

Anterior cruciate ligament reconstruction and return to sport activity: postural control as the key to success

Rocco Papalia · Francesco Franceschi · Andrea Tecame ·
Stefano D'Adamio · Nicola Maffulli · Vincenzo Denaro

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Abstract

Purpose The risk for re-tear following anterior cruciate ligament (ACL) reconstruction is influenced by several hormonal, neuromuscular, biomechanical and anatomic factors. One of the most important negative prognostic factors that markedly increase the risk for ACL re-tear is the presence of high knee-abduction moment (KAM), which can be measured immediately by landing on both feet after a vertical jump. We evaluated the effect in postoperative values for KAM according to the type of graft used for ACL reconstruction (hamstring vs patellar tendon) and a specific rehabilitation protocol focusing on recovery of muscular strength, proprioception and joint stabilisation.

Methods From November 2010 to September 2012, we enrolled 40 female recreational athletes with clinical and imaging evidence of ACL tear and randomised them in two groups. One group of patients underwent reconstruction with a hamstring-tendon graft and the second with a patellar-tendon graft. A custom rehabilitation programme focusing on proprioception was adopted. Clinical outcomes [International Knee Documentation Committee (IKDC) and Lysholm scores] and performance in functional test for stability (single-leg hop,

timed hop, crossover triple hop, KAM test) were assessed preoperatively at three and six months postoperatively.

Results All patients showed statistically significant clinical improvements postoperatively when compared with preoperative values ($P < 0.0001$). No significant intergroup difference was observed in all clinical scores and functional tests, with the exception of the value registered for the KAM test ($P < 0.0001$).

Conclusions ACL reconstruction using patellar-tendon graft followed by rehabilitation centred on strength, proprioception and stability restoration can produce satisfactory values for KAM within the physiological range. The surgical strategies should be adapted to the patient on the basis of a multidisciplinary approach.

Keywords ACL · Reconstruction · Semitendinosus and gracilis · Patellar tendon · Rehabilitation · KAM

Introduction

Biomechanical, neuromuscular, psychological, hormonal and anatomical factors all impact on the risk of developing anterior cruciate ligament (ACL) tears [1–5]. In particular, epidemiological data show that women are particularly at risk for re-tear following ACL reconstruction [6, 7]. Biomechanical studies focusing on the knee-abduction moment (KAM), an index of knee stability, report that the higher the KAM value, the greater the risk of ACL re-tear [7–9]. Several factors influence KAM values; the most important are knee valgus moment, range of motion (ROM) in knee flexion, body mass, tibial length and quadriceps:flexor muscle ratio [8]. In women, KAM values are physiologically higher than in men [10], possibly (at least partially) explaining the higher incidence of re-tear in women. If using autologous semitendinosus and gracilis tendons as the graft for ACL reconstruction, the

R. Papalia · F. Franceschi · A. Tecame · S. D'Adamio · V. Denaro
Department of Orthopaedic and Trauma Surgery, Campus
Bio-Medico University of Rome, Via Alvaro del Portillo 200, Rome,
Italy

N. Maffulli (✉)
Department of Musculoskeletal Disorders, Faculty of Medicine and
Surgery, University of Salerno, 84081 Baronissi, Salerno, Italy
e-mail: n.maffulli@qmul.ac.uk

N. Maffulli
Centre for Sports and Exercise Medicine, Barts and The London
School of Medicine and Dentistry, Mile End Hospital, 275 Bancroft
Road, London E1 4DG, UK

harvest can alter the ratio of strength between knee extensor and flexor muscles, resulting in even higher postoperative KAM values in these patients [11].

The definitive aim of the study was to compare the KAM values assessed in different patients to evaluate the possible different effects of the two surgical approaches (reconstruction using semitendinosus and gracilis vs patellar tendon) on knee stability restoration. Along with this primary intention, we attempted to verify the hypothesis of no difference in functional score [International Knee Documentation Committee (IKDC) and Lysholm score] in patient undergoing ACL reconstruction using either semitendinosus and gracilis or patellar tendon as graft choice in a population of female recreational athletes. We also aimed to verify whether a rehabilitation protocol based on recovery of knee proprioception and postural control can improve postoperative KAM values compared with a historical control group in which a standard rehabilitation protocol was followed after surgery.

