Original Article
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Rectangular-Tunnel Anterior Cruciate Ligament Reconstruction Using Quadriceps Tendon-Patellar Bone Autograft Can Reduce Early Donor Site Morbidity While Maintaining Comparable Short-term Clinical Outcomes

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Background: Rectangular tunnel and graft have been recently designed to closely resemble the native anatomy in anterior cruciate ligament reconstruction (ACLR). This study was performed to compare the short-term clinical outcomes between rectangular and round femoral tunnels in ACLR using quadriceps tendon-patellar bone (QTPB) autografts.

Methods: A total of 78 patients who underwent primary ACLR with QTPB autografts performed by three senior surgeons and had at least 1 year of postoperative follow-up were retrospectively reviewed. Patients who underwent rectangular tunnel ACLR (n = 40) were compared to those treated with the conventional round tunnel ACLR (n = 38). Outcomes including knee stability, clinical scores, quadriceps strength, associated complications, postoperative knee range of motion, and cross-sectional area of the graft were assessed.

Results: Significant improvements in knee stability and clinical scores were observed after surgery in both groups (all $p < 0.001$). The postoperative measurements of knee stability and clinical scores were not significantly different between the two groups. Knee extension strength deficit at 60°/sec was significantly less in the rectangular tunnel group than in the round tunnel group at postoperative 6 months (41.7% vs. 48.9%, $p = 0.032$). The cross-sectional area of the partial-thickness QTPB graft was approximately 60% of the full-thickness QTPB graft.

Conclusions: In the short-term, rectangular tunnel ACLR was comparable to round tunnel ACLR with QTPB autograft despite the smaller cross-sectional area. Additionally, the rectangular tunnel ACLR allowed partial-thickness grafting technique, which could subsequently reduce early donor site morbidity.

Keywords: *Anterior cruciate ligament, Anterior cruciate ligament reconstruction, Quadriceps muscle*

According to a recent anatomical study,[1] the anterior cruciate ligament (ACL) appears to be a flat, ribbon-like structure, and the previously well-known "double-bundle" structure[2] comes from the natural twist of this single, ribbon-like structure. Currently, anatomic ACL reconstruction (ACLR) respecting the native anatomy of the ligament is usually performed because of its biomechanical stability and better long-term clinical outcome.[3]

Rectangular grafts and tunnels have been designed for anatomic ACLR mimicking the flat, ribbon-like shape

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of the native ligament.[4] This technique has been performed with a couple of different types of grafts: bone-patellar tendon-bone (BPTB) graft[4] and quadriceps tendon (QT) graft.[5] A biomechanical comparative study[6] has shown favorable results for the rectangular tunnel when compared to the round tunnel in ACLR with BPTB autograft. Likewise, in ACLR with QT graft, another biomechanical study[7] has shown the advantages of an anatomic, rectangular tunnel over a conventional round one. Moreover, donor-site morbidity can be reduced with a rectangular tunnel ACLR with a QT graft because thinner, partial-thickness grafting is possible. However, its relatively smaller cross-sectional area may negatively affect graft stability and increase the re-rupture rate. To date, there seems to be a paucity of data comparing the clinical outcomes of rectangular and conventional round tunnels in ACLR with QT autograft.

This study was performed to compare the short-term clinical results of rectangular tunnel ACLR and round tunnel ACLR with quadriceps tendon-patellar bone (QTPB) autograft. It was hypothesized that rectangular tunnel ACLR, which respects the native anatomy, would prove better short-term clinical outcomes when compared to the conventional round tunnel ACLR.

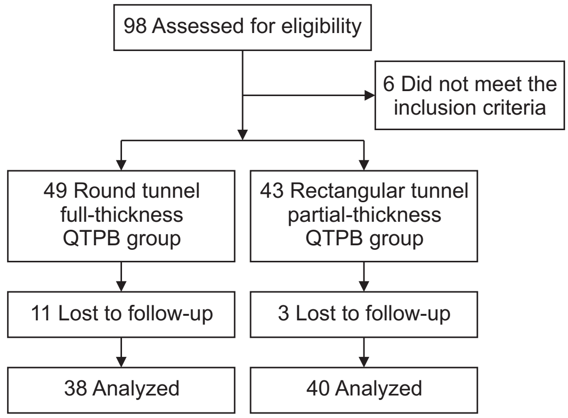

Fig. 1. Flow diagram of patients screened and grouped. QTPB: quadriceps tendon-patellar bone.

