



# Femoral tunnel position in chronic anterior cruciate ligament rupture reconstruction: randomized controlled trial comparing anatomic, biomechanical and clinical outcomes

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## Abstract

**Purpose** The aim of this study was to compare the outcomes between anteromedial (AM) and transtibial (TT) femoral tunnel positioning techniques for the reconstruction of chronic anterior cruciate ligament (ACL) rupture.

**Materials and methods** It is a randomized prospective study of 106 patients who underwent ACL reconstruction because of a chronic ACL rupture (55 AMT, 51 TT). Minimum follow-up was 2 years. Demographic, clinical and radiological data, including MRI grafts' anatomy and biomechanics intraoperative navigation system evaluation, were analyzed. Also, International Knee Documentation Committee score, Tegner Knee score, Lysholm Knee Score, Short-Form Health Survey and 4-point Likert Scale were evaluated.

**Results** The AM technique achieves a more anatomic graft than TT technique in both sagittal and coronal plane (6° approximately). Immediate postoperative biomechanical evaluation of the graft showed both techniques significantly improved translational and rotational laxity ( $p=0.000$ ). AMT showed superiority only in controlling internal rotation ( $p=0.016$ ). Both techniques reported significant improvement in all evaluated score scales, without differences between techniques. Independently of the femoral tunnel positioning technique, patients with cartilage lesion had worse clinical outcomes.

**Conclusions** Our findings suggest that AMT achieves a more anatomical and biomechanically accurate graft allowing better control over internal rotation laxity; however, this does not lead to better clinical outcomes if we compare with TT in the reconstruction of chronic ACL rupture. Patients with chronic ACL rupture and cartilage lesion had worse clinical outcomes, independently the femoral tunnel positioning technique.

**Keywords** Anterior cruciate ligament · Surgery · Navigation · Anteromedial technique · Transtibial technique

## Introduction

Anterior cruciate ligament (ACL) injury is known to be one of the most common sports injuries, and ACL reconstruction is the sixth most common procedure performed in orthopaedics [1]. Preparation of the femoral tunnel plays an important role in knee stability following arthroscopic ACL reconstruction [2]. The most common method for preparing the femoral tunnel was the transtibial (TT) drilling technique according to a 2006 survey [3]. However, in the most recent surveys, published in 2013 and 2015, they found that 68% of surgeons are using an independent drilling technique, anteromedial (AM) technique, and only 31% are still using a TT guide [4, 5]. This trend has been driven by the goal of obtaining the most “anatomic” reconstruction possible [2, 4, 5]. Much has been written about this topic, but high-quality prospective randomized controlled trials to support this

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change in practice patterns are few [2, 6, 7]. Furthermore, all randomized controlled trial performed were done in acute ACL rupture, less than 6 months between rupture and reconstruction surgery, or did not mention the time between injury and surgery [8–12].

Although it is controversial, in the outcomes of surgery reconstruction of acute ACL rupture, no clinical differences between AM and TT femoral tunnel positioning have been published [1, 2, 6, 13]. Nowadays, there is no evidence that this statement could be translated to the outcome of chronic ACL rupture reconstruction. Moreover, it is known that early and delay ACL surgery reconstructions are associated with different risk and complications, like arthrofibrosis in early reconstruction and increased chances of secondary damage to the other intra-articular structures of the knee and may lead to early osteoarthritis in delay reconstruction [5, 14–16].

The purpose of the present study was to compare the outcomes of TT and AM technique for ACL reconstruction in chronic ACL rupture. The hypothesis was that ACL reconstruction, in chronic ACL rupture, the anatomic AM technique provide a better clinical outcome than the TT technique. Furthermore, for the biomechanics assessments, we used an intraoperative navigation system. Also, we compared our results with the prospective randomized controlled trials done in acute ACL reconstruction.

## Materials and methods

A randomized prospective study of patients with a chronic ACL rupture was performed between 2013 and 2016. This study was approved by the hospital ethics committee, and all persons gave their informed consent prior to their inclusion in the study. The inclusion criteria were: (1) Patients were aged > 18 and < 45 years. (2) Patients with a chronic ACL rupture, more than 12 months of injury evolution. (3) Patients with ACL rupture diagnosed by physical exam and confirmed by magnetic resonance images (MRI). Exclusion criteria included: (1) Revision surgery. (2) Concomitant ligaments lesions. (3) A grade 2 or higher osteoarthritis in the Kellgren–Lawrence scale.

