Knee Surg Sports Traumatol Arthrosc (2018) 26:1335–1342
https://doi.org/10.1007/s00167-017-4664-x

KNEE

No clinical differences between anteromedial portal and transtibial technique for femoral tunnel positioning in anterior cruciate ligament reconstruction: a prospective randomized, controlled trial

Peter MacDonald[1] · Chris Kim[1] · Sheila McRae[1] · Jeff Leiter[1] · Ryan Khan[2] · Daniel Whelan[2]

Received: 19 January 2017 / Accepted: 28 July 2017 / Published online: 11 August 2017

Abstract

Purpose The anteromedial (AMP) portal technique was introduced to position the femoral tunnel in anterior cruciate ligament (ACL) reconstruction to more closely replicate the original ACL footprint compared to the transtibial (TT) approach. Few randomized trials have evaluated differences in these techniques with respect to clinical outcomes. The purpose of this study was to determine if there are any differences in clinical outcome between the AMP and TT approaches.

Methods This is a single-blinded, prospective, randomized controlled trial. Participants were randomized to undergo ACL reconstruction using the AMP or TT approach. The primary outcome measure was the ACL quality of life (ACL-QOL), and secondary outcomes were the IKDC knee assessment, side-to-side difference in anterior–posterior knee laxity (KT-1000) and tunnel orientation (X-ray findings) at preoperative, 3, 6, 12, and 24 months postoperative. Statistical comparisons were performed using a series of t tests for independent groups with equal variance.

Results Ninety-six participants were consented and randomized between 2007 and 2011 with eight excluded postrandomization. Mean (SD) preoperative ACL-QOL was 33 (13) for TT and 36 (17) for AMP and improved significantly ($p < 0.001$) in both groups to 79 (18) and 78 (18) at 24 months postoperative, respectively. The preoperative median IKDC grade for both groups was C and improved similarly in both groups at 24 months (n.s.). There was no side-to-side difference in knee laxity based on KT-1000 measurements with a mean (SD) 1 (3) mm between affected and unaffected limbs in the TT group compared to 1 (3) mm for the AMP group. A significant difference was found in femoral tunnel orientation with the AMP group at 43° (7) and the TT group 58° (8) in the coronal plane ($p < 0.001$).

Conclusion No differences in clinical outcome were found when comparing AMP to TT in primary ACL reconstruction using a STG graft. This prospective randomized controlled trial suggests surgeons can use either method without significantly compromising clinical outcome.

Level of evidence I.

Keywords Anterior cruciate ligament · Reconstruction · Semitendinosus · Gracilis · Anteromedial · Trans-tibial · Tibial tunnel independent

✉ Peter MacDonald
pmacdonald@panamclinic.com

Chris Kim
umkim88@gmail.com

Sheila McRae
smcrae@panamclinic.com

Jeff Leiter
jleiter@panamclinic.com

Ryan Khan
khanry@smh.ca

Daniel Whelan
wheland@smh.ca

[1] Department of Surgery, Pan Am Clinic, University of Manitoba, Orthopaedics 75 Poseidon Bay, Winnipeg, MB R3M 3E4, Canada

[2] St. Michael's Hospital, St. Michael's Orthpaedic Associates, 55 Queen St E., Suite 800, Toronto, ON M5C 1R6, Canada

Introduction

Traditional methods of anterior cruciate ligament (ACL) reconstruction may result in persistent rotational laxity [17, 36–38, 42, 43]. Reconstructed knees have demonstrated residual pivot shifts, and less than satisfactory outcomes have been reported [3, 6, 21, 31]. Ardern et al. [4] have suggested that less than 50% of patients will return to competitive sport following traditional methods of ACL reconstruction.

There have been ongoing efforts to improve the stability of the reconstructed knee, and much of the focus has been on establishing anatomic graft position and orientation. A major consideration is optimal placement of the femoral tunnel. Non-anatomic tunnel positioning may lead to abnormal knee kinematics [10, 14, 36–38, 42]. Numerous biomechanical studies have suggested that lowering the tunnel and establishing a more oblique anatomic graft could improve rotational laxity while maintaining similar anteroposterior stability [27, 28, 39, 44]. However, achieving a lower femoral tunnel can be difficult with the traditional transtibial (TT) technique [5, 20]. With the TT technique, the surgeon runs the risk of placing a vertical graft which may increase rotational instability [26]. While some have adopted a modified TT technique to account for these restrictions, [8, 23, 33, 40] others have utilized tibial tunnel-independent techniques to establish the femoral tunnel [24]. The anteromedial portal (AMP) technique, for example, allows more freedom to position the femoral tunnel and establish a more anatomic and oblique graft [11, 13, 15, 16, 18, 32].