Materials and methods

Patients studied were recreational female athletes with a symptomatic, complete ACL tear detected on clinical (positive Lachman and pivot shift tests [12]) and imaging: lateral and anteroposterior (AP) weight-bearing radiographs to detect fractures, osteoarthritis grading and varus–valgus malalignment assessment; MRI to evaluate lesions to the ACL, cartilage, menisci and other knee ligaments.

Patients were all scheduled to undergo ACL reconstruction using a semitendinosus and gracilis or patellar tendon graft, followed by a standardised postoperative rehabilitation programme for 24 weeks. Patients requiring concomitant surgical management of meniscal lesions were also included in the study. Exclusion criteria were history of previous surgery on either knee, detection of cartilage lesions or osteoarthritic changes (joint-space narrowing >50 % in any compartment), multiligamentous involvement [posterior cruciate ligament (PCL), lateral collateral ligament (LCL), medial collateral ligament (MCL), posterolateral corner], concomitant ipsilateral leg fracture and cardiovascular disease.

A total of 73 consecutive female recreational athletes operated at our institution between 2010 and 2012 met our inclusion criteria. However, 13 patients did not want to participate in the study, five had a grade III or IV chondral lesion, seven had multiligamentous injury and eight had positive history of surgery to the same knee; these patients were excluded. Ultimately, 40 patients were considered eligible for the study. The Consolidated Standards of Reporting Trials (CONSORT) flowchart [13] for this trial is presented in Fig. 1. Patients were then randomised into two groups using a

computerised combination generator operated by an investigator with no clinical involvement in the trial (SD). The first group consisted of patients who underwent ACL reconstruction using semitendinosus and gracilis tendon grafts (STG group); the second group consisted of patients undergoing ACL reconstruction using the middle third of the patellar tendon for reconstruction [bone–patellar tendon–bone (BPTB) group].

All patients played either football ($N=16$), volleyball ($N=8$) or basketball ($N=16$). Although they all participated in sports before the accident, significant differences were found given the different types of training, intensity and physical load between required for the different sports. Mean follow-up was 12 months; mean interval of time from injury to surgery was 84 days [standard deviation (SD) ± 20 , 95 % confidence interval (CI) 64–104] for the STG group and 89 days (SD ± 27 , 95 % CI 72–100) for the BPTB group. Prior to data collection, each athlete read and signed an informed consent to participate in the study, which was approved by our Institution ethics committee. The study was conducted at the Department of Orthopaedic and Trauma Surgery of the Campus Bio-Medico University Hospital in Rome.