METHODS

The Institutional Review Board of Seoul National University Hospital approved this retrospective study (No. H-1503-148-661). This study was exempted of patient consent approved by the Institutional Review Board.

From February 2015 to September 2019, 98 patients who underwent either round tunnel ACLR with full-thickness QTPB autograft or rectangular tunnel ACLR with partial-thickness QTPB autograft in a single, tertiary institute were screened. The two different techniques were applied according to the surgeon's preference: one surgeon (HSH) performed ACLR using the rectangular tunnel technique, while the other two (MCL and SHL) used the round tunnel technique. Patients who were followed up for at least 1 year after primary ACLR were selected and the exclusion criteria were as follows: previous knee surgery, previous ligament injury, and concomitant ligament injury of the affected knee (other than grade I or II medial collateral ligament injury). Finally, 78 patients were included in this study (Fig. 1). The demographics of the patients included in the study are shown in Table 1.

Surgical Technique

All surgeries were performed by three senior surgeons (MCL, HSH, and SHL) with more than 20 years of experience in knee arthroscopy. The same surgical techniques were applied by different surgeons. In both groups, concomitant meniscal injuries were assessed intraoperatively and treated according to meniscal stability (Table 2). There was no significant difference of meniscal injury site (medial meniscus or lateral meniscus or both) proportion between the groups (chi-square test, $p = 0.072$).

Round tunnel ACLR group

The QTPB autografts were harvested through a 4-cm midline incision centered over the superior patellar pole.[8] A 10-mm-wide, 20–25-mm long, 7-mm-thick trapezoidal bone block was obtained from the patella with an oscillating saw. In continuity with this patellar bone block, a 10-mm-wide, 6-cm-long, full-thickness strip of the QT was excised. After the harvest, a round tibial tunnel 10 mm in diameter was drilled, and the intra-articular opening of the tunnel was aligned to the center of the ACL attachment. The round femoral tunnel was drilled at the anatomical footprint using the modified transtibial technique as previously described.[9] With the bone block heading to the proximal femoral side, the passed grafts were fixed with a metal interference screw (Conmed) on the femoral side. The tendinous portion was fixed on the tibial side with a 10-mm diameter and 25-mm length bioabsorbable screw (BIORCI-HA SCREW; Smith & Nephew Inc.) augmented by tying sutures over a cortical screw with the knee extended.

Rectangular tunnel ACLR group

The harvest procedures were similar to the round tunnel group except for the thickness of the patellar bone block and QT. The bone block was prepared with a 5-mm thick-

Table 1. Demographic Data of the Patients

Variable	Round tunnel QTPB group	Rectangular tunnel QTPB group	*p*-value
No. of knees	38	40	-
Age (yr)	32.1 ± 11.5	31.4 ± 10.0	0.796
Sex (male : female)	33 : 5	35 : 5	0.931
BMI (kg/m^2)	25.0 ± 4.3	25.2 ± 3.8	0.878
Side (right : left)	18 : 20	17 : 23	0.666

Values are presented as number or mean ± standard deviation.
QTPB: quadriceps tendon-patellar bone, BMI: body mass index.

Table 2. Intraoperative Meniscal Status and Treatment of the Patients in the Study

Variable	Round tunnel QTPB (n = 38)	Rectangular tunnel QTPB (n = 40)
Intact meniscus	22 (57.9)	18 (45.0)
MM tear	11 (28.9)	9 (22.5)
Repair	5	4
Partial meniscectomy	5	2
Observation	1	3
LM tear	2 (5.3)	11 (27.5)
Repair	0	5
Partial meniscectomy	2	6
Observation	0	0
Combined MM and LM tear	3 (7.9)	2 (5.0)
Repair	3	2

Values are presented as number (%) or number.
QTPB: quadriceps tendon-patellar bone, MM: medial meniscus, LM: lateral meniscus.

ness, and the QT was excised in partial thickness (5 mm thick) using a special harvesting device (Quad Cut; Karl Storz).[5] After the harvest, the graft was passed through a rectangular shaped tendon thickness tester to ensure tunnel passage; additional trimming was performed if the passage was insufficient. The tibial and femoral tunnels were prepared with a rectangular shaped rasp and dilator (Karl Storz). The tibial tunnel was centered at the remnant ACL attachment, and the femoral tunnel was made just posterior to the lateral intercondylar ridge at the anatomical footprint at 20-mm depth (Fig. 2). The anteromedial (AM) portal technique was used for femoral tunneling in this group. With the bone block heading to the proximal, femoral tunnel direction, the graft was passed to match the original twist of the graft;[5] the anterior portion of the graft at the tibia was aligned with the proximal part of the graft at the femur to mimic the AM bundle of the graft.[10] The fixation was done using a suspensory device (ACL Tightrope Up; Arthrex Inc.) on the femoral side and a bioabsorbable screw augmented by tying sutures over a cortical screw on the tibial side (Fig. 3).

