

A comparison of the anteromedial and transtibial drilling technique in ACL reconstruction after a short-term follow-up

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Received: 8 October 2013 / Published online: 27 April 2014
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Abstract

Introduction The purpose of this study was to compare clinical and radiological outcomes of patients who underwent single-bundle anterior cruciate ligament (ACL) reconstruction with anteromedial portal (AMP) and transtibial (TT) techniques.

Materials and methods Arthroscopic single-bundle ACL reconstruction was performed using AMP technique in 34 patients and TT technique in 30 patients. The patients were evaluated retrospectively. Aperture fixation was used for femoral fixation, and absorbable screws and U staples were used for tibial fixation of the graft. Pivot shift test, Lachman test, Lysholm, Tegner, and International Knee Documentation Committee (IKDC-2000) scoring systems were used in the clinical and functional evaluation of patients before and after the surgery. Time to return sports and activity level were assessed. In the radiological evaluation of non-anatomic bone tunnel placement, the criteria developed by Illingworth et al. were used. The mean duration of follow-up was 20.4 and 24.6 months in the AMP and TT groups, respectively.

Results There was a significant difference between the AMP group (86.7 %) and the TT (14.7 %) group in terms of anatomical placement of the femoral tunnels and grafts ($p < 0.001$). No significant difference was observed between the two groups in terms of the Pivot shift test, Lachman test, Lysholm, Tegner, and IKDC scores, and activity level ($p > 0.05$). The patients in the AMP

group returned to sports 1.5 months earlier on average ($p < 0.001$).

Conclusions It was shown that AMP technique was superior to the TT technique in providing anatomical placement of the graft and in recovery time to return sports; however, there was no difference between groups in early periods in terms of the clinical and functional outcomes.

Keywords Anatomical reconstruction · Anterior cruciate ligament · Anteromedial portal · Transtibial technique · Single bundle

Introduction

Success after anterior cruciate ligament (ACL) reconstruction depends on the regain of the original biomechanics of the knee at an optimal level [1]. Transtibial (TT) technique is a widely used technique for arthroscopic ACL reconstruction [2]. Transtibial drilling of femoral tunnel is a straightforward procedure and reduces surgical time. However, this technique fails to accurately position femoral and tibial tunnels within the native ACL insertion site [3]. Transtibial technique may not restore normal knee functions and prevent osteoarthritis [4, 5]. In addition to initial chondral damage and associated meniscal injury, non-anatomic bone tunnel positions may contribute to the onset of osteoarthritis [7–9].

Anteromedial portal (AMP) technique has gained popularity in recent years to achieve anatomical ACL reconstruction. The main advantage of this technique is drilling femoral tunnel independently from the tibial tunnel [10–14]. In this manner, the femoral and tibial tunnels could be placed in the footprints of ACL, hence it would be possible to place the graft anatomically both in the sagittal and

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frontal planes [17]. It was suggested that the stability and kinematics of the knee would be similar to the normal knee with the use of anatomical ACL reconstruction, and thus the joint cartilage might be protected [7, 14]. Anatomical ACL reconstruction via anteromedial portal technique is promising. Although anteromedial portal technique provides better anatomical bone tunnel placement than transtibial technique, the superiority of this technique in terms of clinical outcomes is unclear [15, 16].

The purpose of this study was to retrospectively compare the transtibial and anteromedial portal technique in patients who had undergone ACL reconstruction regarding both radiological and particularly clinical outcomes. We hypothesized that AMP technique could provide better anatomical bone tunnel placement along with better knee function and stability compared to the transtibial technique.

Patients and methods

A total of 72 patients underwent ACL reconstruction using AMP or TT technique between 2009 and 2012. Three patients had inadequate follow-up and five patients were lost to follow-up. A total of 64 patients (89 %) who have adequate follow-up were included in the study. Of those 30 patients (AMP group: 1 female, 29 males; mean age 26.5 years, range 17–35 years) who were treated with AMP, and 34 patients (TT group: 1 female, 33 males; mean age 27.6 years, range 18–38 years) who were treated with TT technique were retrospectively evaluated. All patients were operated by a single surgeon (IA). Inclusion criteria were as follows: active male soccer players, age between 16 and 40 years, isolated primary ACL injury, and healthy contralateral knee. The patients with multi-ligament injury, the patients who had previous meniscectomy, the patients who had previous injury in the contralateral knee, the patients aged below 16 and above 40 years, and the patients who underwent microfracture or mosaicplasty were excluded. The study was performed after obtaining the approval of the local ethics committee.

