Peroneus Longus Tendon Autograft is a Safe and Effective Alternative for Anterior Cruciate Ligament Reconstruction

Fu-Dong Shi, MD, PhD[1] Daniel Edward Hess, MD[2] Jin-Zeng Zuo, MD[3] Shi-Jie Liu, MD[1] Xue-Chen Wang, MD[1] Yong Zhang, MD[1] Xiao-Guang Meng, MD[1] Ze-Jun Cui, MD[1] Shao-Ping Zhao, MD[1] Chang-Jiang Li, MD[1] Wan-Ning Hu, MD[1]

[1] Department of Orthopaedics, Tangshan People's Hospital, Tangshan, China
[2] Department of Orthopaedic Surgery, University of Virginia, Charlottesville, Virginia
[3] Department of Orthopaedic Trauma, The Second Hospital of Tangshan, Tangshan, China

Address for correspondence Daniel Edward Hess, MD, Department of Orthopaedic Surgery, University of Virginia, 400 Ray C. Hunt Dr., Charlottesville, VA 22903 (e-mail: dh4nb@virginia.edu).

J Knee Surg

Abstract

The ipsilateral peroneus longus tendon (PLT) was utilized as an autograft for anterior cruciate ligament (ACL) reconstruction of patients with acute ACL rupture and grade III medial collateral ligament (MCL) injury. We investigated the efficacy and safety of this alternative autograft compared with autologous hamstring tendon (HT). Biomechanical testing of the graft options was performed and compared with the native ACL. Thirty-eight patients with acute ACL ruptures and grade III MCL injuries were treated with ACL reconstruction with a doubled autologous PLT or quadrupled autologous HT. Knee stability and function was evaluated clinically with the Lachman test and KT-2000 arthometer as well as subjectively with functional scores. Effects on the donor ankle were evaluated by biomechanical testing. The ultimate tensile strengths of doubled PLT and quadrupled HT were significantly higher than that of the native ACL and the ultimate tensile strength of doubled PLT was comparable with that of quadrupled HT. There were no significant differences in clinical or functional scores between the two groups. There were no significant differences in pre- and postoperative biomechanical testing of the donor ankle. PLT is a suitable alternative autograft for an ACL reconstruction in patients with a concomitant grade III MCL injury without a significant biomechanical disadvantage to the ankle donor site.

Keywords
- ACL reconstruction
- peroneus longus
- autograft

Many graft options exist for reconstruction of an anterior cruciate ligament (ACL) rupture with injury-specific and patient-specific considerations that need to be made during preoperative planning. Most commonly described and used techniques for index procedures are bone–patellar–bone autograft and quadrupled, or four-strand, hamstring autograft.[1–6] However, bone–patellar–bone autograft, while having the longest history of use, can be complicated by anterior knee pain, especially in patients who spend a lot of time on their knees for their culture, job, or sport, and less commonly can be associated with postoperative patella fracture, fat pad fibrosis, or patellar tendon contracture.[1,2,7–9] Hamstring harvest medially can damage the saphenous nerve and could potentially lead to instability of the medial knee joint if the ACL rupture is accompanied by a grade III injury of medial collateral ligament (MCL).[9–12] Postoperative varus or valgus instability from collateral ligament injuries can jeopardize the durability of the graft. In addition, ACL and MCL

received
September 29, 2017
accepted after revision
July 23, 2018

DOI https://doi.org/10.1055/s-0038-1669951.
ISSN 1538-8506.

combined injuries are typically higher energy injuries with larger zones of injury and published data have shown an increase in prevalence of such injuries in recent years.[13–15] Medial hamstring harvest should be avoided in patients with skin and soft tissue injury in the area of the pes anserine insertion to avoid surgical infection. Additionally, another feasible autograft would be useful in revision situations or as a supplement to other autograft choices.