Although biomechanical studies have shown improvement in rotational laxity with lower femoral tunnels [27, 28, 39, 44], the clinical implications are not yet clearly defined. This study aims to determine if there are any clinically significant differences in using the AMP technique over the traditional TT technique for femoral tunnel positioning in ACL reconstruction surgery using a hamstring autograft. The hypothesis is that the more anatomic femoral tunnel position afforded by the anteromedial technique may manifest in small functional benefits with respect to subjective outcome as measured by the ACL quality of life questionnaire at 2 years postoperative. The secondary hypothesis is that there will also be differences in clinical outcome between TT and AMP techniques as measured by the IKDC Knee Assessment form and the KT-1000 to measure AP translation. This study is the first randomized controlled trial to compare the subjective and clinical outcomes of these two techniques.

Materials and methods

This was a multicentre, prospective, single-blinded, parallel, 1:1 randomized controlled trial conducted at two sites with patient randomized between August 2007 and August 2011. Two fellowship-trained knee surgeons (one at each centre) with over 10 years of experience performed all surgeries. Approval to conduct this research was obtained from the local Institutional Research Ethics Boards of the two centres involved prior to commencement of study activities.

Participants

Patients referred to the participating surgeons with an ACL tear were screened for eligibility. Inclusion criteria included men and women between the ages of 18 and 50 diagnosed with a complete ACL tear confirmed on MRI. Patients were not eligible if they had concomitant collateral ligament tears, significant chondromalacia (with loss of more than 50% thickness based on diagnostic imaging (MRI)), previous lower limb surgery, history of arthritis, were unable to comply with rehabilitation protocols (e.g. bucket handle, simple vertical or radial meniscal tears requiring repair and different postoperative protocol) or study follow-ups, or were pregnant. Patients deemed eligible after clinical consultation were introduced to the study and, if interested, a research assistant undertook the informed consent process. Baseline data were collected following consent and a surgery date booked.

Randomization was performed intra-operatively once eligibility was confirmed. If the diagnostic arthroscopy revealed an incomplete ACL tear or additional pathology outside of the study criteria, patients were excluded from the study and treated accordingly. Randomization was computer generated utilizing blocks of 10 with a sealed opaque sequentially numbered envelope opened that indicated group allocation to undergo ACL reconstruction with a TT technique or an AMP technique for femoral tunnel positioning.

Rehabilitation programs were standardized across all patients and provided upon discharge from hospital. Patients were directed to weight bear as tolerated. Emphasis was placed on early swelling control, knee range of motion and closed chain exercises. An evaluator, blinded to group allocation, performed postoperative assessments at 3-, 6-, 12-, and 24-month intervals. Patients were blinded to group allocation during the course of the study.

Surgical technique

All patients had a single tunnel ACL reconstruction with an autologous four-stranded, semitendinosis and gracilis (STG) tendon graft. In patients randomized to the TT technique, a guidewire was inserted through the tibia at a 55 degree angle to the tibial plateau into the anatomic tibial ACL attachment area. After reaming to the appropriate tendon graft diameter, an offset guide was placed through the tibial tunnel to approximately the 11 o'clock or 1 o'clock clock-face notch position in the right and left knee, respectively. In patients randomized to the AMP technique, a guidewire was inserted through an accessory medial portal at 10 o'clock or 2 o'clock position in the

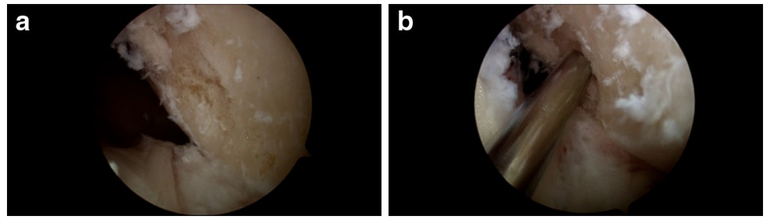

Fig. 1 **a** An oblique view of the lateral condyle notch surface in preparation for drilling of the AM tunnel; **b** An oblique view of the position of the drill creating the AM tunnel in relation to the ACL footprint on the lateral femoral condyle

right and left knee, respectively [19]. The guidewire was to be inserted into the centre of the anatomic femoral insertion of the ACL. With the knee in 120 degrees of flexion, the guidewire was then driven retrograde up through the cortex of the femur and through the skin (Fig. 1). Femoral fixation was done with a cortical suspensory button device, and tibial fixation was done using a biocomposite interference screw.

