Risk Factors for Abnormal Anteroposterior Knee Laxity After Primary Anterior Cruciate Ligament Reconstruction

Riccardo Cristiani, M.D., Magnus Forssblad, M.D., Ph.D., Björn Engström, M.D., Ph.D., Gunnar Edman, M.D., Ph.D., and Anders Stålman, M.D., Ph.D.

Purpose: To identify preoperative and intraoperative factors associated with abnormal anterior knee laxity after primary anterior cruciate ligament (ACL) reconstruction. **Methods:** A total of 5,462 patients who underwent primary ACL reconstruction at our institution from January 2000 to October 2015, with no associated ligament injuries, were included. Demographic data, information regarding graft used, concomitant meniscal surgery, and instrumented laxity were reviewed. The KT-1000 arthrometer, with an anterior tibial load of 134 N, was used to evaluate knee laxity preoperatively and at 6-month follow-up. Patients were considered to have abnormal anterior knee laxity if the postoperative side-to-side difference was greater than 5 mm (International Knee Documentation Committee laxity grade C or D). A logistic regression analysis was used to evaluate whether patient age, gender, preoperative knee laxity, graft type, and presence of medial or lateral meniscus resection or suture were risk factors for abnormal knee laxity. **Results:** The risk of having abnormal anterior knee laxity was significantly related to younger age (<30 years) (odds ratio [OR] 1.44; 95% confidence interval [CI], 1.07-1.95; $P = .016$), preoperative side-to-side difference greater than 5 mm (OR, 6.57; 95% CI, 4.94-8.73; $P < .001$), hamstring tendon graft (OR, 1.83; 95% CI, 1.08-3.11; $P = .025$), and medial meniscus resection (OR, 2.22; 95% CI, 1.61-3.07; $P < .001$). Female gender (OR, 0.96; 95% CI, 0.72-1.28; $P = .80$), medial meniscus suture (OR, 0.82; 95% CI 0.42-1.62; $P = .58$), lateral meniscus resection (OR, 0.73; 95% CI 0.49-1.10; $P = .13$), and lateral meniscus suture (OR, 0.99; 95% CI, 0.46-2.11; $P = .98$) were not associated with increased risk of abnormal knee laxity. **Conclusions:** Age less than 30 years, preoperative side-to-side difference greater than 5 mm, hamstring tendon graft, and medial meniscus resection are associated with increased risk of having abnormal anterior knee laxity 6 months after primary ACL reconstruction. **Level of Evidence:** Level III, retrospective comparative trial.

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An anterior cruciate ligament (ACL) tear is responsible for abnormal knee biomechanics, leading to a greater anterior displacement and internal rotation of the tibia.[1] The KT-1000 arthrometer (MEDmetric, San Diego, CA) is the most commonly used instrument to evaluate the anterior laxity of the knee joint and is considered to be more precise compared with the clinical Lachman test.[2]

Instrumented laxity examination is not only used before surgery, but also after ACL reconstruction (ACLR) to measure the anterior restraint provided by the ACL graft.[3] According to the International Knee Documentation Committee form, a side-to-side (STS) difference of more than 5 mm is considered to be abnormal and therefore a failure of the reconstruction.[4] Persistent knee laxity after ACLR can increase the load on the joint surfaces and the meniscus with an increased risk of sustaining subsequent meniscus and cartilage injuries, leading to osteoarthritis.[5,6]

Questions remain about how patient demographic and intraoperative factors affect postoperative knee laxity. Some authors found increased anterior knee

From the Capio Artro Clinic (R.C., B.E., A.S.), and Department of Molecular Medicine and Surgery, Stockholm Sports Trauma Research Center, Karolinska Institutet (M.F., G.E.), Stockholm, Sweden.

