

Anatomic anterior cruciate ligament reconstruction: reducing anterior tibial subluxation

Bart Muller¹ · Eric R. H. Duerr² · C. Niek van Dijk¹ · Freddie H. Fu²

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Abstract

Purpose To measure and compare the amount of anterior tibial subluxation (ATS) after anatomic ACL reconstruction for both acute and chronic ACL-deficient patients.

Methods Fifty-two patients were clinically and radiographically evaluated after primary, unilateral, anatomic ACL reconstruction. Post-operative true lateral radiographs were obtained of both knees with the patient in supine position and knees in full passive extension with heels on a standardized bolster. ATS was measured on the radiographs by two independent and blinded observers. ATS was calculated as the side-to-side difference in tibial position relative to the femur. An independent *t* test was used to compare ATS between those undergoing anatomic reconstruction for an acute versus chronic ACL injury. Chronic ACL deficiency was defined as more than 12 weeks from injury to surgery.

Results Patients averaged 26.4 ± 11.5 years (mean \pm SD) of age, 43.6 % were female, and 48.1 % suffered an injury of the left knee. There were 30 and 22 patients in the acute and chronic groups, respectively. The median duration from injury to reconstruction for the acute group was 5 versus 31 weeks for the chronic group. After anatomic ACL reconstruction, the mean ATS was 1.0 ± 2.1 mm. There was no statistical difference in ATS between the acute and chronic groups (1.2 ± 2.0 vs. 0.6 ± 2.3 mm, n.s.). Assessment of inter-tester reliability

for radiographic evaluation of ATS revealed an excellent intraclass correlation coefficient of 0.894.

Conclusions Anatomic ACL reconstruction reduces ATS with a mean difference of 1.0 mm from the healthy contralateral limb. This study did not find a statistical difference in ATS between patients after anatomic ACL reconstruction in the acute or chronic phase. These observations suggest that anatomic ACL reconstruction, performed in either the acute or the chronic phase, approaches the normal AP relationship of the tibiofemoral joint.

Level of evidence IV.

Keywords ACL · Anterior tibial subluxation · Anatomic ACL reconstruction

Introduction

It has been established that ACL deficiency causes a passive alteration of the tibiofemoral relationship in the sagittal plane: the tibia subluxates anteriorly with respect to the femur, as can be objectified from MRI and radiographs [7, 17]. This anterior tibial subluxation (ATS) increases as time between injury and surgery increases and is positively correlated with instability [14].

Conventional non-anatomic ACL reconstruction techniques have proven unable to adequately reduce the tibia and therefore restore the native tibiofemoral relationship [1, 4]. Additionally, it was suggested that irreducible ATS could explain why OA still may develop in stable, reconstructed knees in spite of the improved stability [4].

Since conventional ACL reconstruction techniques fail to restore the native anatomy, biomechanics and knee kinematics [4, 6, 16], anatomic ACL reconstruction aims to more closely restore the native anatomy; consequently,

✉ Freddie H. Fu
ffu@upmc.edu

¹ Department of Orthopaedic Surgery, Academic Medical Center, University of Amsterdam, PO Box 22700, 1100 DE Amsterdam, The Netherlands

² Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, University of Pittsburgh, 3471 Fifth Avenue, Suite 1011, Pittsburgh, PA 15213, USA



Fig. 1 Patient positioning for radiography. **a** Patient supine, with the heels on a standardized bolster and knees in passive terminal extension. **b** Stabilization of the lateral malleoli with a foot support platform so that the hallux would point upwards, perpendicular to the table

the anatomic technique has been found to be significantly superior to conventional techniques with regard to patient-reported outcome measures and knee laxity testing [11, 18]. Although it is generally thought that anatomic ACL reconstruction sufficiently restores the tibiofemoral relationship, this has yet to be evaluated.

The purpose of this study was to assess the tibiofemoral relationship in the sagittal plane after anatomic ACL reconstruction and compare the anterior and rotational laxity (quantified using KT-1000 evaluation and pivot shift testing) with ATS (quantified using a standardized radiography protocol) for both acute and chronic ACL-deficient patients.