Outcome measures

The primary outcome measure was the ACL quality of life questionnaire (ACL-QOL) [30]. The ACL-QOL is a patient-reported, disease-specific outcome instrument comprised of 32 100-mm visual analogue scale questions divided into six domains: symptoms, work, recreation, sports participation, lifestyle, and emotional and social issues [41]. A higher score reflects a better quality of life. Secondary outcomes included a clinical exam (range of motion, effusion, Lachman and anterior drawer tests, pivot shift, reverse pivot shift) and a functional test (one leg hop test) as contained in the International Knee Documentation Committee (IKDC) Knee Examination Form. Tibial translation was measured with the KT-1000 arthrometer (Medmetric Corporation, San Diego, CA).

Surgical findings were reported including femoral and tibial tunnel lengths, graft size, episodes of chondral injury while performing technique. Complications were documented in a standardized fashion both intra-operatively and postoperatively (infection, stiffness, graft re-rupture).

Radiographic images of the affected knee were obtained to evaluate femoral and tibial tunnel orientation in the coronal plane at 12 months. Tunnel orientation on each X-ray was measured by two independent evaluators. Using the tunnel view in JPG format, Image J NIH software was used to draw a horizontal line along the femoral condyle and another line cantered and parallel to the femoral tunnel. The angle of these two lines was measured. The average of the measures from each of the two evaluators was used to compare surgical techniques.

This study was approved by the University of Manitoba Biomedical Research Ethics Board, B2007: 107 and the St. Michael's Research Ethics Board 08-186.

Statistical analysis

Sample size was calculated based on the primary outcome instrument, the ACL-QOL. Sample size calculations were based on unpublished pilot data from one of the study sites with a minimally clinically important difference of 10%, standard deviation of 17%, α at 0.05 and $\beta = 0.8$. Based on these parameters, 45 participants were needed per group. Recruitment was inflated to 48 participants per group to account for loss to follow-up.

Descriptive statistics were calculated for all variables by group. A repeated-measures ANOVA was performed to compare ACL-QOL scores within each group across time points. Two independent group t tests were used to compare ACL-QOL between TT and AMP groups at each time point. In addition, due to higher than expected loss to follow-up rate, t tests were performed to compare between groups while bringing forward the score of the last visit at which patients were seen to account for missing values. Side-to-side differences in KT-1000 measures as well as tunnel angle based on radiographic measurement were compared using independent t tests. IKDC Knee Assessment scores were compared between groups based on Fisher's exact test. All tests were carried out at a significance of $p < 0.05$ adjusted for multiple testing and a power of 80%.

Results

A total of 96 patients (39 TT; 45 AMP) were enrolled in the study. A CONSORT diagram outlining the flow of patients through the study is provided in Fig. 2. Eight patients who were randomized but did not meet study criteria were excluded—seven were excluded intra-operatively due to pathology revealed on diagnostic arthroscopy (one with a tibial plateau fracture, four with significant meniscal tears requiring repair, one with a ganglion cyst on the ACL, and one had previous knee surgery) and one was excluded at her 3-month follow-up as she was pregnant. Those that were excluded did not differ from those maintained in the study with respect to age, gender, or preoperative ACL-QOL scores.

Seventy-one of 88 participants or 81% (35 TT; 36 AMP) were available for final follow-up at 24 months. There were