## Randomization

This was a randomized controlled trial. Patients were randomized using a computer-generated sequence into two groups with an allocation ratio of 1:1. No changes were performed after the start of the trial. A total of 116 patients (58 TT; 58 AM) were enrolled in the study. Nine patients who were randomized were excluded at final analysis because they were lost during the follow-up. One hundred and seven

participants (51 TT; 56 AM) were available for final follow-up at 24 months.

## Surgical technique

Two senior knee surgeons performed all surgeries (JM, EC), and both were present in all surgeries. A combined spinal anesthesia with regional nerve blockade was used. The patient was placed in supine position without a leg support to have a free range of motion (ROM) of the knee. The arthroscopy and navigation systems were placed opposite to the knee to be operated on. An emitter was fixed to the distal third of the tibia and another one on the medial femoral epicondyle with two 2.5 mm percutaneous wires. The mobile emitter was adapted to different instruments such as palpators or tibial and femoral guides. We used the Orthopilot® navigator (B/Braun, Tuttlingen, Germany) with a specific ACL surgery software (ACL 2.0) (Fig. 1).

An exploratory arthroscopy was first performed to confirm ACL rupture and check for concomitant meniscal or chondral lesions. Autologous 4-bundle hamstring tendon was employed in all cases. The femoral graft fixation was a suspension system (Retrobutton, Arthrex, Naples, Florida, USA), and a Delta bioabsorbable screw (Arthrex, Naples, Florida) with an extracortical supplementary metal staple for tibial fixation.

In group 1 (AM), the femoral tunneling was made through an accessory anteromedial portal with a transportal offset guide (Arthrex, Naples, Florida, USA) with knee hyperflexion of about 110°–120°. Tibial tunnel was performed at the center of the tibial insertion. In group 2 (TT), the femoral tunnel was performed through the tibial tunnel using specific offset guides (Arthrex, Naples, Florida, USA) in 90° of knee flexion. Tibial tunnel was made slightly posterior to the center of the tibial insertion (Fig. 2).

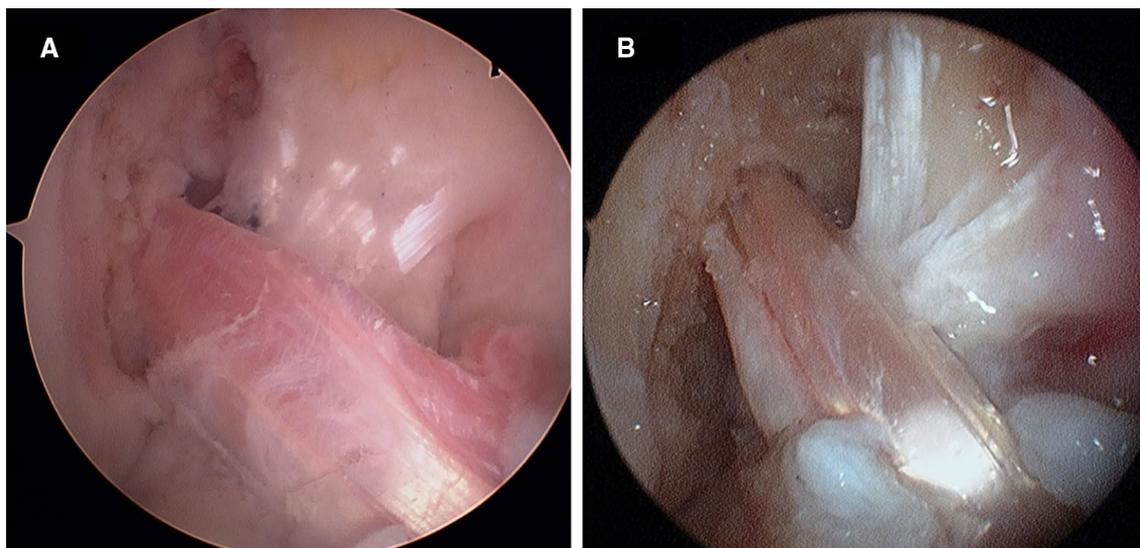
Postoperatively, all patients had the same postoperative management, including a peripheral catheter during the first 48 h postoperative and a physical rehabilitation program.