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Address correspondence to Riccardo Cristiani, M.D., Capio Artro Clinic, Stockholm Sports Trauma Research Center, Sophiahemmet Hospital Building O, Valhallavägen 91, 11486 Stockholm, Sweden. E-mail: riccardo.cristiani87@gmail.com

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laxity after ACLR in females,[7-9] whereas others found no gender differences.[10,11] The graft potential in restoring knee laxity is still a topic of great debate with several studies indicating no differences in anteroposterior laxity with bone—patellar tendon—bone (BPTB) compared with hamstring tendons (HT) graft,[8,10,12] in contrast with others suggesting less laxity for the BPTB graft.[13,14] A definitive conclusion about the role of the menisci as secondary knee stabilizers has not been made. There are studies showing increased anterior knee laxity with medial meniscus resection,[15,16] and others showing that medial meniscus resection does not affect anterior laxity.[17,18] Moreover, no consensus is present about the importance of the lateral meniscus regarding anterior laxity.[19,20]

Finally, the correlation between preoperative and postoperative laxity is poorly studied.[17,21,22] Thus, research is needed to identify factors that can affect the objective outcome after ACLR.

The purpose of this study was to identify preoperative and intraoperative factors associated with abnormal knee laxity after primary ACLR. We hypothesized that female sex, younger age, preoperative knee laxity, HT graft, and concomitant meniscus resection would be risk factors for abnormal knee laxity after primary ACLR.

Methods

Participants

A total of 7,185 patients who underwent primary ACLR, from January 2000 to October 2015 at our clinic, with no concomitant ligament injuries, were identified. After excluding patients who had contralateral ACL injuries or reconstructions (n = 274), as well as patients with no preoperative or postoperative KT-1000 arthrometer data available (n = 1,449), 5,462 patients with complete instrumented laxity values were eligible to form the study population.

Ethical approval for this study was obtained by the Regional Ethics Committee.

Surgical Technique, Rehabilitation, and Arthrometric Evaluation

All patients were operated using a single-bundle technique. Graft choice was according to the surgeon's preference. The BPTB graft was harvested as the central third of the patellar tendon with 2 bone blocks, and for the HT graft, the quadrupled semitendinosus tendon or semitendinosus and gracilis tendons were used. The femoral tunnel was drilled with a transtibial or anteromedial portal technique. Both grafts were routinely fixed using an Endobutton fixation device (Smith & Nephew, Andover, MA) on the femoral side, and Ethibond no. 2 sutures (Ethicon, Sommerville, NJ) tied over an AO bicortical screw with a washer as a post or using an interference screw on the tibial side. Meniscal repair was performed with an arthroscopic all-inside technique using a FasT-Fix suture anchor device (Smith & Nephew) for tears in the dorsal and middle portions of the menisci. Tears located in the anterior portion of the menisci were repaired using an outside-in technique with PDS 0 (Ethicon).

All patients followed a standardized postoperative rehabilitation protocol. In case of isolated ACLR or ACLR with concomitant meniscus resection, full weight bearing and full range of motion were encouraged as tolerated. If meniscal repair was performed, patients wore a postoperative hinged knee brace. Flexion was limited from 0° to 30° for the first 2 weeks, from 0° to 60° for the third and fourth weeks, and from 0° to 90° for the fifth and sixth weeks after surgery. During the first 6 weeks, partial weight bearing was recommended. From the seventh week, the knee brace was discontinued and progressive weight bearing was allowed. For all patients, quadriceps strengthening was restricted to closed kinetic chain exercises in the first 3 months.

Preoperatively and 6 months after surgery, all patients underwent instrumented laxity assessment. All knee laxity evaluations were performed at our outpatient clinic by experienced sports medicine physiotherapists, using the KT-1000 arthrometer (MEDmetric). A standard 30 lbs force, corresponding to 134-N anterior tibial load, at 20° of knee flexion, was applied. At least 3 measurements of each knee were made, and the median value was registered. The postoperative difference in displacement (STS difference) between the ACL injured knee and the healthy knee was expressed in millimeters.

