences for the SF-36 BP sub score (p = 0.296) between the quadriceps muscle strength subgroups two years after surgery.

Subjects were also classified from whether they had meniscus injury at baseline or not (table 5). Those with meniscus injury at baseline had a significantly (p = 0.036) lower Cincinnati Knee Score two years after ACL reconstruction. Mean difference between those with and without meniscus injury was 5.9 points. Those with meniscus injuries also had a significantly lower score (p = 0.028) on the SF-36 BP sub score, with a mean difference of 11.3 points. There was no difference in quadriceps strength for those with meniscus injury compared to those without.

DISCUSSION

Our hypothesis was supported as preoperative quadriceps strength was the most significant (p = 0.005) predictor for the Cincinnati Knee Score two years after ACL reconstruction.

This is the first prospective study to report significant predictors at baseline for knee function two years after ACL reconstruction. In a recent retrospective review, de Jong *et al*[14] found that individuals with preoperative strength deficits greater than 20% had significantly lower limb symmetry for the single-legged hop tests six and nine months postoperatively, but that these differences were eliminated at 12 months. Quadriceps muscle strength deficits, however, were shown to persist up to 12 months after ACL reconstruction. When we categorised our subjects in the same way, we found corresponding results, in that preoperative muscle strength deficits larger than 20% resulted in a significantly lower Cincinnati Knee Score (p = 0.008) and quadriceps strength (p = 0.001) two years after surgery. There were no significant differences for the SF-36 BP sub score (p = 0.296).

In addition to quadriceps muscle strength the predictive model also identified meniscus injuries and SF-36 BP sub score as significant predictors (p = 0.029 and 0.042, respectively) for the Cincinnati Knee Score two years after ACL reconstruction. When comparing those with preoperative meniscus injury to those without, we found significant differences for the Cincinnati Knee Score of 5.9 points (p = 0.036) and for the SF-36 BP sub score of 11.3 points (p = 0.028) two years after surgery, indicating that preoperative meniscus injuries have a clinically relevant negative influence on the long term postoperative function. Meniscus injuries and associated symptoms, such as pain and range of motion deficits,[49 50] may hinder compliance to an adequately intensive preoperative quadriceps muscle strength exercise protocol. We did, however, not find any significant differences in quadriceps strength two years after ACL reconstruction between the meniscus injury subgroups in this study.

Table 4 Cincinnati Knee Score, quadriceps strength and bodily pain (BP) sub score of the Short-Form-36 (SF-36 BP) two years after ACL reconstruction for subjects with quadriceps strength deficits equal to or less than 20% (n = 35) and larger than 20% (n = 25) at baseline

Functional outcome two years after ACL reconstruction	Deficit ⩽20% (n = 35)		Deficit >20% (n = 25)		p Value
	Mean	*SD*	*Mean*	*SD*	
Cincinnati Knee Score	90.9	9.8	83.4	10.9	0.008
Quadriceps strength (index)	96.7	11.4	85.7	12.6	0.001
SF-36 BP sub score	86.2	18.9	80.5	20.9	0.296

ACL, anterior cruciate ligament; SF-36 BP, Short Form-36 bodily pain sub score

Table 5 Cincinnati Knee Score, quadriceps strength and bodily pain sub score of the Short-Form-36 two years after ACL reconstruction for subjects with meniscus injury (n = 30) or no injury (n = 30) at baseline

Functional outcome two years after ACL reconstruction	No injury (n = 30)		Injury (n = 30)		p Value
	Mean	*SD*	*Mean*	*SD*	
Cincinnati Knee Score	91.0	8.7	85.1	12.1	0.036
Quadriceps strength (index)	92.6	9.9	91.9	15.7	0.846
SF-36 BP sub score	89.5	13.4	78.2	23.6	0.028

ACL, anterior cruciate ligament; SF-36 BP, Short Form-36 bodily pain sub score.