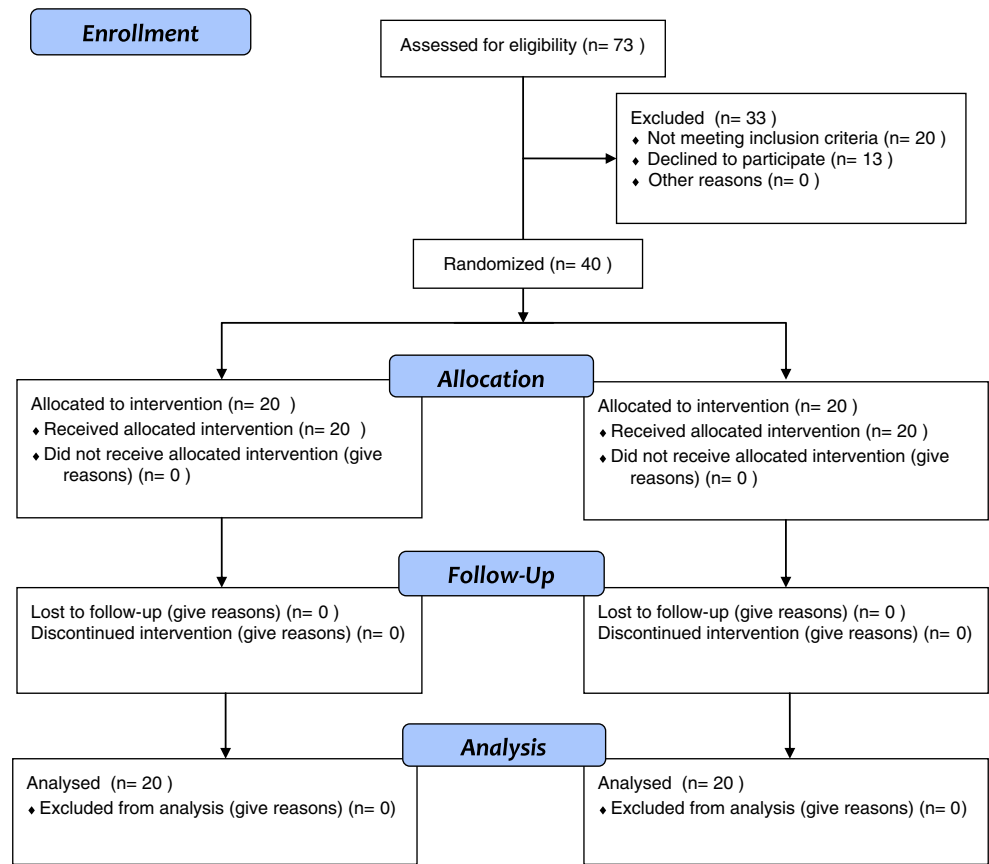
Operative findings and surgical technique

All patients were operated by two experienced orthopaedic surgeons (RP and FF) who performed routine ACL reconstructions using the transtibial technique [11, 14]. At diagnostic arthroscopy, all 40 patients were confirmed to have complete ACL tears. In the STG group, six underwent partial meniscectomies (three medial and three lateral) and three medial meniscus repair for a red–red zone tear. In the BPTB group, six patients underwent partial meniscectomies (three medial and three lateral) and two a meniscal repair: one for a red–red zone and one for a white–red zone tear. In the BPTB group, fixation was accomplished using metal interference screws (Arthrex, Naples, FL, USA); in the STG group, femoral fixation was accomplished using the TightRope® system (Arthrex). In the tibia, the graft was fixed using absorbable screw (Arthrex).

Rehabilitation protocol

All recruited patients followed a standard rehabilitation programme for a period of 24 weeks that consisted of five phases focusing on different recovery objectives: ROM (one to two weeks), force (three to four weeks), proprioception and stability (five to 11 weeks), run (nine to 14 weeks), power (15–24 weeks). Particular attention was paid to the third stage—fifth to 11th week—during which patients trained proprioception and postural stability. No patient withdrew from the study, and all attended at least 85 % of the rehabilitation sessions.

Fig. 1 Consolidated Standards of Reporting Trials (CONSORT)



Postoperative clinical evaluation

Anteroposterior and rotational laxity were assessed using the Lachman [15] and the pivot shift [15] test, which were graded according to the IKDC. Pre- and postoperative clinical function was assessed according to the IKDC subjective knee assessment form [16] and Lysholm score [17]. These tests were evaluated preoperatively and at three and six months

Table 1 Patient demographic data

	STG group (n=20)	BPTB group (n=20)
Sex (M/F)	0/20	0/20
Mean age (years)	25.4 years	24.7 years
Mean weight (kg)	69.3 kg	67.2 kg
Mean height (cm)	165.3 cm	167.6 cm
Graft	Semitendinosus and gracilis tendon	Patellar tendon
Mean time from injury to surgery (days)	84 days	89 days
Type of sport	8 basketball, 4 volleyball, 8 football	8 basketball, 4 volleyball, 8 football

BPTB bone–patellar tendon–bone, STG semitendinosus and gracilis tendon graft

after surgery. Two weeks after the end of the rehabilitation protocol, all participants arrived at the Department of Physiotherapy to perform stability tests, which consisted in four exercises designed to evaluate both the knee stability and postural control. Tests used were single-leg hop, crossover triple hop, timed hop and KAM test.