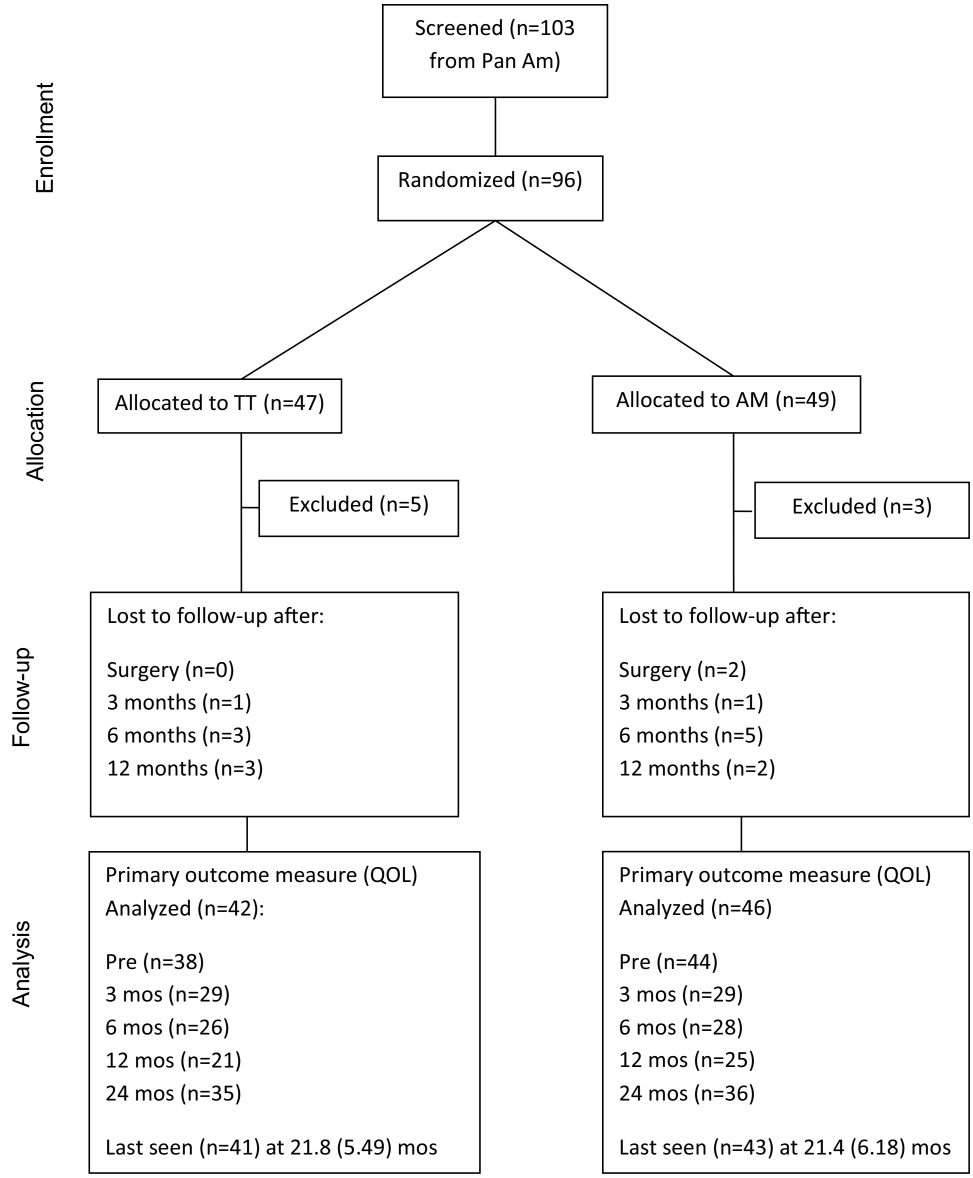

Fig. 2 Flow diagram of participant progress through the phases of the study

Table 1 Patient demographics by study group

Parameter	TT group ($n = 42$)	AM group ($n = 46$)	p value
Mean age (SD) (years)	32.4 (8.9)	30.7 (9.3)	n.s.
Sex (male to female ratio)	27/15	31/15	n.s.
Preoperative mean QOL (SD)	32.8 (12.7)	35.9 (16.7)	n.s.
Preoperative median IKDC	C	C	n.s.

no differences between study groups in age, male to female ratio, or preoperative ACL-QOL scores (Table 1).

Mean (SD) baseline ACL-QOL scores for the TT and AMP groups were 33% (13) and 36% (17), respectively (Fig. 3). At 24 months postoperative, both groups improved significantly from baseline to 79% (18; $p < 0.001$) and 79% (18; $p < 0.001$), respectively. There were no differences in ACL-QOL between groups at any time point. As not all patients returned for their 24-month visit, the QOL scores from the patients' last study visit (at 6 months or later) were also compared and no differences were found.

The baseline median IKDC grade for both groups was C ('Abnormal') with no significant difference between groups (n.s.). Both groups improved over time, and no significant differences between groups were found at any time point with 40% of patients with 'Normal' (A) and

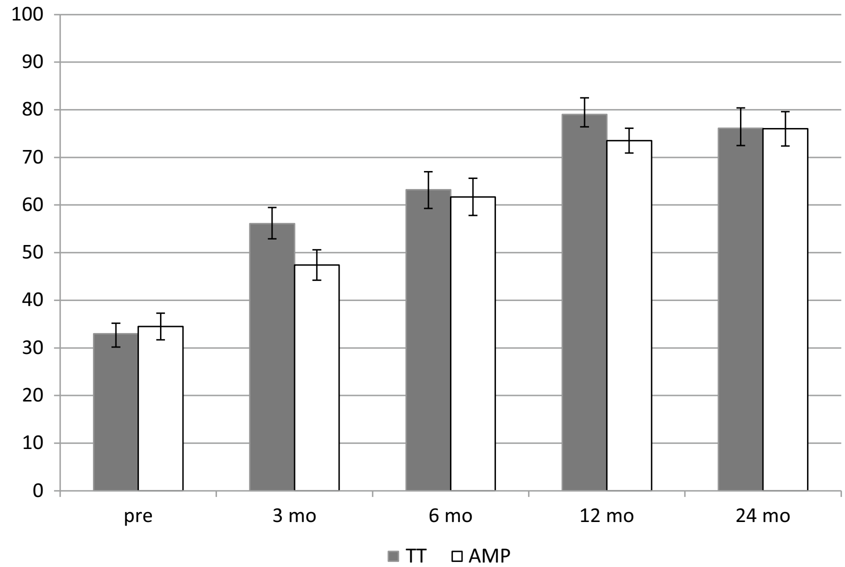

Fig. 3 ACL-QOL (%) over time by study group ± SE. Differences between groups by time point were nonsignificant