It was hypothesized that anatomic ACL reconstruction reduces ATS within 2.0 mm from the healthy contralateral side for acute ACL-deficient knees, but that chronic ACL deficiency would lead to fixed ATS irreducible with anatomic ACL reconstruction, thus resulting in a significantly greater degree of post-operative ATS in chronic versus acute ACL-deficient knees. Similarly, it was hypothesized that joint laxity would be greater for chronic ACL deficiency compared with acute ACL deficiency after anatomic ACL reconstruction.

Using a standardized and validated imaging technique after anatomic ACL reconstruction, this study was the first to compare the residual ATS for patients that were acutely and chronically ACL deficient. In contrast to what previous studies have found, chronic ACL deficiency does not appear to lead to a fixed altered tibiofemoral relationship, and anatomic ACL reconstruction may adequately reduce anterior tibial subluxation. Given the current trend in ACL reconstruction, these observations hold important implications regarding surgical technique. Further longitudinal studies are underway to compare the pre- and post-surgical tibiofemoral relationship.

Materials and methods

Fifty-two patients that had suffered an isolated ACL injury were seen in the outpatient clinic and retrospectively

evaluated at a minimum of 4 months after primary, unilateral, anatomic ACL reconstruction. All patients were without history of trauma or symptoms to the contralateral knee and without extension deficit of either knee.

With a higher occurrence of intra-articular pathology after 8–12 weeks of ACL deficiency [9, 13], chronic ACL deficiency was defined as 12 or more weeks between injury and surgery and under 12 weeks was regarded as acute ACL deficient [presented at 15th ESSKA Congress by Kaeding et al.: P19-782. Defining chronicity in an ACL deficient knee: When is a knee with an acutely torn ACL no longer “acute”?].

All patients underwent clinical examination. Antero-posterior (AP) laxity was evaluated by measuring the side-to-side difference of the KT-1000 arthrometer (MedMetric, San Diego, CA, USA) at 89 N manual force, and rotational laxity was determined by the clinical grade of the pivot shift test according to the IKDC criteria (grade 0–3).

At the same visit, radiographs were obtained of all patients, made according to a special protocol: patients were positioned in supine position on the radiography table, with the heels on a standardized bolster (part of KT-1000 arthrometer system) and knees in passive terminal extension. The lateral malleoli were stabilized with a foot support platform (part of KT-1000 arthrometer system) so that the hallux would point upwards, perpendicular to the table. The focal point-to-film was always one metre, with the cassette placed on the medial side of the knee. As such, true lateral knee radiographs were obtained bilaterally, using the healthy knee as the patient’s own control (Fig. 1).

Radiographs of the bilateral knees were loaded into Stentor (Stentor Inc., Brisbane, CA, USA), and measurements were taken by two blinded and independent observers, according to a previously described and validated technique [1, 2, 4, 7]. First, a line was drawn along the subchondral plate of the tibial plateau. At the most posterior aspect of the medial and lateral portions of the tibial plateau, lines were then drawn tangent to the cortex and perpendicular to the first line (Fig. 2a). The shortest distance from these lines to the most posterior cortical extent