- Single-leg hop: with this test we calculated the maximum distance the patient could cover with a skip performed with one leg, taking off and landing on operated limb.
- Timed hop (6 m): we calculated the time spent by the patient in covering a distance of 6 m jumping on one leg.
- Crossover triple hop: three consecutive jumps were performed on one leg alternately from side to side of a line drawn on the floor, at the end of which the patient had to stop at the exact spot where she landed after the last jump and stand in balance.

Table 2 International Knee Documentation Committee (IKDC) and Lysholm scores in semitendinosus and gracilis tendon graft (STG) group

Score	Preoperative	Follow-up 3 months	Follow-up 6 months	P value
IKDC	50.22 (±9.2)	72.15 (±7.7)	90.97 (±5.1)	<0.0001
Lysholm	53.12 (±14.4)	79.34 (±13.7)	93.17 (±10.3)	<0.0001

Table 3 International Knee Documentation Committee (IKDC) and Lysholm scores in the bone–patellar tendon–bone (BPTB) group

Score	Preoperative	Follow-up 3 months	Follow-up 6 months	<i>P</i> value
IKDC	47.62 (±4.7)	69.32 (±3.6)	86.9 (±11.7)	<0.0001
Lysholm score	49.46 (±10.1)	66.21 (±13.9)	87.4 (±13.8)	<0.0001

– KAM test: Patients were asked to jump from a box 30 cm high and, once they had touched the ground, to maintain the position of equilibrium. The exercise was repeated twice, and in the third repetition, two jumps as high as possible were performed after landing. This exercise primarily evaluated KAM and valgus attitude upon landing, an element that is particularly significant in predicting the risk of re-tear of the ACL. Upon landing, the patients’ ability to absorb the shock with their gluteus without subsequent knee failure was also evaluated. To supervise proper execution of this exercise, the instructor directed each patient to land with the weight equally divided between both lower limbs. This test was conducted under the supervision of two observers: a trained orthopaedic surgeon described the task and supervised the patient during the entire exercise to guarantee correct execution while preventing injuries. The other observer recorded the task using a series of HD video recorders located precisely in front and at both sides of the individual at a distance of 5 m from the landing surface. This individual measured knee angles in the coronal and sagittal planes by tracing the axes of interest using computer software on single frames. Knee abduction angles were the primary points of interest of these measurements, being a reliable indicator of KAM borne by the knee.

Statistical analysis

Descriptive statistics were calculated. Clinical improvement over time was assessed using analysis of variance (ANOVA) with repeated-measures analysis in clinical and functional scores. A *P* value of <0.05 was considered to be statistically significant. Statistical analysis was carried out using the

Table 4 International Knee Documentation Committee (IKDC) score

IKDC score	BPTB group	STG group	<i>P</i> value
Preoperatively	50.22 (±9.2)	47.62 (±4.7)	0.1625
3 months	72.15 (±7.7)	69.32 (±3.6)	0.1857
6 months	90.97 (±5.1)	86.9 (±11.7)	0.1424

BPTB bone–patellar tendon–bone, *STG* semitendinosus and gracilis tendon graft

Table 5 Lysholm score

Lysholm score	BPTB group	STG group	<i>P</i> value
Preoperative	53.12 (±14.4)	49.46 (±10.1)	0.3750
3 months	79.34 (±13.7)	66.21 (±13.9)	0.1814
6 months	93.17 (±10.3)	87.4 (±13.8)	0.1428

BPTB bone–patellar tendon–bone, *STG* semitendinosus and gracilis tendon graft

Statistical Package for the Social Sciences (SPSS) software version 20.0 (SPSS Inc., Chicago, IL, USA).

We performed a priori power analysis to estimate the sample size: we took into account a large anticipated effect size (Cohen’s *d* value) of 0.9, setting statistical significance (*P* value) at 0.05 to reach a desired statistical power of ~0.80, obtaining a minimum required sample size per group of 20 patients to achieve this level of significance for our comparison.

Results

The patient median age at presentation was 25.4 years (18–36) for the STG group and 24.7 years (17–30) for the BPTB group. All additional demographic data are shown in Table 1.