## Follow-up and outcome measures

Patients demographic, clinical and radiological data were collected preoperatively, postoperatively and during the follow-up period (1, 3, 6, 12 and 24 months postoperatively). The latest data from each patient were used for analysis. Demographic and clinical data included: patient's age at the time of surgery, sex, the cause of the injury, time between injury and surgery, body mass index (BMI), range of motion, ligament instability assessed using the drawer testes, pivot shift and varus–valgus stability test at 30° knee flexion and concomitant lesions found in arthroscopic surgery. In addition, specific functional knee scales as the subjective International Knee Documentation Committee



**Fig. 1** Intraoperative images showing the use of navigation system



**Fig. 2** Arthroscopic image of anterior cruciate ligament reconstruction with anteromedial and transtibial technique

(IKDC) score, the Lysholm Knee Score and the Tegner Knee Score were collected. To assess quality of life and patient satisfaction at final follow-up, we used the Short-Form Health Survey (SF-36) questionnaire (0–100) and the five-point Likert Scale (very unsatisfied, unsatisfied, neutral, satisfied, and very satisfied). The four physical SF-36 components (physical functioning, role limitations due to physical health, bodily pain and general health) and the four mental components (vitality, social functioning, role limitations due to emotional problems and mental health) along with their respective summary components

were calculated. All scores were measured by the same observer.

Radiological analysis included and postoperative MRI to evaluate the graft orientation. Two independent radiologists with expertise in musculoskeletal pathology measured the angulation of the graft in a coronal and sagittal planes. We took into account Illingworth's criteria for anatomic graft angulation (ACL inclination angle  $49.5 \pm 2.7$ ) [17]. The biomechanical analysis was performed using an intraoperative image-free navigation system with passive emitters. Nowadays, navigation system is a reliable and accurate system

assessing both tunnel placement and knee kinematics. Moreover, it is considered the gold standard for the validation of innovative and noninvasive (skin-mounted) inertial sensors for clinical practice (e.g., KiRA, Orthokey) [18]. Assessed values included preoperative and immediate postoperative anterior translation at 30° of knee flexion (Lachman maneuver) and internal and external rotation at 30° of knee flexion. A maximum force was applied and the measured were done five times in each patient. For the analysis, we used the mean value.

## Statistical analysis

Statistical analysis was performed with the Stata 14.2 version (StataCorp, Texas, USA). We calculated the sample size to be at least 50 participants in each group in order to detect a statistically significant difference between the two techniques, with a power of 90% and a significance level of 0.05. We assessed the inter-observer and intra-observer reliability by the intra-class correlation coefficient (ICC) with the respective 95% confidence intervals. The categorical variables were described with their absolute values and percentages. The quantitative variables were presented by their measures of central tendency (mean and standard deviation). The categorical variables were compared with Fisher's exact test. For the comparison of means, Student *t* test were used. Differences with *p* value < 0.05 were considered statistically significant.

## Results

A 70% of ACL injuries included in our study were sports related: 46% soccer, 14% ski, 8% basketball and 8% motor-bike accidents. Mean time between rupture and surgery was  $34 \pm 40.2$  in the AM group and  $38.5 \pm 44.2$  in the TT group. Demographic variables showed no differences between groups (Table 1).

Intraoperative, 64 patients (60.4%) was diagnosed with a concomitant meniscal lesion (34% internal meniscal tear, 15% external meniscus and 11% both), and 17 patients (16.0%) with a cartilage lesion.