Data Sources

Demographic data (age and gender), preoperative laxity values, graft type, and meniscus surgery performed at the index ACLR were collected in our local database. Meniscus surgery was classified as follows: no meniscus surgery, meniscus resection, or meniscus repair for both medial and lateral meniscus. Instrumented laxity measurements at 6-month follow-up were reviewed. Knee laxity was classified according to the International Knee Documentation Committee examination form.[4]

Statistics

The postoperative STS difference between the injured and noninjured knee was dichotomized into 2 classes, normal (≤5 mm) and abnormal (>5 mm). A logistic regression analysis was performed with age, gender (1 = man; 2 = woman), preoperative laxity (1 = STS difference ≤5 mm; 2 = STS difference >5 mm), graft (1 = BPTB; 2 = HT), medial meniscus resection, medial meniscus suture, lateral meniscus resection, or lateral meniscus suture as independent variables and abnormal postoperative laxity (STS difference >5 mm) as a dependent variable. Age was dichotomized into unbiased classes close to the median (<30 years vs ≥30 years). The risk of having abnormal laxity after surgery was expressed as an odds ratio (OR) with 95% confidence interval (CI). The level of significance was 5% (2-tailed).

Results

Complete laxity data were available for 5,462 patients who formed the study cohort. The mean (standard deviation) time from injury to surgery was 15 (11.4) months. Patients' characteristics are summarized in Table 1.

A total of 223 patients of the studied cohort showed abnormal knee laxity at the follow-up arthrometric evaluation. Logistic regression analysis showed abnormal laxity to be associated with younger age (<30 years) (OR 1.44; 95% CI, 1.07-1.95; $P = .016$), preoperative STS difference greater than 5 mm (OR, 6.57; 95% CI, 4.94-8.73; $P < .001$), HT graft (OR, 1.83; 95% CI, 1.08-3.11; $P = .025$), or concomitant medial meniscus resection (OR, 2.22; 95% CI, 1.61-3.07; $P < .001$). No correlation was found between abnormal knee laxity and female gender, medial meniscus suture, lateral meniscus resection or suture (Table 2).

Discussion

The most important findings of this study are that patient age less than 30 years, preoperative STS difference greater than 5 mm, HT graft, and medial meniscus resection were found to be 4 independent risk factors for abnormal knee laxity after ACLR. On the contrary, we have not found any correlation between female gender, medial meniscus suture, lateral meniscus resection or suture, and the risk for abnormal knee laxity.

There is an ongoing debate about the potential of HT and BPTB grafts in restoring knee laxity after ACLR. In the literature, there are some studies that revealed no differences between HT and BPTB in terms of anterior knee laxity[1,7,10,12,23] and others that found a difference in favor of the BPTB graft.[8,13,14] A recent published meta-analysis comprising 858 patients (422 BPTB, 436 HT) with KT-1000/2000 values available, found no differences between the BPTB and HT autograft in resuming anterior knee laxity after ACLR.[24] Our study, on the contrary, indicates that graft choice has an impact on restoring knee laxity. The HT graft was found to be an independent risk factor for abnormal knee laxity after ACLR. The increased postoperative laxity with the HT graft could be related to the tendon-to-bone healing and slower ligamentization process of this graft.[25-27]

Previous clinical studies investigated the effect of the menisci as secondary knee stabilizers. However, they reported conflicting results. Wu et al.[18] found no differences in terms of postoperative anterior knee laxity, measured with KT-2000 arthrometer Man-Max, between intact or deficient menisci on 63 patients after ACLR. Ahn and Lee,[17] in a recent study, found no significant influence of concomitant meniscal surgery on the objective postoperative knee stability in 131 patients after ACLR. On the contrary, Shelbourne and Gray[20] reported less laxity, assessed with KT-1000 arthrometer Man-Max testing, for patients having both menisci intact compared with patients with any

Table 1. Patient Characteristics (n = 5,462 Patients)

		Mean ± SD Postoperative STS Difference, mm
Preoperative variables		
Age at surgery, yr, mean ± SD	28.1 ± 10.3 (range, 9-63)	
Aged younger than 30 yr	20.9 ± 4.7; 3,223 (59)	1.9 ± 2.2
Aged 30 yr or older	38.6 ± 6.6; 2,239 (41)	1.5 ± 2.2
Gender		
Male	3,051 (55.8)	1.7 ± 2.2
Female	2,411 (44.2)	1.9 ± 2.2
Preoperative STS difference		
>5 mm	1,208 (22.1)	3.0 ± 2.3
≤5 mm	4,254 (77.9)	1.4 ± 2.0
Intraoperative variables		
Graft type		
HT autograft	4,770 (87.3)	1.8 ± 2.2
BPTB autograft	692 (12.7)	1.2 ± 2.1
No meniscus surgery	3,435 (62.9)	1.6 ± 2.1
Medial meniscus surgery		
Resection	777 (14.2)	2.2 ± 2.5
Repair	266 (4.9)	1.7 ± 2.3
Lateral meniscus surgery		
Resection	824 (15.1)	1.9 ± 2.2
Repair	160 (2.9)	1.9 ± 2.1

NOTE. Data are reported as n (%), unless otherwise indicated.