No statistically significant differences were found between groups in preoperative assessment (*P*<0.0001) (Tables 2 and 3).

Postoperative results at three and six months showed a statistically significant increase in IKDC and Lysholm scores compared with mean preoperative values in both treatment groups (Tables 4 and 5, Figs. 2 and 3). Approximately two weeks after completing rehabilitation, patients underwent knee-stability evaluation using the functional tests. While the single-leg hop, timed hop and crossover triple hop tests showed no statistically significant differences between

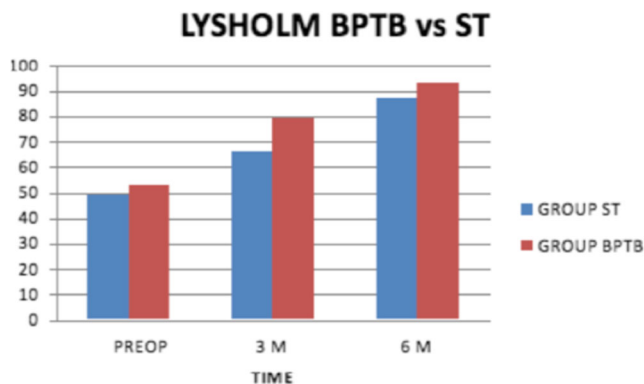


Fig. 2 Comparison of Lysholm score assessment between groups during follow-up

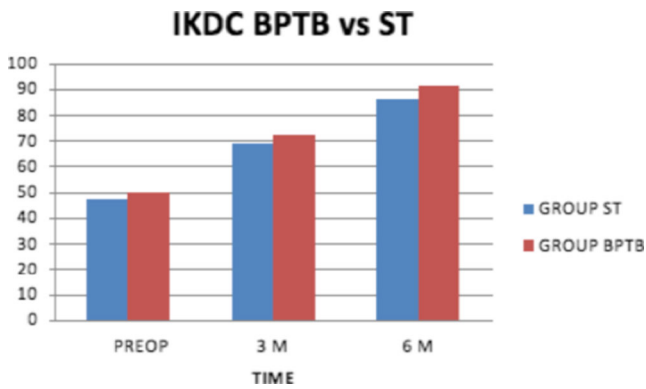


Fig. 3 Comparison of International Knee Documentation Committee (IKDC) score assessment between groups during follow-up

groups, the BPTB group, the KAM test was significantly reduced compared with the STG group ($P < 0.0001$). (Table 6)

These values were then compared with a historical control group of 40 female athletes who underwent ACL reconstruction to match the experimental groups for graft type used. However, these patients were treated with a standard postoperative rehabilitation approach. Statistically significant intergroup differences were found in this case, as shown in Tables 7 and 8.

Discussion

ACL reconstruction is undertaken to restore knee stability. An ACL lesion predisposes to a meniscal tear, and the association between the latter and an increased risk to develop knee osteoarthritis has been well established [12, 18–30]. Restoration of knee stability becomes a crucial aspect in athletes in whom articular demands are significantly higher [31–35].

Despite great advances in all aspect of ACL reconstruction surgery, such as graft type, bone-tunnel drilling technique, possible repair augmentation [36–38] and graft-fixation means [39], the rate of re-rupture remains high, particularly in women. The reasons for this are not entirely clear, but great efforts have been made to identify possible determinants [40–43].

KAM is an expression of dynamic stability of the knee, and it is a good predictor of the risk for the ACL to rupture [42].