Surgical technique

Before harvesting the graft, arthroscopic examination was done and ACL rupture was confirmed. In all patients quadruple-stranded hamstring auto-grafts (gracilis and semitendinous) were used.

In the TT group, the technique described by Morgan et al. [17] was used. The knee was flexed to 90° and a tibial guide frame was distally placed medial and proximal to the tibial tuberosity in a tibial angle of 20° and 55° in

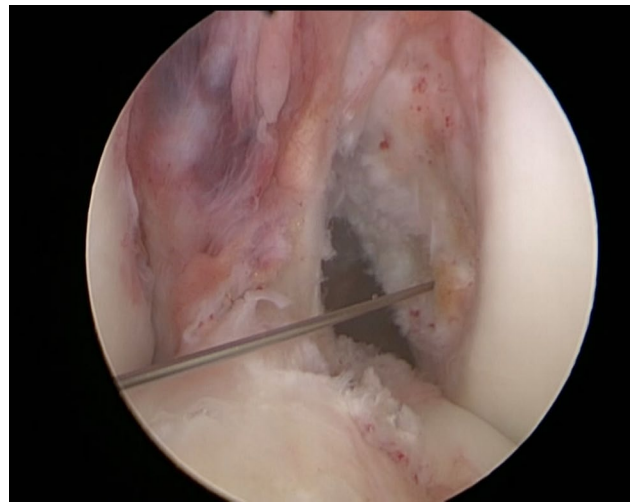


Fig. 1 Central anteromedial portal provides excellent arthroscopic view of wall of the lateral femoral condyle

the frontal and sagittal plane, respectively. A guide pin was introduced through the tibia and its exit point was continuous with a line marking the posterior edge of the lateral meniscus and the medial tibial spine. A cannulated reamer was used to create tibial tunnel. A standard aiming instrument with a 7-mm offset was placed through the tibial tunnel and a guide pin was advanced to determine the femoral tunnel placement. A cannulated reamer was introduced transtibially and the femoral tunnel was created.

In the AMP group, three portal techniques was used [18]. After creating high anterolateral portal, the central anteromedial portal was created under arthroscopic visualization; a spinal needle was advanced into the joint through the medial third of the patellar tendon just above the joint line. This portal provides excellent visualization of the femoral attachment of the ACL (Fig. 1). Then the accessory anteromedial portal was created to prepare the femoral tunnel independently from the tibial tunnel. A spinal needle was advanced into the joint approximately 2 cm medial to the medial border of the patellar tendon and was directed towards the footprint of the ACL. There should be at least 2 mm between the guide pin and medial femoral condyle to avoid damaging cartilage during femoral tunnel drilling. The midpoints of remnants of the anteromedial and posterolateral bundle of the ACL were marked. Then the knee was taken into 120° of flexion and femoral tunnel was drilled over a guide wire. Then the knee was taken into 90° of flexion and ACL tibial guide was set to an angle of 55° and placed medial to the center of the remaining tibial stump of the native ACL through central anteromedial portal. Then the tibial tunnel was drilled over a guide wire. Then the graft was inserted and fixed in 15° of flexion.

Postoperative follow-up and evaluation

The same rehabilitation protocol was used in both groups to decrease the swelling to achieve the patellar mobility and range of joint motion rapidly, including early weight-bearing and proprioceptive exercises. The patients were evaluated with knee radiographies, stability tests, and standard forms at the third, sixth, twelfth months and at the final follow-ups.