Fig. 2. Postoperative computed tomography scan of a patient. The black arrowhead points to the position of the graft in the femoral tunnel.

Rehabilitation Protocol

The postoperative rehabilitation protocol was uniform over the entire study period. Continuous passive motion was initiated with an assistive device within 2 days after surgery and continued for 1–2 days during the period of hospitalization. A motion control brace set at 0°–90° was applied for 2 weeks. Full flexion was obtained within additional 2 weeks. Patients were limited to partial weight-bearing for 4 weeks and then progressed to full weight-bearing as tolerated. Full sports activity was allowed 6 months after surgery, and the recovery of quadriceps muscle strength was confirmed.

Clinical Evaluation

Clinical assessments were performed preoperatively, at 6 months postoperatively, and annually thereafter. Outcomes of interest included knee stability, quadriceps strength, clinical scores, postoperative knee range of motion (ROM), and any associated complications. Knee stability was evaluated via physical examinations (Lachman test and pivot-shift test) and KT-2000 arthrometer (MED

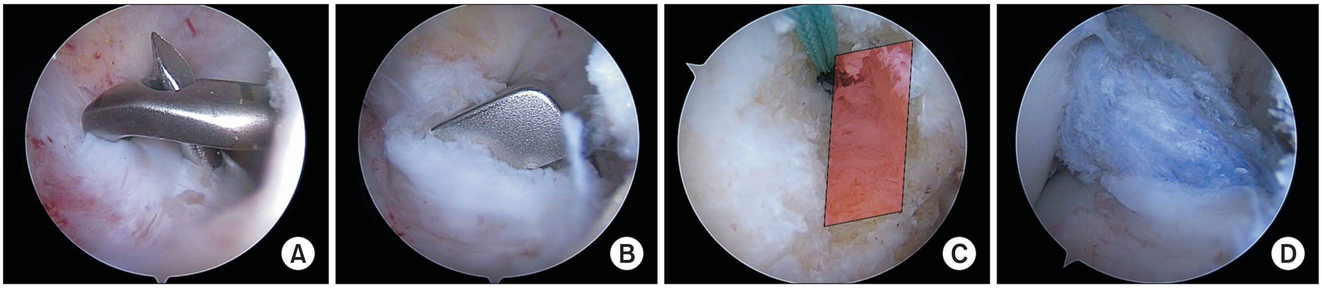

Fig. 3. Tunnel making and graft passage of the rectangular tunnel anterior cruciate ligament reconstruction group. (A) Tibial tunnel positioning using a guide pin. (B) Tibial tunnel preparation using a rectangular shaped dilator. (C) Femoral tunnel viewed from the previously made tibial tunnel. The red-shaded area denotes the rectangular shape of the femoral tunnel. (D) Anterior cruciate ligament graft viewed from the anterolateral portal after graft passage.

Metric Corp.). All physical examinations were performed by an independent observer (DWL). Physical examination grades were assessed in comparison to the contralateral side and side-to-side difference was used for the arthrometer. Contralateral knee pathologies were excluded in all of the patients because there were neither trauma history nor any symptoms, and no definite instability was observed in physical examinations of the contralateral knees. Quadriceps strength was measured using a Cybex II isokinetic dynamometer (CYBEX). The Cybex II results were recorded as percentage relative to the contralateral (normal) side. The Lysholm, subjective International Knee Documentation Committee (IKDC), Tegner Activity Scale, and Knee Injury and Osteoarthritis Outcome Score (KOOS) were obtained as clinical scores. Any complications, such as rerupture or anterior knee pain, were also recorded. Finally, the outcomes of the round tunnel ACLR and rectangular tunnel ACLR groups were compared.

Fig. 4. Mid-sagittal T1-weighted magnetic resonance image of a patient in the study. Thickness of the quadriceps muscle was measured at 2 cm above the upper pole of the patella. The white line segment indicates the thickness of the graft in the patient.

