Can rotatory knee laxity be predicted in isolated anterior cruciate ligament surgery?

Nicola Lopomo · Cecilia Signorelli · Tommaso Bonanzinga · Giulio Maria Marcheggiani Muccioli · Maria Pia Neri · Andrea Visani · Maurilio Marcacci · Stefano Zaffagnini

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Abstract

Purpose Despite the overall success of the surgical anterior cruciate ligament (ACL) reconstruction, some patients still present with instability symptoms even after the surgery, mainly due to the presence of associated lesions. At present, the pivot shift test has been reported to be the benchmark to assess rotatory knee laxity. The purpose of this study was to quantitatively evaluate rotatory knee laxity at time-zero in order to determine whether detected post-reconstruction laxity was predictable by its value measured before the reconstruction, which was hypothesized to be influenced by the presence of associated lesions.

Methods Rotatory knee laxity was retrospectively analysed in 42 patients, including two different ACL reconstructions. The maximal anterior displacement and the absolute value of the posterior acceleration reached during the reduction of the tibial lateral compartment were intra-operatively acquired by using a navigation system and identified as discriminating parameters. For each parameter, statistical linear regression

analysis (line slope and intercept) was performed between pre- and post-reconstruction values.

Results No statistically significant influence of the initial posterior acceleration on the post-reconstruction outcome was found (line slope, $p>0.05$), although a statistically significant line intercept was indeed identified ($p<0.001$). A statistically significant influence on the surgery outcome was instead found for the initial value of the anterior tibial displacement (line slope=0.39, $p=0.004$), meaning that, on average, about 40 % of the post-reconstruction lateral compartment displacement could be explained by the corresponding pre-reconstruction value. Both of these findings highlighted the importance of intra-operative quantification of rotatory knee laxity to identify correct indications for the surgery.

Conclusions This study provided important implications for the future possibility of defining a quantifying tool able to assess rotatory knee laxity during ACL reconstruction. This could allow detection of additional injuries to secondary restraints by easily performing rotatory knee laxity tests, which in turn could reduce post-surgical recurrence of knee instability.

N. Lopomo (✉) · C. Signorelli · T. Bonanzinga ·
G. M. Marcheggiani Muccioli · A. Visani · M. Marcacci ·
S. Zaffagnini

Laboratorio di Biomeccanica e Innovazione Tecnologica, Istituto
Ortopedico Rizzoli, Via di Barbiano 1/10, 40136 Bologna, Italy
e-mail: n.lopmo@biomec.ior.it

N. Lopomo
Laboratorio di NanoBiotecnologie-NaBi, Istituto Ortopedico Rizzoli,
Bologna, BO, Italy

C. Signorelli
Dipartimento di Elettronica, Informazione e Bioingegneria,
Politecnico di Milano, Milano, MI, Italy

T. Bonanzinga · G. M. Marcheggiani Muccioli · M. P. Neri ·
M. Marcacci · S. Zaffagnini
II Clinica Ortopedica e Traumatologica, Istituto Ortopedico Rizzoli,
Bologna, BO, Italy

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Introduction

Despite the overall success of anterior cruciate ligament (ACL) reconstruction—which generally reports from good to excellent results in terms of functional outcomes [1–4]—some treated subjects continue to complain about their knee instability even after the surgery [5, 6]. The symptoms have been reported to be frequently associated with residual laxity,

which are mainly due to the presence of combined lesions, affecting also collateral ligaments and menisci [7]. Because of this combination, this residual laxity may not be eliminated by an isolated ACL reconstruction [3, 8]. Moreover, the implanted ACL graft could be subjected to additional stress due to this residual laxity, which might be responsible for a premature loosening of the graft itself and, therefore, for the need of a revision procedure. In any case, controversy exists regarding the importance of pre-reconstruction knee laxity as a potential risk factor for ACL reconstruction failure [1, 9, 10] and knee soft tissue damage [11].

In clinical practice this residual laxity is usually identified as rotatory knee laxity and could be evaluated using the pivot shift (PS) manoeuvre [12–15]. This clinical test tries to reproduce the knee pathomechanics by applying a combination of standardized rotational stresses [16–18]. Scientific literature reports many parameters that could be used in the quantitative analysis of the PS test [18] based on different technologies. The most important attention should be focused on the lateral tibial compartment, being the one mainly affected by the PS phenomenon [10, 19]. In 2010 Lopomo et al. specifically demonstrated the translation of the lateral compartment as a reliable index which can be used in the clinical assessment of rotational instability [19]. Moreover, in 2008 Kuroda et al. also analysed the acceleration reached by the lateral compartment during tibial reduction [20].