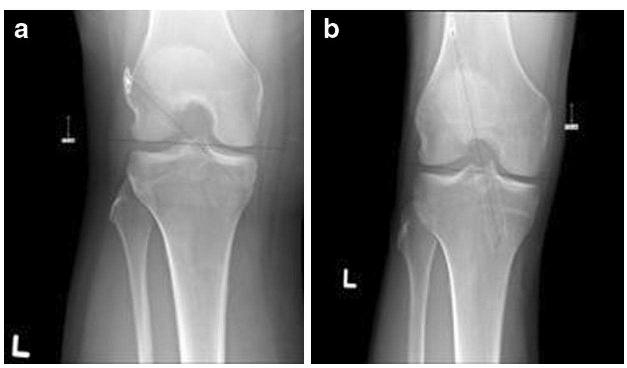

Fig. 4 Femoral tunnel positioning on radiograph in the coronal plane: **a** anteromedial portal placement; **b** transtibial placement

47% with 'Near normal' (B) clinical evaluations in the TT group and 50% of patients reporting 'Normal' (A) and 43% 'Near normal' (B) in the AMP group at 24 months postoperative (n.s.).

There were no side-to-side differences in knee laxity based on KT-1000 measurements with a mean difference of 1 (3) mm in the TT group compared to 1 (3) mm in the AMP group at 24 months postoperative (n.s.). There was no difference in pivot positive patients in either group at final clinical follow-up (9/30 TT versus 5/29 AM, n.s.). There were no reports of ACL re-rupture on the operative side within the 24-month follow-up period.

As expected, a significant difference was found between groups with respect to femoral tunnel orientation in the coronal plane ($p < 0.001$) (Fig. 4).

Discussion

The most important finding of the present study was that there were no clinical differences between TT and AMP techniques. The ACL-QOL was the primary outcome measure, a validated, disease specific, health-related quality of life outcome score employed to detect a clinically relevant difference with respect to patient satisfaction. After 2-year follow-up, differences in the ACL-QOL or in any secondary outcomes (clinical assessment, knee laxity, and rate of revision surgery) were not found. The mean QOL difference between groups was very small (less than 1%) at the final endpoint (24 months) and was much lower than the estimated minimal clinically relevant difference of 10% used in the study's sample size calculation.

Tibial tunnel-independent techniques have become the prevailing choice for tunnel placement in ACL reconstruction [24]. In 2006, a survey by the American Orthopaedic Society for Sports Medicine reported 90% of surgeons used the transtibial technique [12]. A survey in 2011 of members of the Canadian Orthopaedic Association showed that 70% still preferred the transtibial technique [29]. By 2013, an international survey showed that only 31% of surgeons were using the transtibial technique, with 68% using tibial tunnel-independent techniques [9]. Based on the literature to date, evidence has varied on whether tibial tunnel-independent techniques result in any clinically significant differences. Studies looking at patient outcomes are beginning to emerge with varied results. Some studies have suggested a possible advantage of the AMP technique in the earlier stages following reconstruction, with earlier functional return and better outcome scores [1]. However, the same differences have not been detected in the long term [1, 45]. A recent meta-analysis comparing the TT and AMP techniques in bone-patellar tendon-bone ACL reconstructions suggested possible advantages of the AMP technique in early follow-up [1]. Alentorn-Geli et al. [1] found significantly earlier return to activities and better range of motion, as well as Lachman and KT-1000 values at 1–2 year follow-up. These differences were not significant, however, in later follow-ups at 3–5 and 6–10 years. In a subsequent cross-sectional comparative study by the same group, Alentorn-Geli et al. [2] demonstrated significantly earlier return to activities, as well as better KT-1000, Lachman, pivot shift, and objective IKDC values in the AMP group. On the other hand, a more recent and comprehensive systematic review and meta-analysis comparing TT vs tibial tunnel-independent drilling (OI and AMP) found no differences in failure rates, IKDC objective scores, or Tegner scores [35].