Radiological Evaluation

Radiologically, the cross-sectional areas of the two groups were compared. The graft thickness of full-thickness QTPB was calculated by measuring the thickness of the QT in the mid-sagittal plane using a preoperative magnetic resonance image scan (Fig. 4). The measurements were constantly made 2 cm above the upper pole of patella aiming at the mid-substance of ACL, which is about 4 cm in total length.[11] In contrast, due to the harvesting method, the graft thickness of partial-thickness QTPB was consistently 5 mm. Considering the flat shape of the graft in both groups, the cross-sectional area of the graft could be inferred by multiplying the width of the graft (which was 10 mm for both groups) and the thickness of the graft. Since the width of the grafts was the same between the groups (10 mm), the cross-sectional area of the graft between the groups was proportional to the thickness of the graft. All the radiological measurements were performed with a Picture Archiving and Communication System.

Statistical Analysis

Continuous variables were presented as mean and standard deviation, and categorical variables were presented as frequency and percentage. Comparisons between the round tunnel ACLR and rectangular tunnel ACLR groups were performed using the independent *t*-test and Fisher's exact test for continuous and categorical variables, respectively. Statistical analyses were performed using IBM SPSS ver. 25.0 (IBM Corp.). In all analyses, $p < 0.05$ was considered to indicate statistical significance.

RESULTS

Significant improvements in knee stability were observed after surgery in both groups, as determined by physical examination and knee arthrometry (Table 3). Postoperative knee stability in terms of Lachman, pivot-shift test, and KT-2000 arthrometry were not significantly different between the two groups. Postoperative knee ROM was also not significantly different between round and rectangular tunnel ACLR groups (139.8° ± 7.8° and 139.5° ± 4.4°, respectively, $p = 0.888$). The Cybex II results showed decreases in knee extension strength (both 60° and 180°) at postoperative 6 months, which partially recovered at 1 year postoperatively (Fig. 5).

The extension strength deficits at postoperative 1 year were not significantly different between the two groups. However, extension strength deficit at 60° was significantly higher in the round tunnel ACLR group than in the rectangular tunnel ACLR group at 6 months postoperatively (48.9% vs. 41.7%, $p = 0.032$). Clinical scores (IKDC, Lysholm, Tegner, and KOOS) improved markedly after ACLR in both groups (Table 4). There were no significant differences in the preoperative clinical scores except for IKDC scores. The preoperative IKDC score was significantly higher in the rectangular tunnel ACLR group ($p = 0.02$). The clinical scores were not significantly different between the groups postoperatively. No complications such as retear or anterior knee pain were observed until the 1-year follow-up in both groups.

The thickness of the full-thickness QTPB graft was 8.0 ± 1.1 mm, which was thicker than the partial-thickness QTPB graft (5 mm). By multiplying the width of the graft (10 mm), the average cross-sectional area of the full-thickness and partial-thickness QTPB grafts was 80 mm^2 and 50 mm^2, respectively. The cross-sectional area of the partial-thickness QTPB graft (rectangular tunnel ACLR group) was 62.5% of the average cross-sectional area of the full-thickness QTPB graft (round tunnel ACLR group).

DISCUSSION

The most important findings of this study are as follows: (1) despite a smaller cross-sectional area (about 60%), rectangular tunnel ACLR showed comparable short-term clinical outcomes in comparison to conventional round tunnel ACLR and (2) postoperative reduction in knee extension strength was smaller with the partial-thickness QTPB (rectangular tunnel ACLR group) at 6 months, although this difference was not maintained until 1 year. These findings imply that in the short-term, rectangular tunnel ACLR with partial-thickness QTPB is a comparable reconstruction technique and reduces donor site morbidity (knee extension strength deficit).

According to a recent study by Smigielski et al.,[1] the

Table 3. Evaluation of Knee Instability in the Two Groups before Surgery and at Postoperative 1 Year