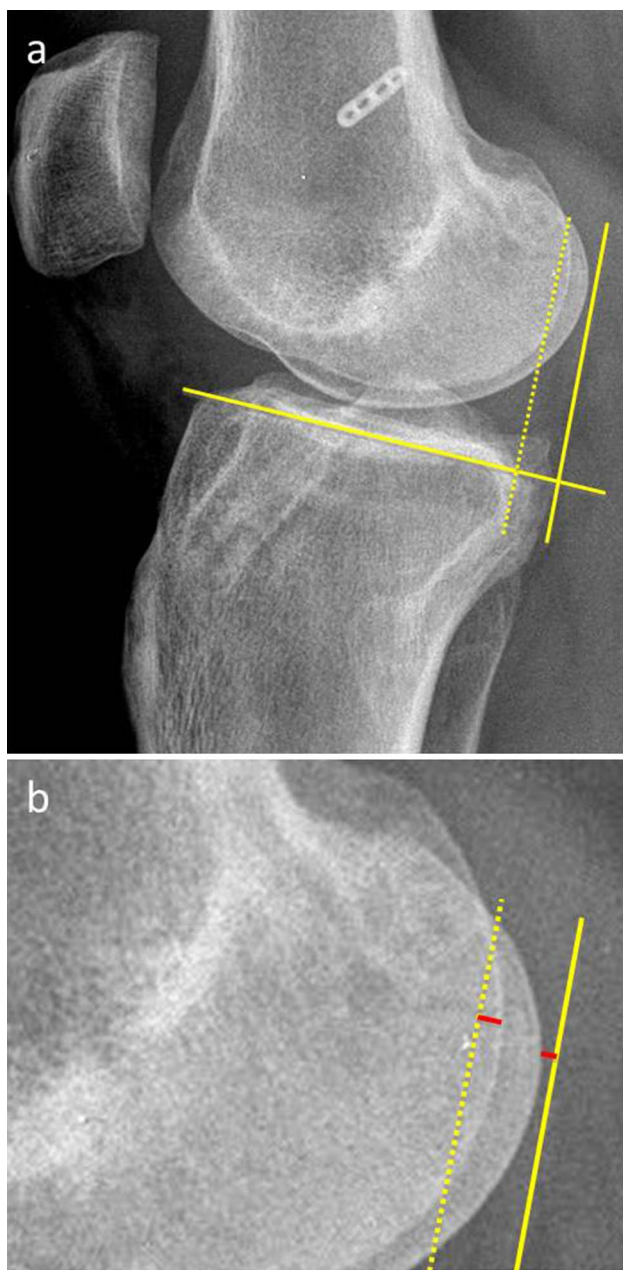


Fig. 2 ATs measurement technique. **a** First, a line along the subchondral plate of the tibial plateau was drawn, followed by *tangent lines* at the most posterior aspects of both the medial (*solid line*) and lateral (*dashed line*) portions of the tibial plateau. **b** Then, the distance was measured (*red lines*) relative to the position of the medial and lateral femoral condyles. ATs was subsequently calculated relative to the uninjured limb

of the respective femoral condyles was measured (Fig. 2b). To correct for potential, minimal rotation on the radiographs, the values for the medial and lateral side were averaged—positive values indicated that the posterior margin of the tibia was anterior to the most posterior extent of the femoral condyles and negative values indicated a posterior

Table 1 Results

		Acute	Chronic	<i>P</i> value
Demographics	Age (years)	23.1 ± 9.3	30.8 ± 13.0	0.024
	Female	12 (40 %)	6 (27 %)	n.s.
Technique	SB	17	16	n.s.
	DB	13	6	
Graft type	Quad	23	12	n.s.
	Soft tissue	7	10	
Graft source	Auto	28	14	0.003
	Allo	1	8	
	Hybrid	1	0	
Surgery follow-up (weeks)		35 ± 13	34 ± 13	n.s.

position of the tibia relative to the femoral condyles. ATs was then calculated as the side-to-side difference in tibial position relative to the femur. The measurements were not normalized using the size of the tibia to account for differences in magnification, as described previously. The absolute measurement in millimetres was used for this study because a standardized radiographic technique was used for each subject, which minimizes variability in magnification.

For both the acute and chronic groups, the graft type and technique, ATs and laxity-test measurements were recorded and analysed. All data were recorded in a Microsoft Excel spreadsheet (Microsoft, Redmond, WA, USA).

Exempt institutional review board (IRB) approval was obtained from the University of Pittsburgh under IRB number PRO12020619 to use clinical and imaging data from a research registry of patients presenting to the senior author (F.H.F.) for ACL evaluation.

Statistical analysis

Statistical analysis was performed with independent *t* tests and Chi-square tests to assess the equality of means (PASW Statistics 18, IBM Corp, Armonk, NY, USA). Statistical significance was set at a *p* value <0.05.

Post hoc power analysis for a clinically relevant difference of 2.0 mm (α value of 0.05) was performed.

Additionally, to assess inter-observer reliability, the intraclass correlation coefficient (ICC) was calculated.