BPTB, bone−patellar tendon−bone; HT, hamstring tendon; mm, millimeter; SD, standard deviation; STS, side-to-side.

Table 2. Factors Associated With Abnormal Laxity (STS Difference >5 mm) After ACL Reconstruction in Logistic Regression Analysis

Risk Factor	Regression Coefficient (ß)	SE	OR (95% CI)	*P* Value
Age <30 yr	0.37	0.15	1.44 (1.07-1.95)	.016*
Female gender	−0.04	0.14	0.96 (0.72-1.28)	.80
Preoperative STS >5 mm	1.88	0.14	6.57 (4.94-8.73)	<.001*
HT graft	0.60	0.27	1.83 (1.08-3.11)	.025*
Medial meniscus resection	0.80	0.16	2.22 (1.61-3.07)	<.001*
Medial meniscus suture	−0.18	0.34	0.82 (0.42-1.62)	.58
Lateral meniscus resection	−0.30	0.20	0.73 (0.49-1.10)	.13
Lateral meniscus suture	−0.008	0.38	0.99 (0.46-2.11)	.98

ACL, anterior cruciate ligament; CI, confidence interval; HT, hamstring tendons; OR, odds ratio; SE, standard error; STS, side-to-side.
*Statistically significant.

part of the medial or both menisci removed. Our study confirmed the importance of medial meniscus preservation on postoperative anterior knee laxity. Medial meniscus resection significantly increased, and medial meniscus repair did not show an increased risk of having abnormal laxity. Resection or repair of a lateral meniscus tear was not associated with a higher risk of having abnormal anterior knee laxity after ACLR. However, previous studies reported the lateral meniscus to be an important secondary knee stabilizer for rotational laxity.[28,29]

We found age less than 30 years to be an independent risk factor for abnormal knee laxity after ACLR. A possible explanation for this result could be that older patients have a "stiffer" knee due to the progressive degenerative changes of the joint. At the same time, it is also possible that younger patients are more prone to follow a more intense and aggressive rehabilitation compared with older patients, causing a stretching of the graft. Marchand et al.[30] found a greater "residual laxity," measured with laximeter GNRB (GeNouRoB, Laval, France) with 134-N anterior tibial load at an average follow-up of 26 months after ACLR, in patients younger than 20 years. The authors concluded that younger patients represent a population at risk of graft elongation, and for this reason, they recommended to modify the postoperative management of these patients. Delayed weight bearing, articulated splinting, slower rehabilitation were suggested during the first postoperative months.

Several studies described increased knee laxity in women after ACLR.[7-9,31,32] On the other hand, Eriksson et al.[10] and Jansson et al.[11] found no gender differences at the postoperative arthrometric evaluation. Our findings are in line with the latter studies. We were not able to show any increased risk of having abnormal laxity in the female gender in this big cohort of patients.

An interesting finding of this study is the strong correlation between prereconstruction and post-reconstruction laxity. This is in contrast with previous studies that showed no association between preoperative and postoperative anterior tibial translation after ACLR.[17,21] However, recently Signorelli et al.[22] assessed the ACL injured knee in 6 different laxity tests before and after ACLR and pointed out that prereconstruction laxity values influence post-reconstruction ones, even though postoperative anteroposterior laxity at 30° was barely affected by the presurgery condition. An ACL injury is rarely isolated. Severe laxity after ACL tears could be caused by the stretching of other stabilizing structures such as capsular and peripheral ligaments. In this category of patients, surgery limited to ACLR might be insufficient to restore joint laxity. It has been shown that after ACLR there is a nearly constant amount of laxity reduction, regardless of the prereconstruction laxity condition.[22]