The Lachman test was used in the evaluation of the anterior–posterior stability of knee, and the Pivot shift test was used in the evaluation of the rotational stability of knee. In the clinical and functional evaluations, the International Knee Documentation Committee (IKDC-2000), Lysholm and Tegner scoring systems were used [19, 20]. Activity level was classified according to activity level classification by Hefti et al. [21]. In both AMP and TT group all patients participated in soccer (level I) prior to injury. Return to sport criteria was based upon the work of Fitzgerald et al. [22]. Passing return to sport criteria required at least 90 % symmetry between the injured and non-injured limb for quadriceps strength and four hop tests (single, crossover, and triple hops for distance, and a 6 m timed hop) described by Noyes et al. [23]. Single-legged hop test limb symmetry indexes (LSI) were calculated as the longest distance hopped on the involved leg divided by the longest distance hopped on the uninvolved leg $\times 100$. For the 6-m timed hop test, the LSI was calculated as the fastest time hopped on the uninvolved leg divided by the fastest time hopped on the involved leg $\times 100$. Four months after ACL reconstruction patients were allowed to return to sport when they meet specific criteria for quadriceps strength [limb symmetry index (LSI) >90 %] and four single-legged hop tests (LSI >90 % for all four hop tests). If the athlete was unable to score at least 90 % on any of the return to sport criterion, they did not pass and were not cleared to return to sport. Athletes were able to retest, every 2–4 weeks depending upon functional gains, until they achieve a passing score. Patient's satisfaction was assessed with a visual analog scale (VAS) graded on a 0 (completely unsatisfied) to 10 (completely satisfied) scale.

Radiological outcomes were assessed using the criteria developed by Illingworth et al. [24]. These criteria were used to define whether ACL reconstruction fell outside an anatomical range or not. Accordingly, the femoral tunnel angle was measured on the anterior-posterior radiography of the knee at 45° flexion and the inclination angle of the graft was measured in sagittal sections of magnetic resonance imaging (MRI) of the knee at extension. When the femoral tunnel became greater than 32.7° and the inclination angle became greater than 55°, it was considered that ACL reconstruction fell outside an anatomical range.

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences 16.0 for Windows (SPSS Inc., Chicago, IL, USA). The distribution of normality was calculated with Kolmogorov–Smirnov test. For comparing of normally and abnormally distributed continuous variables between two groups, Student *t* test and Mann–Whitney *U* test were used, respectively. Activity level was evaluated with the Chi-square test. The Lachman test, Pivot shift tests and IKDC scores were evaluated with the Kruskal–Wallis test. Time to return sports, Lysholm and Tegner scores were evaluated with the Student *t* test. $p < 0.05$ was accepted as statistically significant.

Results

The mean follow-up time in the AMP group was 20.4 months (range 15–25) and 24.6 months (range 20–34) in the TT group. There were no significant differences in terms of age, gender, preoperative activity between both groups ($p > 0.05$). The mean operative time was 58 min (range 42–80) in the AMP group and 49 min (range 39–76) in the TT group. There was no difference in mean duration of surgery between the two groups ($p > 0.05$).

There was no significant difference between both groups in terms of the Lachman tests, pivot shift-signs tests, IKDC (Kruskal–Wallis, $p > 0.05$) (Table 1). Functional outcomes revealed no statistically significant difference using Lysholm and Tegner scores (Student *t*, $p > 0.05$) (Table 2). Also, VAS for satisfaction with surgery was similar between both groups (Student *t*, $p > 0.05$) (Table 2). The time to return sports was 7.2 months (range 6–10) and 8.7 months (range 7–11) in the AMP and TT groups, respectively. Statistical analysis revealed reduced time to return sports in the AMP group compared to TT group (Student *t*, $p < 0.001$) (Table 2). Twenty (66.7 %) patients in the AMP group and 21 (61.8 %) patients in the TT group returned to pre-injury activity level (level I). There was no significant difference existed in activity level between the two groups (Chi squared, $p = 0.778$) (Table 2). The education level was similar between the two groups (Chi squared, $p = 0.869$). No patient has a history of smoking.

ACL reconstruction fell within an anatomical range in 26 patients (86.7 %) in the AMP group and in five patients (14.7 %) in the TT group (Figs. 2, 3). Statistically significant difference was observed between the two groups (Chi squared, $p < 0.001$). Notchplasty was performed in three patients in the TT group whereas it was not required in any patient in the AMP group. Infection was seen in one case in each group. Joint aspiration was followed by bacteriological examination. In both cases an antibiotic