Variable	Preoperative			Postoperative 1 year		
	Round tunnel QTPB	Rectangular tunnel QTPB	*p*-value	Round tunnel QTPB	Rectangular tunnel QTPB	*p*-value
Lachman test			0.976			> 0.999
Grade 0	2 (5.3)	2 (5.0)		21 (55.3)	22 (55.0)	
Grade 1	18 (47.4)	17 (42.5)		16 (42.1)	16 (40.0)	
Grade 2	16 (42.1)	18 (45.0)		1 (2.6)	2 (5.0)	
Grade 3	2 (5.3)	3 (7.5)		0	0	
Pivot shift test			0.983			> 0.999
Grade 0	4 (10.5)	5 (13.8)		20 (52.6)	21 (52.5)	
Grade 1	12 (31.6)	14 (35.0)		16 (42.1)	17 (42.5)	
Grade 2	19 (50.0)	18 (45.0)		2 (5.3)	2 (5.0)	
Grade 3	3 (7.9)	3 (7.5)		0	0	
KT-2000 arthrometry	3.7 ± 2.0	3.7 ± 2.1	0.269	2.1 ± 1.1	1.8 ± 1.0	0.975

Values are presented as number (%) or mean ± standard deviation.
QTPB: quadriceps tendon-patellar bone.

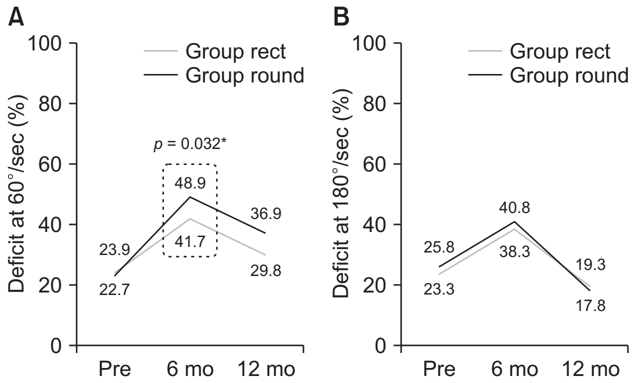

Fig. 5. The mean side-to-side ratio of peak torque values according to Cybex II isokinetic testing performed at 60° (A) and 180° (B) per second at each time period (rectangular tunnel QTPB group [Group rect] vs. round tunnel QTPB group [Group round]). QTPB: quadriceps tendon-patellar bone. The asterisk denotes the statistically significant difference (< 0.05).

Table 4. Clinical Scores of the Two Groups before Surgery and at Postoperative 1 Year

Variable	Round tunnel QTPB	Rectangular tunnel QTPB	*p*-value
Subjective IKDC			
Preoperative	48.1 ± 14.5	57.1 ± 12.8	0.02
Postoperative 1 yr	76.5 ± 11.8	80.8 ± 11.2	NS
Lysholm			
Preoperative	67.1 ± 16.2	72.7 ± 14.3	NS
Postoperative 1 yr	90.6 ± 7.1	91.5 ± 7.8	NS
Tegner			
Preoperative	3.3 ± 1.7	2.8 ± 1.3	NS
Postoperative 1 yr	4.9 ± 1.6	5.1 ± 1.0	NS
KOOS			
Preoperative	274 ± 103	316 ± 64.1	NS
Postoperative 1 yr	420 ± 45.7	425 ± 43.6	NS

Values are presented as mean ± standard deviation.
QTPB: quadriceps tendon-patellar bone, IKDC: International Knee Documentation Committee, KOOS: Knee Injury and Osteoarthritis Outcome Score, NS: not significant.

shape of the ACL from mid-substance to femoral attachment is flat, ribbon-like, rather than circular. The ACL was thought to be divided into two separate bundles, AM and posterolateral (PL) for the past several years.[12] However, this cadaveric study[1] revealed that the flat, ribbon-shaped ACL was twisted to mimic the two strands (AM and PL) and was not actually divided. The ACL functionally becomes a double-bundle (AM and PL) structure by such a twist of the ligament. As a result, questions have been raised upon the conventional method of making the bone tunnel into a circular shape using a circular drill and incorporating a circular graft (hamstring, etc.). The double-bundle reconstruction method also has several disadvantages, such as a long operation time, problem of bone tunneling during revision surgery, and disparity from the actual anatomy.[13] Therefore, ACLR using a rectangular tunnel and graft is newly performed to resemble the native anatomy of the ACL.