Even if there is no clear correlation between anterior knee laxity and subjective clinical outcome,[33,34] the understanding of the risk factors associated with abnormal laxity after ACLR is of great importance. Failure of an ACL graft should be considered when restoration of laxity has not been achieved after ACLR,[35] and an abnormal knee laxity could be responsible for progressive cartilage degeneration.[5] Struewer et al.[6] found a significant correlation between a higher degree of osteoarthritis and increased anterior laxity measured with the KT-1000 arthrometer. A higher risk of graft failure and ACL revision have been described with the use of an HT graft compared with a BPTB graft for primary ACLR.[36,37] This could be partly explained by the increased laxity associated with the HT autograft.

Robb et al.[19] reported that knee stability after ACLR is more likely in those patients with intact or repaired medial or lateral menisci. Moreover, they showed that failure of ACLR was predicted by the condition of the meniscus as present or deficient. Patients who underwent meniscal repair did not show any increased risk of failure. After medial meniscectomy, in situ forces increased in the ACL replacement graft by 33% to 55%.[38] The greater laxity in patients with meniscus deficiency alters the joint kinematics and could lead to a higher risk of graft failure.

Our study showed the importance of graft choice, meniscus status, and preoperative laxity for postoperative laxity. As hypothesized, the HT graft, medial meniscus resection, and greater preoperative laxity were found to be independent risk factors for abnormal postoperative laxity. These findings should be taken into account when performing ACLR. The graft for ACLR should be chosen according to its pro and cons, considering also the graft potential in restoring knee laxity. The meniscus should be preserved whenever possible for avoiding the risk of jeopardizing knee kinematics, and preoperative laxity should also be carefully considered before surgery. The use of a BPTB graft in patients with 1 or more risk factors for abnormal postoperative knee laxity, like greater preoperative laxity, younger age, and/or medial meniscus resection might be considered.

The main strength of this study is the analysis of a large cohort (5,462 patients). All patients received surgery, rehabilitation, and preoperative and postoperative laxity assessment at the same institution. Moreover, the impact on postoperative knee laxity of medial and lateral meniscus resection or suture were analyzed separately.

Limitations

The interobserver variability of the arthrometric evaluation is often discussed as a possible limitation. However, the KT-1000 arthrometer is the most commonly used tool to assess anterior knee laxity, and it is considered more precise compared with the clinical Lachman test,[2] offering a quantitative evaluation of the anterior tibial displacement. In addition, in the present study, all the physiotherapists who performed the laxity evaluations are specialized in sports medicine and very experienced with the use of the KT-1000 arthrometer, and the large cohort studied reduced the influence of this possible limitation.

The lack of details regarding extent and location of meniscal resection or repair is a limitation. Our registry does not contain this information. Thus, we cannot say with the present study if there is a part of the medial meniscus more important to preserve stability and if there is a minimum size of resection needed to impair stability. However, more than 75% of the medial meniscus tears, in patients undergoing ACL surgery, occur in the posterior horn.[39] The posterior horn is described as the most important portion in resisting anterior tibial displacement.[40] Larger resections or resections located in the posterior horn could have a greater influence on the postoperative knee laxity.

Furthermore, even if a fairly standardized surgical procedure for ACLR has been used at our institution, the study timeframe is long and it was not possible to do a thorough analysis of all the surgical variables that could have changed over time. Moreover, the follow-up period is short.

Another limitation is that we have only studied the risk factors for abnormal anterior knee laxity. The pivot shift test was not reported in a standardized manner in our registry, and for this reason, an assessment was difficult to perform. Moreover, evaluation of the pivot shift greatly depends on the clinician's subjective feeling and clinical skill level.[1] Thus, a high variability in laxity assessment is present among the examiners and a quantitative evaluation is very difficult.

A final limitation is the lack of data about other factors that may affect postoperative knee laxity, including knee range of motion and generalized ligamentous laxity.

Conclusions

Age less than 30 years, preoperative STS difference greater than 5 mm, HT graft, and medial meniscus resection are associated with increased risk of having abnormal anterior knee laxity 6 months after primary ACLR.

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