Table 1 Physical examination in both groups

Parameter	Anteromedial (number of patients) (%)	Transtibial (num- ber of patients) (%)	<i>p</i> value
Lachman test			0.670
0	25 (83.3)	27 (79.4)	
1	3 (10)	4 (11.8)	
2	2 (6.7)	2 (5.9)	
3	0	1 (2.9)	
Pivot shift test			0.303
0	26 (86.7)	26 (76.5)	
1	3 (10)	6 (17.6)	
2	1 (3.3)	2 (5.9)	
3	0	0	
IKDC score			0.667
Normal	20 (66.7)	21 (61.8)	
Nearly normal	8 (26.7)	10 (29.4)	
Abnormal	2 (6.6)	3 (8.8)	
Severely abnormal	0 (0.0)	0 (0.0)	

IKDC International Knee Documentation Committee

Table 2 Subjective outcomes, time to return sport, and activity level in both groups

Parameter	Anteromedial	Transtibial	<i>p</i> value
Lysholm score (<i>n</i>) (%)			0.083
85–100 (excellent)	14 (46.7)	15 (44.2)	
70–84 (good)	11 (36.7)	12 (35.3)	
55–69 (fair)	4 (13.3)	6 (17.6)	
0–50 (poor)	1 (3.3)	1 (2.9)	
Mean score	83.7	78.4	
Tegner score (mean ± SD)	6.7 (1.2)	6.1 (1)	0.580
VAS (mean ± SD)	8.9 (0.9)	8.2 (1.1)	0.180
Time to return sport (months) (range)	7.2 (6–10)	8.7 (7–11)	<0.001
Activity level (<i>n</i>) (%)			0.778
Level I	20	21	
Level II	7	8	
Level III	3	5	

VAS visual analog scale

sensitive microorganism was found. Empiric antibiotics were changed with sensitive antibiotics. The patients were recovered with immediate arthroscopic debridement and graft retaining along with antibiotherapy. During the last controls of these two patients, while 5° of extension deficit was noted in the patient in the TT group, the range of joint motion was normal in the patient in the AMP group. A new ACL injury developed in one patient in the AMP group as a result of a sports accident at the eighth month. The patient did not accept revision.

Discussion

The present study compared the AMP and TT techniques in ACL reconstruction. It was observed that the AMP technique is superior to the TT technique in providing ACL reconstruction within an anatomical range, and return to sport activities; however, there was no difference between the groups in the early period in terms of the Lachman test, pivot shift-sign test, IKDC, Lysholm and Tegner scores.

At 2- to 5-year follow-up of ACL reconstruction, the AMP group was superior to TT group in terms of Lachman test, pivot shift test, and IKDC scores [25]. It was reported that in the third and sixth month after surgery, Lysholm score and lateral movement tests (sidestep and carioca) were superior in the AMP group when compared to TT group [26]. The authors recommended that the AMP technique may be preferred for athletes involved in sports that require quick lateral movements such as basketball and team handball.

In the present study, ACL reconstruction fell inside an anatomical range in the AMP group more than TT group ($p < 0.001$). Also, the patients in the AMP group returned to sports 1.5 months earlier when compared to TT group ($p < 0.001$). Although the difference between both groups was not statistically significant in terms of pivot shift test, the percentage of abnormal pivot shift was higher in the TT group when compared to AMP group 24 and 13 %, respectively.

The transtibial technique has advantages such as shorter duration of surgery, easier surgical technique, not requiring knee flexion greater than 90° for femoral tunnel drilling [2]. On the other hand, the fact that the two-dimensional evaluation with the clockface method used in TT technique is limited, it is difficult to determine the notch depth with this method. Also, the position of the femoral tunnel changes according to the degree of knee flexion. The TT technique is restrictive because the placement of the tibial tunnel determines the placement of the femoral tunnel [6]. In a cadaver study where the independent drilling of tunnels and the TT drilling technique were compared, it was demonstrated that grafts were placed anatomically and more horizontal in the independent drilling group [13]. The authors also showed that the horizontal grafts were biomechanically more successful than vertical grafts in providing anterior and rotational stability of the knee.