Results

The results are summarized in Tables 1 and 2. Patients averaged 26.4 ± 11.5 years (mean \pm SD) of age, 43.6 % were female, and 48.1 % suffered an injury of the left knee. Thirty patients were operated in the acute stadium (median = 5, range 1–11 weeks) and 22 in the chronic stadium (median = 31, range 12–1627 weeks). Nineteen

Table 2 Results at follow-up

		Acute	Chronic	<i>P</i> value
KT-1000	(mm)	1.3 ± 1.4	1.1 ± 1.1	n.s.
Pivot shift	None	27	21	n.s.
	Glide	3	1	
ATS	(mm)	1.2 ± 2.0	0.6 ± 2.3	n.s.

patients had an anatomic double-bundle (DB) ACL reconstruction, and 33 had an anatomic single-bundle (SB) ACL reconstruction. Thirty-five patients underwent ACL reconstruction with a quadriceps graft with bone block and 17 patients with a soft tissue graft. Forty-two of the grafts used were autografts, nine were allografts, and one graft was a hybrid graft (autograft and allograft). Time from surgery to radiography was 34 ± 13 weeks on average.

There were no significant differences between the acute and chronic groups with respect to demographics and surgical details except for age (older chronic group, $p = 0.024$) and graft source (more allograft use in chronic group, $p = 0.003$) (Table 1).

At a minimum of 4 months after surgery, none of the patients had an extension deficit, and a mean ATS of <2.0 mm (1.0 ± 2.1 mm) was calculated for all patients included in the study. This finding was consistent for both the acute (1.2 ± 2.0 mm) and chronic (0.6 ± 2.3 mm) groups. The mean difference of 0.6 mm ATS between groups was regarded neither clinically nor statistically significant (n.s.). Knee laxity testing revealed a mean KT-1000 side-to-side difference of <3.0 mm for all patients (1.2 ± 1.3 mm). This finding was consistent for both the acute (1.3 ± 1.4 mm) and chronic (1.1 ± 1.1 mm) groups. None of the patients had a pivot shift test greater than grade 1. In the acute group, 27 patients had no shift at all (grade 0) and three patients a gliding shift (grade 1). In the chronic group, 21 patients had no shift at all and one patient a gliding shift. The mean difference of 0.2 mm in AP laxity between groups was not significant (n.s.), and neither were the differences in rotational laxity (n.s.) (Table 2).

Post hoc power analysis revealed that, with this sample size, a clinically relevant difference of 2.0 mm (α value of 0.05 and the derived SD of 2.1) could be detected with a power of $>85\%$.

As an indication for inter-observer reliability, an ICC of 0.894 (95 % CI 0.819–0.938) was calculated, which was regarded excellent (>0.750).

Discussion

The most important finding of this study was that anatomic ACL reconstruction reduces ATS with a mean difference

of 1.0 ± 2.1 mm anteriorly from the healthy contralateral limb, which validates the hypothesis that anatomic ACL reconstruction reduces the mean ATS to <2.0 mm. Additionally, the results of this study indicate that ATS and knee joint laxity after anatomic ACL reconstruction are not significantly different for both acute and chronic ACL-deficient patients. Thus, the results of this study do not support the hypothesis that ATS and knee joint laxity in chronic patients are significantly greater than in acute patients after anatomic ACL reconstruction.

DeJour et al. [5] were the first to describe the occurrence of translation of the tibia in ACL-deficient patients on lateral radiographs. They concluded that rupture of the ACL allowed for the tibia to translate anteriorly and that lateral radiography was useful in diagnosis.

After this finding, different radiography and MRI techniques were developed to objectify ATS as a secondary sign of ACL injury [7, 8, 14, 15, 17]. It was found that measuring ATS is an accurate way to diagnose rupture of the ACL and that there is a positive correlation with the duration of ACL deficiency [7, 8, 17].

Mishima et al. [14] indicated that ATS, in ACL-deficient knees, increases over time and is positively correlated with AP instability. This led them to conclude that ACL-deficient knees have pathologic tibiofemoral kinematics without external force and that the extent relates to the duration of ACL deficiency and instability.