## Anatomic results

Based on MIR: The AM technique achieves a more anatomic graft than TT technique in both sagittal and coronal planes (6° approximately). In a coronal plane, AM group showed a graft angulation of  $73.7^\circ \pm 9.5$  while the TT group  $79.1^\circ \pm 6.1$  ( $p = 0.016$ ). In a sagittal plane, angulation in AM group was  $53.2^\circ \pm 7.4$  and  $59.5^\circ \pm 5.11$  in the TT group ( $p = 0.002$ ) (Fig. 3). Mean tunnel length was significantly inferior with AM ( $39.4 \pm 4.5$  mm vs.  $50.2 \pm 5.2$  mm;

**Table 1** Demographic information of the patients in our study

Technique (number)	AM (55)	TT (51)	<i>p</i> value
Female/male	19/36	13/38	0.310
Mean age (years old)	$31 \pm 9.7$	$29.8 \pm 8.8$	0.527
BMI (kg/m <sup>2</sup> )	$24.6 \pm 3.5$	$25 \pm 3.8$	0.608
Weight (kg)	$72.4 \pm 12.7$	$74 \pm 15.2$	0.550
Height (m)	$1.7 \pm 0.1$	$1.7 \pm 0.1$	0.813
Time between injury and surgery (months)	$34 \pm 40.2$	$38.5 \pm 44.2$	0.590
Associated meniscopthy	30	35	0.535
Associated chondropathy	10	7	0.346

AM anteromedial, TT transtibial, BMI body mass index, AP anteroposterior, IR internal rotation, ER external rotation

$p = 0.000$ ). MRI measurements showed no intra- or inter-observer differences.

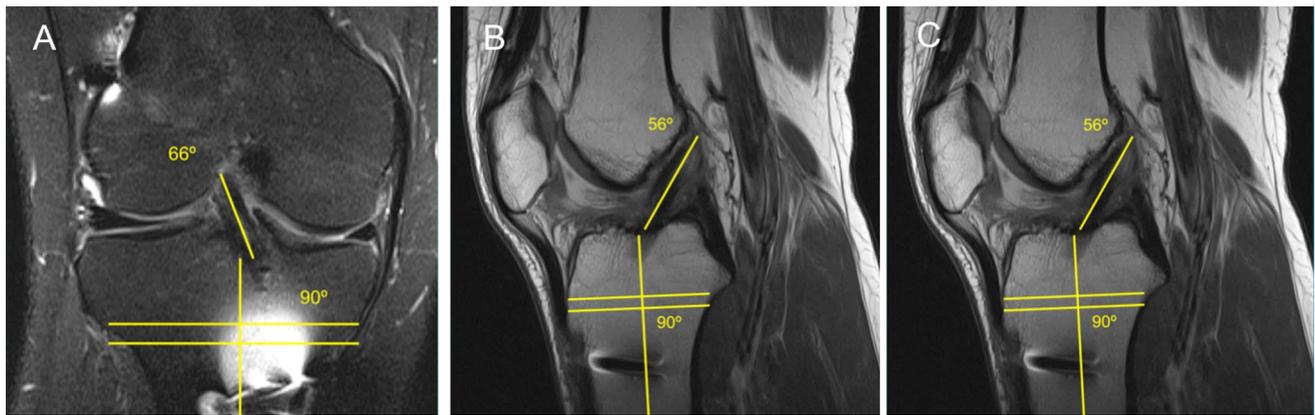
## Biomechanical results

### Based on physical examination assessment

Clinical tests of range of motion, anterior and posterior drawer tests and varus–valgus stress at 30° knee flexion did not show any differences between groups. 91.8% of patients had a positive preoperative pivot-shift test, and 51% of them were grade 2. Immediate postoperative evaluation showed 97.9% of the patients had a negative pivot-shift test, showing no differences between groups. Only two subjects in the TT group had a residual grade 1 pivot-shift test immediately at final follow-up surgery.

### Based on navigation assessment

Preoperative laxity values showed no differences between groups. After surgery, a statistically significant improvement in controlling both translation as well as internal and external rotation was found in both techniques. In order to compare both techniques, an absolute improvement value as to anterior translation were similar between techniques (AM: 8.7 mm, TT: 8.9 mm;  $p = 0.797$ ), as the values of relative improvement (AM: 62.8%, TT: 63.4%;  $p = 0.816$ ). The AM group showed a significant difference regarding the absolute values of internal rotation improvement (AM: 4.9°, TT: 3.8°;  $p = 0.016$ ), whereas comparing relative improvement values, no significant differences were observed (AM: 27.9°, TT: 22.9°;  $p = 0.111$ ). The external rotation was less controlled after ACL repair. There were no differences in absolute values (AM: 2°, TT: 2.7°,  $p = 0.111$ ) or relative improvement values between groups (AM: 11.9%, TT: 15.9%;  $p = 0.172$ ) (Table 2).