Failure of ACL reconstruction commonly results from errors of surgical technique [27]. Among the technical errors, the most common is the tunnel malplacement [6–28]. The TT drilling of femoral tunnel were consistently positioned anterior (“high”) to the anatomic anteromedial and posterolateral tunnels and the tibial tunnel apertures were positioned medial to the anatomic posterolateral and anatomic anteromedial tunnels and posterior

Fig. 2 A case sample of single-bundle (SB) transtibial ACL reconstruction. *a* Posterior to anterior flexion weight-bearing radiograph with a femoral tunnel angle of 16° . *b* With an inclination angle of 59° demonstrating non-anatomic position of the femoral tunnel

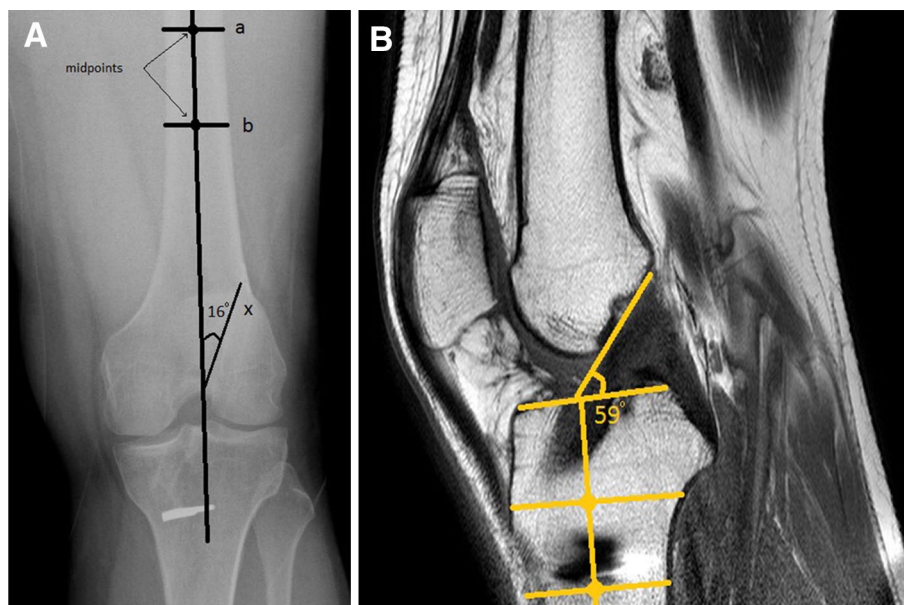
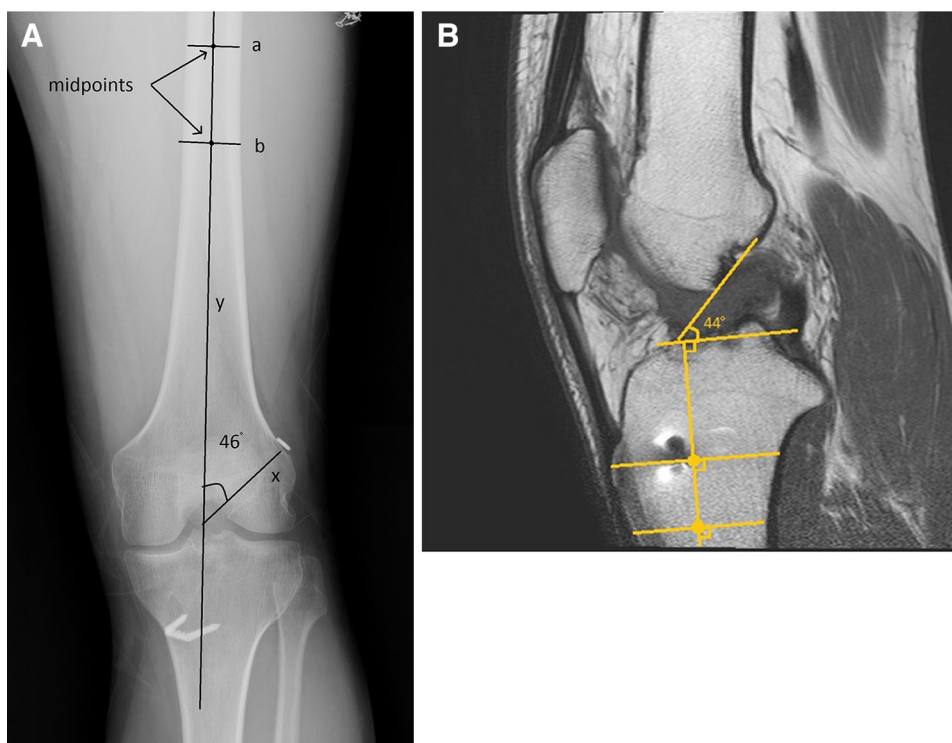


Fig. 3 A case sample of SB anteromedial portal ACL reconstruction. *a* Posterior to anterior flexion weight-bearing radiograph with a femoral tunnel angle of 46° , and *b* an inclination angle of 44° suggest that ACL reconstruction within anatomical range



to the anteromedial tunnel [3]. Non-anatomical bone tunnel placement causes non-anatomical ACL reconstruction which in turn can result in the instability of the knee [6, 7]. Therefore, it was suggested that the instability might cause chondral injury using the TT technique [29].