Based on more recently published prospective clinical trials, it remains unclear whether independent drilling and anatomic femoral tunnel placements for single-bundle procedures result in clinically relevant improvements [22, 25, 45]. A randomized trial by Jepsen et al. [23] found superior IKDC outcomes with a femoral tunnel positioned lower in the notch versus a traditionally oriented tunnel; however, both were drilled via transtibial tunnels. In another prospective non-randomized trial, Koutras et al. [25] compared 51 male patients receiving either the TT or AMP techniques. This was a short-term follow-up study at 6 months, and showed improved Lysholm scores at 3 months and better lateral movement scores at 3 and 6 months in the AMP group. The study suggested possibly quicker functional returns in patients receiving the AMP approach. On the other hand, a prospective randomized study by Zhang et al. [45] with longer follow-up to 12 months, showed no significant differences in Lysholm and KT-1000 scores when comparing TT and AMP groups. Hussein et al. [22] found significantly improved anteroposterior and rotational stability as assessed by KT-1000 and pivot shift testing in the AMP group, respectively. However, they were unable to detect a statistical difference in Lysholm or subjective IKDC scores. They conclude that the objective differences detected may not be clinically relevant.

The AMP technique is not without its pitfalls. It does involve a learning curve, and surgeons should be cautious of creating critically short femoral tunnels [8] or compromising the integrity of the posterior wall of the lateral femoral intercondylar notch [7, 9]. Challenges exist during the requisite knee hyperflexion as well, such as avoiding iatrogenic chondral injury while passing reamers over the guidewire. In fact, a large registry-based study comparing the AMP and TT techniques showed a higher revision rate in the AMP group [34]. This may be due to the learning curve of the less familiar AMP technique.

Limitations exist in this study. One of the primary reasons for introducing independent drilling techniques over the traditional TT approach was to improve anatomic placement and enhance rotational stability. A practical and readily available objective measure of rotational laxity does not yet exist. Many rely on the pivot shift test, but results vary substantially depending on patient comfort and the examiner's experience. Although we assume that rotational stability is one aspect that is reflected in patient quality of life reports, a study that includes an objective measure of rotation would be meaningful, if and when such a measure becomes available. Also, only 96 participants were randomized in this study and the loss to follow-up was higher than expected. Nevertheless, the sample size was calculated based on a clinically meaningful difference of 10% and there was less than a 1% difference between groups in the primary outcome measure at 24 months. It is unlikely that the conclusions gathered from the study would have differed based on a greater number of participants. Another limitation of the study is perhaps the surgical technique with which the femoral tunnel was positioned through the anteromedial portal. Although the clock-face description was used (10 o'clock versus 11 o'clock), this has become less popular as our understanding of ACL footprint anatomy increases. Due to the three-dimensional nature of the footprint location, the clock-face description of the notch may not be optimal for standardizing tunnel location between subsequent patients.

ACL graft choices and tunnel positioning continue to evolve in order to better resemble the native ACL. Studies have shown improved stability with anatomic grafts [15–17], and the potential advantages of tibial tunnel-independent drilling techniques to achieve anatomic tunnels [26–28, 32]. Based on biomechanical evidence, surgeons may opt for the AMP technique, but based on the present study findings, such biomechanical differences appear to be undetectable to the patient and did not impact re-rupture rate to 2 years postoperative. From a clinical standpoint, either the TT or AMP technique can be used without compromising subjective outcome.

Conclusion

No differences in clinical outcome were found when comparing AMP to TT in primary ACL reconstruction using a STG graft. This prospective randomized controlled trial suggests surgeons can use either method without significantly compromising clinical outcome.

Acknowledgements The authors would like to thank Treny Sasyniuk for her valuable contributions to this project.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Funding Funding for this study was provided by the University of Manitoba Alexander Gibson Fund.

Ethical approval This study was approved by the University of Manitoba Biomedical Research Ethics Board and the St. Michael's Hospital Research Ethics Board and was performed in accordance with the Declaration of Helsinki (developed by the World Medical Association in 1964; seventh revision in 2013).