**Fig. 3** Evaluation of the graft’s angulation in a coronal (a) and sagittal (b) plane using magnetic resonance imaging

**Table 2** Biomechanical outcomes measured by navigation system in the present study

Surgical technique	Preoperative		Postoperative	
	AM	TT	AM	TT
Anteroposterior translation	13.7 ± 3.4 mm	13.8 ± 3.04 mm	13.7 ± 2.7 mm	13.7 ± 3.1 mm
Internal rotation	18.3 ± 4.3°	17.4 ± 3.8°	13.4 ± 3.9°	13.6 ± 3.7°
External rotation	18.1 ± 5°	17.3 ± 4.3°	16.1 ± 2.3°	14.6 ± 4.1°

AM anteromedial, TT transtibial

**Clinical results**

**Based on assessment scores**

Subjective IKDC scores improved globally from 53.9 preoperatively to 79.8 at final follow-up ( $p=0.000$ ), with no differences between groups. Lysholm scores improved from 61.9 preoperatively to 85.3 at final follow-up ( $p=0.000$ ), with no differences between groups. Sports activity, evaluated with Tegner scale, revealed a meaningful improvement after surgery. Mean Tegner value was 7 pre-injury, after the lesion 3, and at final follow-up was 5. No differences between groups were observed (Table 3). The SF-36 scale evidenced a progressive improvement in its eight dimensions. No differences were found in assessment scores between both groups. Respect patients’ satisfaction 79.2% of patients referred being very satisfied with the procedure, 74% very satisfied with pain improvement, 79.2% very satisfied with the capacity of performing daily activities and 63.6% very satisfied in relation to their return to sports.

**Regarding concomitant lesions found during surgery**

Patients with a concomitant meniscal lesion did not get worse clinical results at final follow-up, according to the IKDC and Lysholm scores. Patients with cartilage lesion had worse clinical outcomes. Subjective IKDC at final follow-up scored 83.1 for patients without chondral lesions,

**Table 3** IKDC and Lysholm values preoperatively, at 12 months and at 2 years after surgery between techniques

	Technique	N	Mean	SD	p value
IKDC Preoperative	AM	54	55.1	15.5	0.455
	TT	51	52.7	17.7	
IKDC 12 months	AM	35	73.2	12.8	0.230
	TT	39	69.4	14	
IKDC 24 months	AM	48	79.7	18.7	0.976
	TT	42	79.8	16.5	
Lysholm Preoperative	AM	52	64.8	15.2	0.081
	TT	51	58.9	18.6	
Lysholm 12 months	AM	35	82.3	12.7	0.685
	TT	39	83.5	12	
Lysholm 24 months	AM	48	84.3	17.8	0.539
	TT	42	86.4	14.6	

AM anteromedial, TT transtibial, IKDC International Knee Documentation Committee

whereas IKDC lowed down to 63.2 for patients with cartilage damage ( $p=0.000$ ). No significant differences were found regarding Lysholm scale (scoring 86.1 for patients with intact cartilage and 80.9 for patients with cartilage damage ( $p=0.132$ )). Patients with chondropathy scored significantly less on SF-36physical function (91.78 vs. 82;  $p=0.011$ ) and SF-36 pain (82.86 vs. 70.5;  $p=0.029$ ).

## Regarding perioperative complications

We had nine cases of graft failure (8.57%), four in AM group and five in the TT group. Two patients underwent surgical removal of the metal staple due to local intolerance. One patient had an acute articular infection caused by *Enterobacter cloacae* that was diagnosed 1 week after surgery. When the infection was solved, a revision ACL graft with an allograft tendon was performed. Complications related to the navigation system are scarce; only one case of superficial pin infection at the tibia successfully treated with antibiotics, and one case of tibial pin-related stress fracture, which resolved with conservative management.

## Discussion

The most important finding of this study was that in ACL reconstruction of chronic ACL rupture there are no clinical differences between AM and TT technique. In our study, like previous studies, AM technique achieves a more anatomical graft (measured by MRI) and with slightly superior biomechanics (regarding internal rotation, measured with intraoperative navigation system) than the TT technique. This anatomical and biomechanics improvement does not lead to better clinical outcomes. Furthermore, we found that patients with chronic ACL rupture and cartilage lesion had worse clinical outcomes, independently the femoral tunnel positioning technique.