Anatomic ACL reconstruction became commonly used to achieve the original anatomy and kinematics of the knee. ACL reconstruction with the AMP technique has some advantages such as the independent preparation of

femoral and tibial tunnels which tunnels could be placed in the center of anatomic insertions of ACL, provides more horizontal placement of the graft, decreases the possibility of graft impingement, limits the necessity of notchplasty, allows drilling of femoral tunnel without the need of a specific instrument, and reduces the difficulties of revision surgeries [10, 11, 14, 16, 29, 30].

The AMP technique has some disadvantages. First, learning curve and duration of surgery are more prolonged.

Second, short femoral tunnel (25–30 mm) may occur if the knee is not flexed adequately. This may compromise graft fixation particularly if a suspension method is used. Third, the cartilage of the medial femoral condyle can be damaged. This may be prevented to introduce a guide wire at least 2 mm away from medial femoral condyle. Fourth, the posterior wall of the lateral femoral condyle can be fractured (blow-out). Fifth, the posterolateral structures mainly the peroneal nerve can be damaged but may be decreased by 120° of knee flexion [31]. Finally, visualization can be limited because at least 120° of knee flexion is necessary during the preparation of femoral tunnel [2]. To improve visualization during preparation of femoral tunnel in the AMP technique Cohen et al. [18] proposed central anteromedial portal which is created into the medial third of the patellar tendon just above the joint line. On the other hand, Kim et al. [16] used two anteromedial portals in ACL reconstruction and suggested this technique as an effective method for reproducing the anatomy of the ACL because the technique allowed for a better field of view and lower obliquity of the reconstructed ACL compared to the transtibial technique.

In the present study, notchplasty was required in three patients in the TT group to prevent graft impingement, whereas notchplasty was not required in any patients in the AMP group. We consider that anatomical placement of the graft in the AMP group may play a role in decreasing the requirement of notchplasty. We think that the disadvantages of AMP technique can be prevented by flexing the knee more than 120° during femoral tunnel drilling, using central anteromedial portal to improve visualization, and correct placement of accessory medial portal.

In the assessment of tunnel and graft placement after ACL reconstruction, Illingworth et al. [24] confirmed with 3D computed tomography that a femoral tunnel angle greater than 32.7° (100 % sensitivity and 85 % specificity) on the anteroposterior radiograph of the knee and an inclination angle less than 55° (100 % sensitivity and 87.5 % specificity) on the sagittal MRI of the knee is an effective method to determine whether the ACL reconstruction is within the anatomical ranges. In the current study, we observed that the AMP technique was superior to TT technique in providing ACL reconstruction within anatomical range ($p < 0.001$). We consider that the radiological evaluation method of Illingworth et al. [24] is easy and beneficial to determine whether ACL reconstruction is within the anatomical ranges or not.

A controlled laboratory study showed that the AMP technique better restores the femoral external rotation at midstance and anterior–posterior translation during the swing phase than the TT technique does [6]. However, the AMP technique is also correlated with an extension loss during the late stance phase. In a recent meta-analysis of 15 studies including cadaveric, in vivo and clinical

studies showed that there are biomechanical data suggesting improved knee stability and more anatomic graft placement with independent drilling [32]. Although improved Lysholm scores with independent drilling were reported, the clinical relevance of this small difference is questionable. There were no significant differences in IKDC or Tegner scores between groups. A retrospective comparative study ($n = 88$) showed that patients who underwent ACL reconstruction with AMP approach showed fewer but not statistically significant degenerative changes than those patients who underwent ACL reconstruction with TT approach at 5-year follow-up [15]. A recent multicenter study ($n = 380$) showed that patients who underwent ACL reconstruction with a transtibial technique had significantly higher odds of undergoing repeat ipsilateral knee surgery relative to those who underwent reconstruction with an anteromedial portal technique.