Rectangular tunnel and graft have shown favorable results with BPTB graft.[6,14,15] Anatomic rectangular tunnel ACLR with BPTB graft resulted in excellent subjective and objective clinical outcomes in a case series of 61 patients.[15] At 2 years after ACLRs, all of the patients were classified as normal or nearly normal in the subjective IKDC assessment; 98.4% and 95.1% of the patients had negative Lachman and pivot-shift test, respectively. The postoperative rate of anterior knee pain was not assessed in the study.[15] Higher proportion of negative Lachman and pivot-shift test (98.4% and 95.1%, respectively) was observed in the previous study[15] compared to the current study (55% and 52.5%, respectively). Different graft choice (BPTB and QTPB graft) between the studies may have accounted for this large difference; however, subjective nature of physical examination (different interpreters) and lack of preoperative Lachman and pivot-shift test in the former study[15] hinder direct comparison. In a biomechanical cadaveric study[6] that compared rectangular versus round tunnel ACLR with BPTB graft, rectangular tunnel ACLR better resembled the normal knee. The normal positional relationship between the femur and tibia was impaired in the round tunnel group. Femoral tunnel enlargement was also smaller in another study[14] that compared rectangular BPTB with double-tunnel hamstring ACLR, although the graft choice (instead of tunnel shape) may have accounted for the difference.

Rectangular tunnel and graft have also been applied in QT grafts by some surgeons, and their surgical methods (without any clinical outcomes yet) have been published.[5] Herbort et al.[7] performed a cadaveric study comparing the biomechanics between a rectangular tunnel ACLR with a QT and BPTB graft versus a round tunnel ACLR with a hamstring graft. In the study,[7] ACLR with a rectangular-tunnel (either QT or BPTB) resulted in better anterior stability at low flexion angles (0° and 15°). However, to our knowledge, no study has yet evaluated the clinical outcomes of rectangular tunnel and graft in ACLRs with

QT grafts. Despite the relatively lower usage of QT grafts in ACLR over the past years, a recent meta-analysis[16] comparing QT and BPTB in ACLR showed that the two graft choices have similar clinical outcomes and failure rates, while anterior knee pain was less common with the QT graft. These findings suggest that QT is an excellent alternative to other popular grafts (BPTB, hamstring) in ACLR. Moreover, owing to its thicker anatomy compared to the patellar tendon, partial-thickness grafting is possible for QT. Partial-thickness QT grafts in ACLR have shown non-inferior clinical outcomes and less donor-site morbidity when compared to full-thickness QT grafts.[17] In this study, short-term sparing of extensor strength was reproduced in partial-thickness QTPB (rectangular tunnel group), although there were no significant clinical differences.

ACL strength is related to graft diameter according to biomechanical and clinical evidence.[18,19] In the current study, the cross-sectional area of partial-thickness QTPB (50 mm^2) was approximately 60% of the average full-thickness QTPB graft (80 mm^2). Despite the significantly smaller cross-sectional area, clinical outcomes, including knee stability, were not negatively affected in the short term. It is noteworthy that this smaller cross-sectional area of partial-thickness QTPB (50 mm^2) is still larger than the average mid-substance cross-sectional area of native ACL[20] (46.9 mm^2) and thus may have led to comparable knee stability in this analysis. In accordance with our study, smaller size autografts were as effective as larger size allografts in a recent study[21] on ACLR. Theoretically, thicker grafts in ACLR may lead to graft impingement and consequently reduce knee ROM. However, despite the differences in graft thickness, postoperative knee ROM was not significantly different between the groups in this study.

This study has some limitations. First, retrospectively collected data were analyzed. Second, the follow-up period was short, and the sample size was not large. Third, the patients in the study underwent surgery by 3 different surgeons, and this difference may have affected the clinical results of the study. Nevertheless, to date, this is the first study comparing the clinical results of rectangular tunnel ACLR with round tunnel ACLR with QTPB autograft.

In the short term, rectangular tunnel ACLR was comparable to round tunnel ACLR with QTPB autograft despite a smaller cross-sectional area. Additionally, the rectangular tunnel ACLR allowed the partial-thickness grafting technique, which could subsequently reduce early donor site morbidity.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Smigielski R, Zdanowicz U, Drwiega M, Ciszek B, Ciszkowska-Lyson B, Siebold R. Ribbon like appearance of the midsubstance fibres of the anterior cruciate ligament close to its femoral insertion site: a cadaveric study including 111 knees. Knee Surg Sports Traumatol Arthrosc. 2015;23(11):3143-50.
2. Suomalainen P, Kannus P, Jarvela T. Double-bundle anterior cruciate ligament reconstruction: a review of literature. Int Orthop. 2013;37(2):227-32.
3. Murawski CD, Wolf MR, Araki D, Muller B, Tashman S, Fu FH. Anatomic anterior cruciate ligament reconstruction: current concepts and future perspective. Cartilage. 2013;4(3 Suppl):27S-37S.
4. Shino K, Nakata K, Nakamura N, Toritsuka Y, Nakagawa S, Horibe S. Anatomically oriented anterior cruciate ligament reconstruction with a bone-patellar tendon-bone graft via rectangular socket and tunnel: a snug-fit and impingement-free grafting technique. Arthroscopy. 2005;21(11):1402.
5. Fink C, Lawton R, Forschner F, Gfoller P, Herbort M, Hoser C. Minimally invasive quadriceps tendon single-bundle, arthroscopic, anatomic anterior cruciate ligament reconstruction with rectangular bone tunnels. Arthrosc Tech. 2018;7(10):e1045-56.
6. Suzuki T, Shino K, Otsubo H, et al. Biomechanical comparison between the rectangular-tunnel and the round-tunnel