From a clinical point of view, the PS test has been reported to be more specific than other clinical tests (i.e. Lachman and drawer) in detecting ACL lesion [21] and to correlate more closely with subjective instability [2], reduced sport activity [22], articular cartilage damage and meniscal damage [23].

Recently, Signorelli et al., focusing on knee static and global laxities, reported the importance of combined lesions on secondary restraints, stressing a full understanding of the residual laxity to optimize the surgical technique [8].

Up to now, literature has not reported any study, performed at time zero, on the influence of pre-operative rotatory knee laxity on the post-reconstruction outcome.

Indeed, identifying from a quantitative point of view, the relationship or the correlation between pre- and post-reconstruction conditions in terms of rotatory knee laxity could be extremely useful to understand how an isolated ACL reconstruction could work even considering secondary lesions and, in a future perspective, to define the first steps in osteoarthritis (OA) prevention.

The main hypothesis of this study relied on the idea that those knees presenting higher values of rotatory knee laxity—quantified through specific parameters—remain higher after isolated ACL reconstruction because of untreated combined lesions. The main goal of this study was therefore to retrospectively investigate whether there was a relationship between the pre-reconstruction rotatory knee laxity and the post-reconstruction one, i.e. whether the post-reconstruction

rotatory knee laxity could be fully or partially explained or somehow predicted by the corresponding pre-reconstruction values, due to the presence of untreated lesions on secondary restraints.

Materials and methods

Patient selection

This study was conducted as a retrospective analysis performed on all the patients who underwent primary navigated ACL reconstruction in the Institute over a five-year period (2009–2013). After the assessment of exclusion criteria—which included bilateral knee injuries, prior ligament surgery, evident restriction of knee range of motion, high generalized joint laxity, severe chondral defects and knee degenerative changes—the cases reporting the evaluation of PS test before and after ACL reconstruction were included in the preliminary recruitment step. Out of these cases—after mining any statistical difference in surgical techniques, as hereinafter described—we chose to include only two different ACL reconstructions in order to avoid possible biases given by the reconstruction itself, thus finally recruiting a total of 42 procedures for the analysis.

Both the reconstructions were performed by the senior author (SZ), using a single bundle with an over-the-top fixation of the graft (SB+LP) [24] and an over-the-top single bundle plus lateral plasty (DB-OTT) [25]. Twenty-one patients were identified in SB+LP procedures and 21 in the DB-OTT procedure. Neither details about additional lesions, including meniscal and ligamentous lesions, nor deep analysis of the differences between the two surgical techniques were here reported, as they were not the focus of this study.

All the acquisitions were previously approved by the Internal Review Board covering several studies, and the patients provided their informed consents to data treatment.

Kinematic acquisition

A commercial navigation system dedicated to intra-operative kinematic assessment (BluIGS/KLEE, Orthokey LLC, Delaware, DE, USA) was used to acquire limb kinematics, following the procedure describe by literature [26]. Reliability analysis of the navigated procedure used to quantify rotatory knee laxity was previously reported [19]. The pivot-shift test was intra-operatively performed on each analysed limb, following the standardized manoeuvre as described by Hoshino et al. [27]. The kinematic assessment was specifically conducted just before and after fixing the graft. In order to avoid any bias, all the tests were blinded and performed by the same senior surgeon (SZ), who did all the surgeries as well.

Data analysis

Following literature, the maximal anterior displacement of the lateral tibial compartment (DISPLACEMENT) and the posterior acceleration reached by the lateral compartment during tibial reduction, considered as an absolute value (ACCELERATION) [12, 28], were specifically evaluated for each acquisition. All the data were off-line analysed in order to decompose the limb kinematics and identify each useful kinematic component [29].

Statistical analysis

Lilliefors test was performed to verify whether the analyzed laxity parameters (ACCELERATION and DISPLACEMENT) came from normally distributed populations, without specifying the expected value and variance of the distribution. Due to the inherent nature of the data (asymmetry caused by considering the absolute values), the analyzed data was found to be not normally distributed and, for this reason, non-parametric statistical tests were implemented.

Two-sample Kolmogorov-Smirnov (K-S) non-parametric test was used to verify the probability distribution equality between the two included ACL reconstructions, by analysing the empirical cumulative distribution functions and data distribution for each analysed parameter in both pre- and post-reconstruction conditions.

Linear regression analysis was performed between pre-reconstruction laxity values (as independent variable) and post-reconstruction ones (as dependent variable), considering each reconstruction technique separately and the whole dataset, respectively. The slope of the lines allows us to establish if a high pre-operative value implies a high laxity level even post-operatively. Specifically, the closer to 0 the slope value, the more the post-operative outcome is unaffected by the initial laxity. On the other hand, the closer the slope gets to 1, the more the post-reconstruction outcome is dependent on the initial laxity. For each linear regression estimator the corresponding confidence intervals at 95 % (CI 95 %), R^2 and the statistics were also reported.