References

1. Alentorn-Geli E, Lajara F, Samitier G, Cugat R (2010) The transtibial versus the anteromedial portal technique in the arthroscopic bone-patellar tendon-bone anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 18:1013–1037
2. Alentorn-Geli E, Samitier G, Álvarez P, Steinbacher G, Cugat R (2010) Anteromedial portal versus transtibial drilling techniques in ACL reconstruction: a blinded cross-sectional study at 2–5-year follow-up. Int Orthop 34:747–754
3. Anderson AF, Snyder RB, Lipscomb AB (2001) Anterior cruciate ligament reconstruction. A prospective randomized study of three surgical methods. Am J Sports Med 29:272–279
4. Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE (2015) Sports participation 2 years after anterior cruciate ligament reconstruction in athletes who had not returned to sport at 1 year: a prospective follow-up of physical function and psychological factors in 122 athletes. Am J Sports Med 43:848–856
5. Arnold MP, Kooloos J, van Kampen A (2001) Single-incision technique misses the anatomical femoral anterior cruciate ligament insertion: a cadaver study. Knee Surg Sports Traumatol Arthrosc 9:194–199
6. Aune AK, Holm I, Risberg MA, Jensen HK, Steen H (2001) Four-strand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction. A randomized study with 2-year follow-up. Am J Sports Med 29:722–728
7. Bedi A, Raphael B, Maderazo A, Pavlov H, Williams RJ (2010) Transtibial versus anteromedial portal drilling for anterior cruciate ligament reconstruction: a cadaveric study of femoral tunnel length and obliquity. Arthroscopy 26:342–350
8. Chang CB, Choi J-Y, Koh IJ, Lee KJ, Lee K-H, Kim TK (2011) Comparisons of femoral tunnel position and length in anterior cruciate ligament reconstruction: modified transtibial versus anteromedial portal techniques. Arthroscopy 27:1389–1394
9. Chechik O, Amar E, Khashan M, Lador R, Eyal G, Gold A (2013) An international survey on anterior cruciate ligament reconstruction practices. Int Orthop 37:201–206
10. Colombet P, Robinson J, Christel P, Franceschi J-P, Djian P (2007) Using navigation to measure rotation kinematics during ACL reconstruction. Clin Orthop Relat Res 454:59–65
11. Dargel J, Schmidt-Wiethoff R, Fischer S, Mader K, Koebke J, Schneider T (2009) Femoral bone tunnel placement using the transtibial tunnel or the anteromedial portal in ACL reconstruction: a radiographic evaluation. Knee Surg Sports Traumatol Arthrosc 17:220–227
12. Duquin TR, Wind WM, Fineberg MS, Smolinski RJ, Buyea CM (2009) Current trends in anterior cruciate ligament reconstruction. J Knee Surg 22:7–12
13. Gadikota HR, Sim JA, Hosseini A, Gill TJ, Li G (2012) The relationship between femoral tunnels created by the transtibial, anteromedial portal, and outside-in techniques and the anterior cruciate ligament footprint. Am J Sports Med 40:882–888
14. Gao B, Zheng (Nigel) N (2010) Alterations in three-dimensional joint kinematics of anterior cruciate ligament-deficient and -reconstructed knees during walking. Clin Biomech 25:222–229
15. Garofalo R, Moretti B, Kombot C, Moretti L, Mouhsine E (2007) Femoral tunnel placement in anterior cruciate ligament reconstruction: rationale of the two incision technique. J Orthop Surg 2:10
16. Gavriilidis I, Motsis EK, Pakos EE, Georgoulis AD, Mitsionis G, Xenakis TA (2008) Transtibial versus anteromedial portal of the femoral tunnel in ACL reconstruction: a cadaveric study. Knee 15:364–367
17. Georgoulis AD, Papadonikolakis A, Papageorgiou CD, Mitsou A, Stergiou N (2003) Three-dimensional tibiofemoral kinematics of the anterior cruciate ligament-deficient and reconstructed knee during walking. Am J Sports Med 31:75–79
18. Hantes ME, Zachos VC, Liantsis A, Venouziou A, Karantanas AH, Malizos KN (2009) Differences in graft orientation using the transtibial and anteromedial portal technique in anterior cruciate ligament reconstruction: a magnetic resonance imaging study. Knee Surg Sports Traumatol Arthrosc 17:880–886
19. Harner CD, Honkamp NJ, Ranawat AS (2008) Anteromedial portal technique for creating the anterior cruciate ligament femoral tunnel. Arthroscopy 24:113–115
20. Heming JF, Rand J, Steiner ME (2007) Anatomical limitations of transtibial drilling in anterior cruciate ligament reconstruction. Am J Sports Med 35:1708–1715
21. Herrington L, Wrapson C, Matthews M, Matthews H (2005) Anterior cruciate ligament reconstruction, hamstring versus bone-patella tendon-bone grafts: a systematic literature review of outcome from surgery. Knee 12:41–50
22. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH (2012) Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3–5-year follow-up. Am J Sports Med 40:512–520
23. Jepsen CF, Lundberg-Jensen AK, Faunoe P (2007) Does the position of the femoral tunnel affect the laxity or clinical outcome of the anterior cruciate ligament-reconstructed knee? A clinical, prospective, randomized, double-blind study. Arthroscopy 23:1326–1333
24. Kim K-I, Lee SH, Bae C, Bae SH (2017) Three-dimensional reconstruction computed tomography evaluation of the tunnel location and angle in anatomic single-bundle anterior cruciate ligament reconstruction: a comparison of the anteromedial portal and outside-in techniques. Knee Surg Relat Res 29:11–18
25. Koutras G, Papadopoulos P, Terzidis IP, Gigis I, Pappas E (2013) Short-term functional and clinical outcomes after ACL reconstruction with hamstrings autograft: transtibial versus anteromedial portal technique. Knee Surg Sports Traumatol Arthrosc 21:1904–1909
26. Lee MC, Seong SC, Lee S, Chang CB, Park YK, Jo H, Kim CH (2007) Vertical femoral tunnel placement results in rotational knee laxity after anterior cruciate ligament reconstruction. Arthroscopy 23:771–778
27. Loh JC, Fukuda Y, Tsuda E, Steadman RJ, Fu FH, Woo SL-Y (2003) Knee stability and graft function following anterior cruciate ligament reconstruction: comparison between 11 o'clock and 10 o'clock femoral tunnel placement. Arthroscopy 19:297–304
28. Markolf KL, Jackson SR, McAllister DR (2010) A comparison of 11 O'clock versus oblique femoral tunnels in the anterior cruciate ligament-reconstructed knee: knee kinematics during a simulated pivot test. Am J Sports Med 38:912–917
29. McRae SM, Chahal J, Leiter JR, Marx RG, Macdonald PB (2011) Survey study of members of the Canadian Orthopaedic Association on the natural history and treatment of anterior cruciate ligament injury. Clin J Sport Med 21:249–258