anterior cruciate ligament reconstruction procedures with a bone-patellar tendon-bone graft. Arthroscopy. 2014;30(10): 1294-302.

7. Herbort M, Tecklenburg K, Zantop T, et al. Single-bundle anterior cruciate ligament reconstruction: a biomechanical cadaveric study of a rectangular quadriceps and bone--patellar tendon--bone graft configuration versus a round hamstring graft. Arthroscopy. 2013;29(12):1981-90.

8. Han HS, Seong SC, Lee S, Lee MC. Anterior cruciate ligament reconstruction : quadriceps versus patellar autograft. Clin Orthop Relat Res. 2008;466(1):198-204.

9. Lee JK, Lee S, Kim KT, Lee MC. Anatomic tunnel placement can be achieved with a modification to transtibial technique in single bundle anterior cruciate ligament reconstruction: a cadaver study. PLoS One. 2017;12(7):e0180860.

10. Shino K, Nakata K, Nakamura N, et al. Rectangular tunnel double-bundle anterior cruciate ligament reconstruction with bone-patellar tendon-bone graft to mimic natural fiber arrangement. Arthroscopy. 2008;24(10):1178-83.

11. Chhabra A, Starman JS, Ferretti M, Vidal AF, Zantop T, Fu FH. Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. J Bone Joint Surg Am. 2006;88 Suppl 4:2-10.

12. Irarrazaval S, Albers M, Chao T, Fu FH. Gross, arthroscopic, and radiographic anatomies of the anterior cruciate ligament: foundations for anterior cruciate ligament surgery. Clin Sports Med. 2017;36(1):9-23.

13. Longo UG, Buchmann S, Franceschetti E, Maffulli N, Denaro V. A systematic review of single-bundle versus double-bundle anterior cruciate ligament reconstruction. Br Med Bull. 2012;103(1):147-68.

14. Tachibana Y, Mae T, Shino K, et al. Femoral tunnel enlargement after anatomic anterior cruciate ligament reconstruction: bone-patellar tendon-bone /single rectangular tunnel versus hamstring tendon / double tunnels. J Orthop Sci. 2018;23(6):1011-8.

15. Tachibana Y, Shino K, Mae T, Iuchi R, Take Y, Nakagawa S. Anatomical rectangular tunnels identified with the arthroscopic landmarks result in excellent outcomes in ACL reconstruction with a BTB graft. Knee Surg Sports Traumatol Arthrosc. 2019;27(8):2680-90.

16. Li F, Gu XD, Wei XC. Outcomes of quadriceps tendon autograft versus bone-patellar tendon-bone autograft for anterior cruciate ligament reconstruction:a meta-analysis. Zhongguo Gu Shang. 2020;33(7):677-83.

17. Kanakamedala AC, de Sa D, Obioha OA, et al. No difference between full thickness and partial thickness quadriceps tendon autografts in anterior cruciate ligament reconstruction: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2019;27(1):105-16.

18. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. J Bone Joint Surg Am. 1984;66(3):344-52.

19. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. Arthroscopy. 2012;28(4):526-31.

20. Iriuchishima T, Yorifuji H, Aizawa S, Tajika Y, Murakami T, Fu FH. Evaluation of ACL mid-substance cross-sectional area for reconstructed autograft selection. Knee Surg Sports Traumatol Arthrosc. 2014;22(1):207-13.

21. Kurtoglu A, Basar B, Basar G, Gezginaslan O, Basar H. Small size autograft versus large size allograft in anterior cruciate ligament reconstruction. Clin Orthop Surg. 2021; 13(1):47-52.