All the data and statistical analyses were performed using Matlab (The Mathworks Inc, USA).

Results

From K-S test, no statistical differences in probability distribution were found between SB+LP and DB-OTT techniques in both pre- and post-operative conditions (all p values >0.05). Corresponding p values are reported in Table 1.

Performed linear regressions are reported in Fig. 1, whereas slope and intercept values, corresponding CI 95 %, R^2 and statistics are reported for each parameter in Table 2.

Discussion

The most important finding of this study was to have analysed the influence of pre-reconstruction rotatory knee laxity in isolated ACL reconstructions, highlighting any possible relationship between pre- and post-reconstruction values, without specifically focusing on the type of secondary lesions present in the joint. Literature reported that the PS test is considered the clinical test most suitable to highlight the rotational behaviour of the knee joint, involving multiple degrees of freedom [10, 30]. In this study, we retrospectively analysed rotatory knee laxity, quantifying the PS test during two different ACL reconstructions by means of a commercial navigation system.

In general, we could consider the whole acquired dataset and not each single reconstruction (i.e. SB+LP and DB-OTT) for two different reasons. First of all, despite the not normal distribution of the data (including ACCELERATION and DISPLACEMENT), two-sample K-S test confirmed the probability distribution equality between the two reconstructions. Secondly, the mean value of each parameter predictor reported in the linear regression analysis (i.e. line slope and intercept) for one specific reconstruction are included in the CI 95 % of the other one. This finding implies that there was no statistical difference between the two reconstructions for what concerns this analysis, confirming the possibility of using the whole dataset.

Specifically concerning the linear regression analysis, we found that the ability of linear models to correctly fit the data was poor to fair, mainly due to the high variability of the values. Low R^2 values are however quite common in any attempt to predict human behaviour.

In any case, for what concerned the posterior acceleration of the lateral tibial compartment, we found no statistically significant influence of the initial laxity on the post-reconstruction outcome (line slope, $p>0.05$), but a statistically significant intercept ($p<0.001$). This means that regardless the pre-reconstruction value of the posterior acceleration, after the surgery you can not reach a value lower than about 250 mm/s², which therefore can be considered, at large, as a threshold for the lateral compartment acceleration whenever you perform an isolated ACL reconstruction. This threshold value is slightly lower when compared to what was highlighted by Kuroda et al. [20] and Lopomo et al. [31] for ACL-intact knees, probably because this threshold is only theoretical and perhaps not associable to any real knee condition and, above all, because the acquisition systems were different (skin-fixed versus bone-fixed ones).

On the other hand, as far as the anterior tibial displacement is concerned, we found a greater influence of the initial anterior tibial displacement on the surgery outcome. The line slope was found to be 0.39 ($p=0.004$), with the CI 95 % upper bound equal to 0.65. Following the definition of linear

Table 1 *P* values for two-sample Kolmogorov-Smirnov (K-S) performed between single-bundle plus lateral plasty (SB+LP) and double-bundle over-the-top (DB-OTT) techniques in each condition and for each analysed parameter

P value	Acceleration		Displacement	
	Pre-reconstruction	Post-reconstruction	Pre-reconstruction	Post-reconstruction
<i>p</i>	0.531	0.797	0.797	0.797

regression, this finding means that an average of about 40 % of the variability identified in the anterior tibial displacement associated to post-reconstruction rotatory knee laxity could be explained by the corresponding pre-reconstruction values.

Therefore, as a first step towards the identification of any provisional parameter for post-operative ACL surgery outcome, we suggested to focus the analysis on the association between pre- and post reconstruction values of the lateral compartment anterior displacement in rotatory knee laxity highlighted during the PS test.

At time zero, the optimal reconstruction surgery for knee laxity after ACL injury nonetheless remains a complex issue and the appropriate surgical treatment can only be determined according to the knee joint status, as diagnosed before and during surgery. In this perspective, this study highlighted the importance of an intra-operative quantification of rotatory knee laxity in order to identify correct indications for the surgery itself, including the possibility of customising the reconstruction technique for each patient, including also additional surgical procedures, such as the introduction of a lateral plasty or the intervention on a collateral ligament.

In 2013, Signorelli et al. already investigated the pre-operative-to-postoperative relationship but concerning static laxity [8]. The anterior-posterior displacement values were shown as having a weak influence on the post-operative outcome of pre-operative laxity during Lachman and drawer tests, contrary to what was found in the present study. This suggests that the static laxity can be reduced by an isolated ACL reconstruction, no matter what the initial condition of the joint is.