Nowadays, the aim of ACL surgery is considered to be an anatomical reconstruction such as the AM technique permit. The TT reconstruction, which is based on an isometric concept, even though is widely used and with good reported outcomes, is considered less appropriate [1, 5, 6]. In our study, we found that that independent tunnel technique achieves a more anatomical and biomechanically graft but without differences on clinical results. This statement has been found in previous studies, that have included meta-analysis, prospective nonrandomized and retrospective studies [1, 7, 13, 19]. Although if we only analyze high-quality prospective randomized controlled trials, this conclusion can be controversial [8, 10–13, 20–23] (Table 4). In 2017, the first meta-analysis of only prospective randomized controlled trials found that the outcome of ACL reconstruction with the AM technique was better than the outcome of TT technique in terms of postoperative stability and functional recovery of the knee [6]. In our study, we do not find the same conclude, we think that this was possible because of the lack of big differences in anatomy and biomechanical measurements in our groups. We think that these could be for the small variations made to the TT technique in order to achieve a more anatomical position of the graft.

About ACL surgery and femoral tunnel positioning reconstruction much has been written [4, 5, 14, 17, 24]. Nevertheless, all of these studies present variable populations with regard for the duration between rupture and surgery [24]. High-quality studies have focused only in acute ACL reconstruction outcomes, surgery between 6 weeks and 6 months between rupture and reconstruction [6, 13]. Only a few patients with chronic ACL rupture have been included, which make it difficult to extrapolate the results found for this specific population [25]. It is known that waiting for ACL reconstruction surgery has negative impacts on patients' outcomes [26]. In this context, it could be think that a more anatomic reconstruction would be needed. To our knowledge, our study is the first prospective randomized controlled trial that compared the femoral tunnel position in reconstruction of chronic ACL rupture. These results are important, because it has been reported that chronic ACL rupture present differences complication risks in relation to the acute ACL rupture, including knee instability, surgery complications, associated intra-articular injuries and risk of osteoarthritis [14, 25, 27].

Even in our study the femoral tunnel position techniques did not affect the final outcomes, the presence of a chondral lesion was the factor with greater impact in conditioning clinical results at final follow-up. Other authors have pointed out that the presence of a chondral or meniscal lesion is significant predicting factors of end clinical results in the knee score scales [25, 26]. In the present study, time lapse between rupture and surgery was significantly superior in patients who presented a chondral lesion (77.2 months vs. 27 months). These results imply that patients who suffer from an ACL injury can eventually develop a chondral lesion [14, 27]. In chondral lesion cases, subjective IKDC scores averaged 20 points less (83.1 vs. 63.2;  $p=0.000$ ). Dimensions of the SF-36 questionnaire were also affected with lower scores in patients with a chondral lesion included: physical functionality, body pain, social functionality, emotional role and mental health. In our study, concomitant meniscopathy seemed to have less impact on clinical results, in our opinion we thought that this is possibly due to short-term follow-up (24 months).

Limitations of the present study include a relatively short-term follow-up only 2 years, so even no clinical differences between AM and TT technique during this period, the possibility that a more anatomic ACL reconstruction decrease the risk of knee osteoarthritis cannot be yet evaluated. Another important weak point of this study is that navigation-assisted biomechanics evaluation was performed only intraoperative at time 0 without follow-up measurements and that we could not evaluate the AP and rotational laxity of the healthy uninjured knee using the navigation system intraoperatively, because measurement by the navigation system requires an invasive procedure of fixing the guide pins to the femur

**Table 4** Summary of high-quality prospective randomized controlled trials that compare anteromedial and trans tibial technique for the femoral tunnel positioning in anterior cruciate ligament reconstruction