30. Mohtadi N (1998) Development and validation of the quality of life outcome measure (questionnaire) for chronic anterior cruciate ligament deficiency. Am J Sports Med 26:350–359
31. Noyes FR, Barber-Westin SD (2001) Revision anterior cruciate ligament reconstruction: report of 11-year experience and results in 114 consecutive patients. Instr Course Lect 50:451–461
32. Pascual-Garrido C, Swanson BL, Swanson KE (2013) Transtibial versus low anteromedial portal drilling for anterior cruciate ligament reconstruction: a radiographic study of femoral tunnel position. Knee Surg Sports Traumatol Arthrosc 21:846–850
33. Piasecki DP, Bach BR, Espinoza Orias AA, Verma NN (2011) Anterior cruciate ligament reconstruction: Can anatomic femoral placement be achieved with a transtibial technique? Am J Sports Med 39:1306–1315
34. Rahr-Wagner L, Thillemann TM, Pedersen AB, Lind MC (2013) Increased risk of revision after anteromedial compared with transtibial drilling of the femoral tunnel during primary anterior cruciate ligament reconstruction: results from the danish knee ligament reconstruction register. Arthroscopy 29:98–105
35. Riboh JC, Hasselblad V, Godin JA, Mather RC (2013) Transtibial versus independent drilling techniques for anterior cruciate ligament reconstruction: a systematic review, meta-analysis, and meta-regression. Am J Sports Med 41:2693–2702
36. Ristanis S, Giakas G, Papageorgiou CD, Moraiti T, Stergiou N, Georgoulis AD (2003) The effects of anterior cruciate ligament reconstruction on tibial rotation during pivoting after descending stairs. Knee Surg Sports Traumatol Arthrosc 11:360–365
37. Ristanis S, Stergiou N, Patras K, Vasiliadis HS, Giakas G, Georgoulis AD (2005) Excessive tibial rotation during high-demand activities is not restored by anterior cruciate ligament reconstruction. Arthroscopy 21:1323–1329
38. Scanlan SF, Chaudhari AMW, Dyrby CO, Andriacchi TP (2010) Differences in tibial rotation during walking in ACL reconstructed and healthy contralateral knees. J Biomech 43:1817–1822
39. Scopp JM, Jasper LE, Belkoff SM, Moorman CT (2004) The effect of oblique femoral tunnel placement on rotational constraint of the knee reconstructed using patellar tendon autografts. Arthroscopy 20:294–299
40. Silva A, Sampaio R, Pinto E (2010) Placement of femoral tunnel between the AM and PL bundles using a transtibial technique in single-bundle ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 18:1245–1251
41. Tanner SM, Dainty KN, Marx RG, Kirkley A (2007) Knee-specific quality-of-life instruments: which ones measure symptoms and disabilities most important to patients? Am J Sports Med 35:1450–1458
42. Tashman S (2004) Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. Am J Sports Med 32:975–983
43. Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL-Y (2002) Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. Am J Sports Med 30:660–666
44. Yamamoto Y (2004) Knee stability and graft function after anterior cruciate ligament reconstruction: a comparison of a lateral and an anatomical femoral tunnel placement. Am J Sports Med 32:1825–1832
45. Zhang Q, Zhang S, Li R, Liu Y, Cao X (2012) Comparison of two methods of femoral tunnel preparation in single-bundle anterior cruciate ligament reconstruction: a prospective randomized study. Acta Cir Bras 27:572–576