Table 6 Functional tests

Test	BPTB group	STG group	P value
Single hop (m)	2.01 (±0.38)	2.17 (±0.38)	0.1527
Timed hop (s)	13.2 (±4.7)	12.4 (±3.5)	0.1659
Crossover hop (m)	5.0 (±1.46)	5.7 (±1.59)	0.1467
KAM (°)	2.67 (±0.52)	10.3 (±2.13)	< 0.0001

BPTB bone–patellar tendon–bone, STG semitendinosus and gracilis tendon graft

Table 7 Bone–patellar tendon–bone (BPTB) group vs historical control group (HCG)

Test	BPTB group	HCG group	P value
Single hop (m)	2.01 (±0.38)	1.23 (±0.22)	< 0.0001
Timed hop (s)	13.2 (±4.7)	17.4 (±3.7)	< 0.0001
Crossover hop (m)	5.0 (±1.46)	2.9 (±0.4)	< 0.0001
KAM (°)	2.67 (±0.52)	6.2 (±0.39)	< 0.0001

KAM knee-abduction moment

Many factors contribute to a KAM value, amongst them being the relationship between quadriceps and flexor muscles [8]. Since STG ACL reconstruction alters this relationship, our study aimed to evaluate whether graft type can affect the KAM value and, subsequently, knee stability.

Our data confirmed that all patients who underwent ACL reconstruction, independently of graft used, demonstrated a statistically significant improvement between pre- and postoperative scores, without significant differences between groups. These data are in full agreement with the literature [44–51].

Histological studies confirmed the presence of neural structures with proprioceptive function in the ACL [12, 52, 53]. An ACL injury may lead to alterations in knee stability not only because of the altered biomechanics caused by the absence of the ligament, but also as a consequence of the alteration of proprioception from knee structures [54–59]. Therefore, full recovery of knee stability depends not only on surgical reconstruction but on a rehabilitation programme aimed at regaining proprioceptive control of the knee [60]. Our patients undertook a dedicated rehabilitation programme that provided, after the first month of standard rehabilitation training, a series of exercises intended to stimulate the recovery of neurological control of the joint. The comparison of postoperative KAM values as an indicator of knee stability between the patients in this series and a historical control group that followed standard rehabilitation demonstrates that the combination of ACL reconstruction and a custom rehabilitation programme based on recovery of postural control and proprioception could be effective in reducing the risk of graft re-rupture.

The current literature does not provide clear evidence as to whether the different surgical techniques adopted by surgeons

Table 8 Semitendinosus and gracilis tendon graft (STG) vs historical controls (HCG)

Test	STG group	HCGgroup	P value
Single hop (m)	2.17 (±0.38)	1.35 (±0.3)	< 0.0001
Timed hop (s)	12.4 (±3.5)	18.1 (±3.3)	< 0.0001
Crossover (m)	5.7 (±1.59)	3.1 (±0.4)	< 0.0001
KAM (°)	10.3 (±2.13)	14.1 (±1.1)	< 0.0001

for ACL reconstruction exert any other effect on postoperative KAM. Investigating this point was the main objective of our study. Results showed that KAM assessment through a functional test exhibited statistically significant differences between patients in whom the ACL was reconstructed using hamstring tendons compared with those in whom the patellar tendon was used. The latter showed lower KAM values, which are related to a lower risk of re-tear after surgery. From this observation, it is possible to hypothesise that surgical technique may have a primary role in attaining maximum knee stability following the intervention in female athletes, confirming previous suggestions of some authors, who demonstrated significantly greater postoperative laxity in reconstructed knees of female patients when using hamstring versus patellar tendons [61]. KAM is influenced by the relationship between quadriceps and flexor muscles of the lower limb. Using the BPTB graft does not alter this relationship, in contrast to using STG [62], and KAM may benefit from this approach. However, it is difficult to ascertain whether the greatest benefit regarding knee stability using this technique is due not only to alteration of muscle ratio or from other biomechanical and constitutional factors.

Strengths of this study are its prospective randomised design, the presence of two experienced orthopaedic surgeons, the presence of an independent operator for data collection and the use of standardised integrated tools to evaluate knee stability and, in particular, KAM. The design is pragmatic and compliant with CONSORT [13] criteria. Limitations are the relatively short follow-up and the small cohort.

Both a surgical and rehabilitation approach focusing on KAM conservation following ACL reconstruction in female athletes can improve stability of the operated knee, thus reducing the risk of postoperative re-ruptures. Results suggest considering the use of the patellar tendon as a graft combined with a dedicated rehabilitation protocol mostly focusing on recovery of postural control, proprioception and stability in female athletes with ACL deficiency.

Conflict of interest None.

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