The total explanatory power of the three predictors identified from our regression model was 30.7%, which means that there are several other contributing factors to the outcome. Still, from a total number of 52 independent variables our main predictor alone explained 15.6% and the three predictors combined almost one third of the expected change in the Cincinnati Knee Score two years after ACL reconstruction. The significant differences in the two year outcome between those with and without severe preoperative quadriceps muscle deficits and those with or without meniscus injury further strengthens the long-term clinical impact of the predictors identified in the model.

Insufficient quadriceps function is believed to be a consequence of both atrophy and activation failure caused by a permanent alteration of muscle activation.[10 13–15 51] Konishi and co-workers have in several studies[52–54] suggested that quadriceps weakness after ACL injury and eventual reconstruction may result from abnormal gamma loop function that leads to insufficient motor unit recruitment during voluntary contraction. Reconstruction seems to affect this neuromuscular deficit further, as quadriceps muscle strength has been reported to be at its lowest level around six months after surgery[11 14 15]—even lower than preoperatively.[11 13 14 18 19] These quadriceps muscle strength deficits have further shown to persist for years after reconstruction, despite the development of more demanding rehabilitation protocols also including open kinetic chain exercises.[11 16 21 55–57] Our results are in line with these findings. Individuals having strength deficits above 20% preoperatively still had significantly larger side-to-side deficits two years after ACL reconstruction, with a mean difference of 14.3% compared to a mean difference of 3.3% among those with smaller preoperative muscle strength deficits. This imply that those having small deficits preoperatively will regain normal symmetry two years after surgery,[44] whereas those with larger deficits will not.

Early surgical intervention with ACL reconstruction has not shown to result in faster restoration of quadriceps muscle strength; rather deficits seem to be more persistent during the postoperative rehabilitation.[57] It has been suggested that aggressive physiotherapy may contribute to a faster restoration of adequate muscle recruitment in the quadriceps muscle.[58] Our results showed that good preoperative quadriceps strength in the injured leg predicted a clinically relevant better function two years after ACL reconstruction. It is, thus, crucial to initiate intensive quadriceps muscle training protocols that aim to restore side-to-side muscular symmetry before reconstructive surgery is conducted. If adequate preoperative rehabilitation can reduce neuromuscular malfunction and subsequent inhibition of voluntary quadriceps contraction, it may reduce persistent postoperative quadriceps muscle strength deficits.

The average time from injury to surgery was in this cohort 45 (range 8 to 154) weeks. This must be taken into consideration when comparing our results to other cohorts with shorter time between injury and reconstruction. However, quadriceps muscle strength deficits have shown to be present shortly after injury as well as being persistent over time.[10 14 15 55 59] Assessment of quadriceps muscle strength should, thus, always be included preoperatively, independent of time since injury.

We need to address some of the limitations of the present study. The number of subjects included in the predictive model is 60, which limited the number of independent variables in the model to six out of a total number of independent variables at baseline of 52. A larger number of subjects would allow more extensive models to be computed.

Since all the subjects in this study were reconstructed with the BPTB-technique, our findings cannot be generalised to subjects reconstructed with other techniques.

The Cincinnati Knee Score was used as dependent outcome variable in the regression analysis. Even though the Cincinnati Knee Score has been shown to be an adequate tool for assessment of knee function after ACL reconstruction,[27] other self-assessment questionnaires for functional status of the knee have later been developed and validated; such as the IKDC2000,[60] the KOS-ADLS[31] and the KOOS.[61] These tools were, however, not completely developed and validated when this study was launched in 1999.

CONCLUSION

The results from the present study clearly indicated that preoperative quadriceps muscle strength deficits and meniscus injuries have significant negative consequences for the long-term functional outcome after ACL reconstruction. Two years after surgery, individuals with preoperative strength deficits on the injured side above 20% still have abnormal muscular asymmetry. Hence, preoperative rehabilitation protocols should emphasise intensive quadriceps muscle strength training in order to improve side-to-side symmetry. From our results we suggest that quadriceps muscle strength deficits of the injured limb should be less than 20% of the uninjured limb before ACL reconstruction to reduce the severity of long-lasting post-operative deficits.

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