	Age (years)	Follow-up (months)	Num-ber of patients		Time between injury and surgery	Conclusions
			AM	TT		
Zhang et al. [20]	28	> 12	31	34	NM	Lysholm scores and KT-10000 anterior laxity were significantly improved after treatment with surgery but did not differ statistically between two groups
Mirzatofooei et al. [22]	AM: 26.6 TT: 26.8	> 18	80	88	NM	AM technique demonstrated better short-term clinical results than the TT technique (IKDC grades; Lysholm scores; Lachman test; PS test)
Hussein et al. [21]	AM: 34.2 TT: 32.6	AM: 50.5 TT: 52	78	72	NM	AMT superior to TT, in controlling translation and rotational stability, even though this does not correlate to a better clinical result (Lysholm scores; IKDC scores)
Noh et al. [10]	AM: 22 (19–44) TT: 24 (18–45)	AM: 29.9 ± 2.7 TT: 30.4 ± 2.8	30	31	AM: 6.0 ± 4.5 weeks TT: 7.3 ± 7.1 weeks	AM technique was more stable in Telos testing, and was three points higher on the Lysholm score. However, there were no statistically significant differences in the Tegner activity scale or IKDC between the two groups (AM or TT)
Guglielmetti et al. [11]	< 40	6	38	35	6.5 months	No statistically significant between the TT and AM groups were found in Anterior drawer test; Lachman test or PS. The IKDC scores were significantly better in the AM group
Youm et al. [8]	AM: 27.6 ± 9.9 TT: 29.7 ± 11.9	24 months (range 19–31)	20	20	AM: 7.1 ± 11.3 weeks TT: 6.8 ± 9.3 weeks	The modified TT technique showed good clinical results (IKDC, Lysholm, Tegner) and anatomic placement of the femoral tunnel, similar with those of the AM portal technique
Bohn et al. [12]	AM: 24.3 ± 4.9 TT: 27.5 ± 7.2	12–18	12	11	AM: 6 (3–16) months TT: 12 (4–42) months	No significant difference in rotational stability walking, running, and pivoting was seen between AM and TT groups
Yanasse et al. [23]	NM No difference between both groups ( $p = 0.8$ )	13 (8–22) months	20	20	NM No difference between both groups ( $p = 0.78$ )	The AM technique allowed a more anatomic graft position and presented better clinical result in the pivot-shift maneuver. No differences in isometricity and functional results were observed in the short follow-up period
MacDonald et al. [13]	AM: 30.7 ± 9.3 TT: 32.4 ± 8.9	24 months	36	35	NM	No differences in clinical outcome were found when comparing AM to TT in primary ACL reconstruction
Our study	AM: 31 ± 9.7 TT: 29.8 ± 8.8	24 months	56	51	AM: 34 ± 40.2 months TT: 38.5 ± 44.2 months	AMT achieves a more anatomical and biomechanically if we compare with TT technique in ACL surgery. Patients with chronic ACL rupture and cartilage lesion had worse clinical outcomes, independently the femoral tunnel positioning technique

AM anteromedial, TT trans tibial, NM No mentioned, IKDC International Knee Documentation Committee, PS pivot shift, ACL anterior cruciate ligament

and tibia intraoperatively using a piercing technique, which could not be done to a contralateral healthy knee. Nevertheless, the limitations, this study had several unique attributes. First is the first prospective randomized controlled trial that compared the femoral tunnel position in reconstruction of chronic ACL rupture. Second, biomechanical results were measured by navigation system. Nowadays, navigation system is a reliable and accurate system assessing both tunnel placement and knee kinematics [18]. To our knowledge, no other clinical studies have been published comparing both techniques using a navigation system. In our study, we also found the safeties of this procedure, only 1.8% present complications related to the navigation system. One case of superficial pin infection at the tibia successfully treated with antibiotics, and one case of tibial pin-related stress fracture, which resolved with conservative management.

In summary, our study provides evidence that suggests that in short-term follow-up no clinical differences are found between AM and TT technique for the femoral tunnel position in reconstruction of chronic ACL rupture. The AMT achieves a more anatomical graft (measured with MRI) and with slightly superior biomechanics (regarding internal rotation); however, this does not translate into better clinical results. The chondral lesion was the factor with greater impact in conditioning clinical results. We think that longer follow-up will need to find if a more anatomic ACL reconstruction decrease the risk of knee osteoarthritis in chronic ACL insufficiency rupture.

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### Compliance with ethical standards

**Conflict of interest** No conflicts of interest were declared by the authors.

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