Furthermore, supporting the validity of analysing PS test, in 2010 Yamamoto et al. also demonstrated a positive correlation between clinical grading and antero-posterior displacement during the PS test, while there was no correlation between clinical grading and tibial rotation [32]. In 2008, Lane et al. noted a good correlation between the clinical grade of PS and tibial rotation, anterior tibial translation and acceleration of posterior translation [33]. In 2010, also Lopomo et al. demonstrated that the displacement of the lateral tibial compartment during the PS test is consistent with the IKDC score [19]. Summarizing the hypothesis, we know from literature that: (1) the clinical grade of the PS better correlates with

Fig. 1 Linear regression analysis. The whole dataset is reported, highlighting the SB+LP and DB-OTT groups, the corresponding regression line (straight lines) and the confidence intervals at 95 % (dashed lines). Black lines correspond to the analysis considering the whole dataset

Table 2 Linear regression analysis. Values of line slope and intercept, the corresponding confidence intervals at 95 %, R^2 and statistics for each analysed parameter are reported. Intercept values for acceleration are inmm/s², whereas for displacement they are in mm. Slope values, p -values, and R^2 are nondimensional

Measure		Acceleration			Displacement		
		All	SB+LP	DB-OTT	All	SB+LP	DB-OTT
Slope	Value	0.06	−0.01	0.21	0.39	0.38	0.42
	CI 95 %	[−0.14, 0.26]	[−0.28, 0.25]	[−0.16, 0.55]	[0.13, 0.65]	[−0.03, 0.78]	[0.05, 0.79]
	p	0.558	0.910	0.261	0.004*	0.065	0.027*
Intercept	Value	236.81	269.01 mm/s ²	181.44 mm/s ²	2.47 mm	3.22 mm	1.25 mm
	CI 95 %	[119.61, 354.01]	[99.91, 438.11]	[−3.77, 366.66]	[−3.31, 8.26]	[−5.52, 11.96]	[−7.34, 9.84]
	p	<0.001*	0.004*	0.054	0.392	0.450	0.763
R^2		0.01	<0.01	0.07	0.19	0.17	0.23

* $p < 0.05$

functional outcome and the development of OA after ACL reconstruction surgery [21, 34, 35] compared to Lachman and drawer tests [10, 36]; (2) the anterior displacement of the lateral compartment correlates to IKDC grading during PS test; and (3) the pre-operative anterior displacement can therefore provide an indication of possible OA development after ACL surgery; (4) about one half of the patients with higher values of the lateral compartment anterior displacement may maintain higher values also after isolated ACL reconstruction. Therefore, in extrema ratio, we could suggest that the quantification of the anterior displacement of the lateral compartment during PS test could be identified as a possible quantitative provisional parameter able to indicate the susceptibility to OA onset.

However, the complexity of the results confirms that the interpretation of the PS test and the individualization of a valid parameter to quantify its results clearly remain the main problems in using such kind of test. Nevertheless, despite the introduction of non-invasive systems [17, 31], it is still unclear which measurement devices should be reliably used for a quantitative PS evaluation during in-office evaluation [18]. Hence, it may be beneficial to provide patients with the correct information to help manage their expectations.

The present study however has some limitations. Even including all the available patients, the sample size is not extremely large, limiting the generalizability of the results. Second, although the PS manoeuvre was performed following the same indications [27] for a whole set of patients, the load required to elicit the pivot shift is critical and variable between patients, this in turn affects the possibility of comparing the results in assessing instability attributable to ACL injury. Moreover, the study is based on manual clinical examination and consequently there is a lack of consistent stress loading among the patients. Third, the knees were evaluated immediately after surgery, and therefore the results represent time-zero conditions.

In the future, increasing the number of patients and including their grouping following combined lesions would allow to analyse the influences of these. Moreover, a coupled prospective study on patients presenting a high value of lateral compartment anterior displacement would establish if they are the same as those who develop OA at short- and long-term follow-up.

Conclusions

From a clinical point of view it would be extremely important to verify whether patients presenting pre-operatively higher rotatory knee laxity values maintain higher values even after the ACL reconstruction. The finding of this article pointed out the importance of combined lesions to secondary restraints in isolated ACL reconstruction even from the point of view of rotatory knee laxity acquired during PS test. This information together with what was reported by Signorelli et al. [8] is extremely useful to define a comprehensive understanding of all the damaged structures in the setting of an ACL reconstruction. Furthermore, considering and measuring pre-operatively the knee laxity would underline the necessity to perform additional stabilization procedures in order to protect the graft itself to excessive stress and the joint cartilage as well. In the future the quantification of rotatory knee laxity will allow to perspective identify several pathological laxity thresholds that can highlight the need for an integration of ACL surgery and peripheral procedures. Furthermore, future efforts will be required to explore the effects of the residual laxities during short- and long-term follow-up, in order to also give quantitative prognostic values to the pre-operative acquisition.

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