This study has several limitations. First, this is a retrospective study with no randomization. Second, it comprises a relatively small number of patients. Third, it is a short-term study. Finally, X-ray or computed tomography control measures were not used for exact tunnel position. Future studies with long-term follow-up may investigate the superiority of AMP technique in terms of failure and osteoarthritis of the knee.

In conclusion, the AMP technique was superior to the TT technique in providing the anatomical placement of the graft and regarding time to return sports in ACL reconstruction. However, there was no significant difference between the groups in the early period in terms of the clinical outcomes.

Acknowledgments Authors thanks to Dr. Ebubekir Şenates for his contribution to this study.

Conflict of interest None.

References

1. Musahl V, Plakseychuk A, Van Scyoc A, Sasaki T, Debski RE, McMahon PJ, Fu FH (2005) Varying femoral tunnels between the anatomical footprint and isometric positions: effect on kinematics of the anterior cruciate ligament-reconstructed knee. *Am J Sports Med* 33:712–718
2. Streich NA, Reichenbacher S, Barié A, Buchner M, Schmitt H (2013) Long-term outcome of anterior cruciate ligament reconstruction with an autologous four-strand semitendinosus tendon autograft. *Int Orthop* 37:279–284
3. Kopf S, Forsythe B, Wong AK, Tashman S, Irrgang JJ, Fu FH (2012) Transtibial ACL reconstruction technique fails to position drill tunnels anatomically in vivo 3D CT study. *Knee Surg Sports Traumatol Arthrosc* 20(11):2200–2207
4. Inderhaug E, Strand T, Fischer-Bredenbeck C, Solheim E (2013) Long-term results after reconstruction of the ACL with hamstrings autograft and transtibial femoral drilling. *Knee Surg Sports Traumatol Arthrosc* 21(9):2004–2010