Using the measurement technique that Franklin et al. [7] had developed, Almekinders et al. [3] found fixed ATS that could not be reduced by an external posterior force on the tibia after failed (conventional) ACL reconstruction. Moreover, Almekinders and de Castro [1] reported that even after successful conventional ACL reconstruction, the tibiofemoral relationship was not normalized and there was residual fixed ATS observed with stress radiographs. They rightfully stated: “if this phenomenon is confirmed in further studies, it could seriously bring into question our approach and reported outcome of ACL reconstruction”. In a follow-up study, Almekinders et al. [4] found that irreducible ATS remains after conventional reconstruction of the ACL. Stress radiography showed a maximum anterior translation of 9.0 ± 4.5 mm for ACL deficiency, 4.8 ± 3.8 mm after ACL reconstruction and 0.4 ± 2.3 mm for uninjured knees.

This study, however, found a remaining anterior subluxation of 1.0 ± 2.1 mm after anatomic ACL reconstruction. Although it has not been established what an acceptable remaining ATS would be after ACL reconstruction, 1.0 ± 2.1 mm ATS does appear to be a closer approximation of the normal tibiofemoral relationship (uninjured knees: 0.4 ± 2.3 mm, [4]) than previous studies were able to demonstrate.

Previous studies suggested that the fixed ATS may in part be due to restricted posterior translation [4]. However,

since the most fundamental difference between this study and previous studies is the surgical technique, these results suggest that the reported irreducibility may also in part have been due to non-anatomic tunnel placement. Additionally, since tibial reference points may shift relatively to the femur, it only seems appropriate to not use these reference points, but rather the insertion sites and (bony) landmarks on each respective bone as reference points to position the tunnels [12]. Performing surgery in an anatomic fashion seems to adequately reduce the tibia with respect to the femur and may therefore also obviate additional surgical interventions such as notchplasty, as was recently suggested [19]. This is consistent with a study by Hatayama et al. [10] showing that more anterior placement of the tibial tunnel results in significantly more reduced post-operative anterior tibial translation after anatomic ACL reconstruction than posterior placement does without increasing the risk of post-operative loss of extension or graft failure.

There are some limitations to this study. The first limitation is that this study was performed under static conditions and was limited to sagittal plane movement. Dynamic data would certainly be helpful to assess how this altered tibiofemoral relationship affects actual three-dimensional movement. Another limitation is that this study only addressed the post-operative situation and therefore it is uncertain whether pre-operative subluxation changes after surgery or not. We are currently prospectively recruiting patients at our institution to compare the pre- and post-surgical tibiofemoral relationship in a separate study. A minor limitation of this study is the lack of randomization. Some statistical differences between the two groups (i.e. graft choice and age) might not have occurred if groups were randomized, but it remains questionable whether these factors would have influenced the outcome measures for this particular study. Also, the differences between the two groups are likely the direct result of the individualization of our treatment: younger patients have on average a more active lifestyle and will thus be operated in an earlier stage. Vice versa, older patients are more compliant with conservative treatment and will therefore be operated in a later stage. A similar argument can be made for the higher allograft use in the chronic group; since there are older patients in the chronic group—who also are more compliant with the post-operative protocols and thus have a lower re-tear rate—the use of allograft is more often preferred.

The findings of this study suggest that anatomic ACL reconstruction adequately (<2.0 mm) restores the tibiofemoral relationship in the sagittal plane in both acute and chronic ACL-deficient patients and that operating in either stadium yields similar, near-normal results (no statistical difference). For clinical practice, this means that—when performing ACL reconstruction in an anatomic fashion—it does not matter whether surgery is performed in the acute

or chronic phase with respect to restoration of the tibiofemoral relationship in the sagittal plane.

Conclusions

This is the first study to investigate the tibiofemoral relationship in the sagittal plane in addition to overall knee stability after anatomic ACL reconstruction. With a standardized imaging protocol and validated reliable measurement technique, under static conditions, without externally applied force, it was found that anatomic ACL reconstruction restores the tibiofemoral relationship within 1.0 mm on average from the contralateral, healthy knee. Operating in the acute or chronic phase does not yield different results with respect to reducing ATS or knee laxity.

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