5. Papannagari R, Gill PJ, DeFrate LE, Moses JM, Petruska AJ, Li G (2006) In vivo kinematics of the knee after anterior cruciate ligament reconstruction: a clinical and functional evaluation. *Am J Sports Med* 34:2006–2012
6. Wang H, Fleischli JE, Zheng NN (2013) Transtibial versus anteromedial portal technique in single-bundle anterior cruciate ligament reconstruction: outcomes of knee joint kinematics during walking. *Am J Sports Med* 41:1847–1856
7. Marchant BG, Noyes FR, Barber-Westin SD, Fleckenstein C (2010) Prevalence of nonanatomical graft placement in a series of failed anterior cruciate ligament reconstructions. *Am J Sports Med* 38:1987–1996
8. Crawford SN, Waterman BR, Lubowitz JH (2013) Long term failure of anterior cruciate ligament reconstruction. *Arthroscopy* 29:1566–1571
9. Abebe ES, Moorman CT 3rd, Dziedzic TS, Spritzer CE, Cothran RL, Taylor DC et al (2009) Femoral tunnel placement during anterior cruciate ligament reconstruction: an in vivo imaging analysis comparing transtibial and 2-incision tibial tunnel-independent techniques. *Am J Sports Med* 37(10):1904–1911
10. Noh JH, Roh YH, Yang BG, Yi SR, Lee SY (2013) Femoral tunnel position on conventional magnetic resonance imaging after anterior cruciate ligament reconstruction in young men: transtibial technique versus anteromedial portal technique. *Arthroscopy* 29:882–890
11. Kopf S, Forsythe B, Wong AK, Tashman S, Anderst W, Irrgang JJ, Fu FH (2010) Nonanatomic tunnel position in traditional transtibial single-bundle anterior cruciate ligament reconstruction evaluated by three-dimensional computed tomography. *J Bone Joint Surg Am* 92:1427–1431
12. Bedi A, Maak T, Musahl V, Citak M, O’Loughlin PF, Choi D, Pearle AD (2011) Effect of tibial tunnel position on stability of the knee after anterior cruciate ligament reconstruction: is the tibial tunnel position most important? *Am J Sports Med* 39:366–373
13. Steiner ME, Battaglia TC, Heming JF, Rand JD, Festa A, Baria M (2009) Independent drilling outperforms conventional transtibial drilling in anterior cruciate ligament reconstruction. *Am J Sports Med* 37:1912–1919
14. Takahashi M, Doi M, Abe M, Suzuki D, Nagano A (2006) Anatomical study of the femoral and tibial insertions of the anteromedial and posterolateral bundles of human anterior cruciate ligament. *Am J Sports Med* 34:787–792
15. Franceschi F, Papalia R, Rizzello G, Del Buono A, Maffulli N, Denaro V (2013) Anteromedial portal versus transtibial drilling techniques in anterior cruciate ligament reconstruction: any clinical relevance? A retrospective comparative study. *Arthroscopy* 29(8):1330–1337
16. Kim MK, Lee BC, Park JH (2011) Anatomic single bundle anterior cruciate ligament reconstruction by the two anteromedial portal method: the comparison of transportal and transtibial techniques. *Knee Surg Relat Res* 23:213–219
17. Morgan CD, Kalman VR, Grawl DM (1995) Definitive landmarks for reproducible tibial tunnel placement in anterior cruciate ligament reconstruction. *Arthroscopy* 11:275–288
18. Cohen SB, Fu FH (2007) Three-portal technique for anterior cruciate ligament reconstruction: use of a central medial portal. *Arthroscopy* 23(3):325 (e1–5)
19. Hefti F, Muller W, Jakob RP, Staubli HU (1993) Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc* 1:226–234
20. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res* 198:43–49
21. Hefti F, Müller W (1993) Current state of evaluation of knee ligament lesions. The new IKDC knee evaluation form. *Orthopade* 22(6):351–362
22. Fitzgerald GK, Axe MJ, Snyder-Mackler L (2000) A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. *Knee Surg Sports Traumatol Arthrosc* 8(2):76–82
23. Noyes FR, Barber SD, Mangine RE (1991) Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med* 19(5):513–518
24. Illingworth KD, Hensler D, Working ZM, Macalena JA, Tashman S, Fu FH (2011) A simple evaluation of anterior cruciate ligament femoral tunnel position: the inclination angle and femoral tunnel angle. *Am J Sports Med* 39:2611–2618
25. Alentron-Geli E, Samitier G, Alvarez P, Cugat R (2010) Anteromedial portal versus transtibial drilling techniques in ACL reconstruction: a blinded cross-sectional study at two-to five-year follow-up. *Int Orthop* 34:747–754
26. Koutras G, Papadopoulos P, Terzidis IP, Gigis I, Pappas E (2013) Short term functional and clinical outcomes after ACL reconstruction with hamstring autograft: transtibial versus anteromedial portal technique. *Knee Sports Traumatol Arthrosc* 21:1904–1909
27. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD (1996) Revision anterior cruciate ligament surgery: experience from Pittsburgh. *Clin Orthop Relat Res* 325:100–109
28. Fu FH, Bennett CH, Ma CB, Menetrey J, Lattermann C (2000) Current trends in anterior cruciate ligament reconstruction. Part II operative procedures and clinical correlations. *Am J Sports Med* 28:124–130
29. Zhang C, Xu H, Li X, Wang Y, Zhang Q, Zhu Q (2013) Oblique femoral tunnel or oblique graft? A modified anteromedial portal technique to obtain vertical femoral tunnel and oblique graft in anatomic anterior cruciate ligament reconstruction. *Eur J Orthop Surg Traumatol* 23:731–735
30. Silva A, Sampaio R, Pinto E (2012) ACL reconstruction: comparison between transtibial and anteromedial portal techniques. *Knee Surg Sports Traumatol Arthrosc* 20:896–903
31. Otani M, Nozaki M, Kobayashi M, Goto H, Tawada K, Waguri-Nagaya Y et al (2012) Comparative risk of common peroneal nerve injury in far anteromedial portal drilling and transtibial drilling in anatomical double-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 20:896–903
32. Riboh JC, Hasselblad V, Godin JA, Mather RC 3rd (2013) Transtibial versus independent drilling techniques for anterior cruciate ligament reconstruction: a systematic review, meta-analysis, and meta-regression. *Am J Sports Med* 41(11):2693–2702
33. Duffee A, Magnussen RA, Pedroza AD, Flanigan DC, Kaeding CC, MOON Group (2013) Transtibial ACL femoral tunnel preparation increases odds of repeat ipsilateral knee surgery. *J Bone Joint Surg Am* 20(95):2035–2042