An ideal autograft donor should have an acceptable amount of strength, be of adequate size, and be easily and safely harvested. There is precedent in the literature suggesting alternative autografts for ACL reconstruction, such as the peroneus longus tendon (PLT).[16] Zhao and Huangfu found that the anterior half of peroneus longus tendon (AHPLT) has enough length and strength to be effective as an autograft choice in an ACL reconstruction. Satisfactory results after 2 years of follow-up was shown when using the anterior half of the PLT, but there was no direct comparison of the functional outcomes between AHPLT and hamstring tendon (HT).[17] Biomechanical and kinematic studies have shown that removing the entire PLT has no effect on gait or stability of the ankle.[18]

In this study, fresh PLT, HT, and ACL specimens were obtained from the limbs of patients who received a transfemoral amputation above the lower third of the thigh and underwent biomechanical testing. Multiple biomechanical studies have already looked at load to failure of various graft choices. The intact native ACL load to failure has been reported to be 1,725 Newtons. In comparison, bone-patellar tendon-bone autograft and quadrupled HT autograft load to failure have been shown to be 2,600 and approximately 4,000 Newtons, respectively.

MCL injury of a grade II or more has been shown to be an independent risk factor for postoperative knee instability after ACL reconstruction.[10] Given the difficulties and potential complications fraught with a medial hamstring harvest in a grade III MCL–ACL combined injured knee, our purpose in this study was to highlight an alternative autograft option. Once establishing the feasibility of using a peroneus longus graft with in vitro testing, our study then aimed to show in vivo data to show the effectiveness and safety of the PLT in ACL reconstruction with concomitant MCL repair is comparable to an accepted gold standard (HT).

Materials and Methods

Specimens for Graft Biomechanical Testing

Fresh PLT, HT, and ACL specimens were obtained from the limbs of 16 patients (11 males, 5 females; age range, 35–65 years) who received a transfemoral amputation above the lower third of the thigh at our institution between January 2009 and June 2011. Indications for amputation were trauma and malignant tumor involvement of the pelvis or femur. Specimens with damage to the PLT and/or HT were excluded. The study was approved by the Institutional Ethics Committee, and written consents were obtained from all participants.

Patients

A total of 38 acute ACL ruptures with concomitant grade III MCL injuries admitted to our institution between December 2002 and October 2012 were included in this study. This was a consecutive series of patients with this injury pattern and all received surgery. The diagnosis was made based on clinical exam, magnetic resonance imaging (MRI), and eventual arthroscopy. All of the patients included in this study were skeletally mature with closed physes. They were randomly divided into two groups: group A (18 cases) used ipsilateral autologous double-strand PLT for the ACL reconstruction, while the patients in group B (20 cases) received autologous four-strand HT graft. The patients were divided into the two groups using a random number method. In all patients, after ACL reconstruction, the MCL was repaired with TWINFIX (Smith & Nephew, London, UK) suture devices. All MCL repairs were from the distal insertion. The posterior oblique ligament and proximal MCL were not involved in any of our included patients. Group A had an average age of 42 years old (range, 19–58 years old). The average age in group B was 40 years old (range, 21–54 years old). There were comparable male:female ratios in each group and the preoperative activity level, preoperative Tegner scores, and comorbidities were similar between the two groups.

Biomechanical Testing

The double-strand PLT and four-strand HT were harvested from the amputated limbs as described previously. The gracilis and semitendinosus tendons were harvested using a standard medial approach and a tendon stripper (►**Fig. 1**). The PLT was harvested with a lateral incision and the tendonous portion resected. The tendon was harvested 1 to 1.5 cm proximal from its distal insertion. The PLT autograft was divided into an upper section and a lower section at its midpoint. The HT and PLT were both preloaded for 10 minutes with 10 pounds and then placed into the tensile testing machine. The ultimate tensile strengths (N) and maximum length of deformation (mm) of double-strand PLT, four-strand HT, and native ACL were detected by tensile testing machine (Bose 3200). Preoperative and postoperative function of the donor ankle on patients in group A was evaluated by ankle biomechanical testing machine (Bose 3200). The amount of force that the ankle could generate with dorsiflexion and plantar flexion (N) was measured preoperatively and postoperatively at 12 and 24 months after surgery. The amount of torque (Nm) that the donor ankle could generate compared with the nondonor side was measured at the preoperative visit and 24 months postoperatively using the Biodex System 4 robotic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). Eccentric and concentric contraction forces were measured with the ankle performing inversion and eversion motions at various test speeds (30 and 180 deg/s). The torque force was compared with the donor ankle prior to tendon harvest as well as the contralateral ankle 24 months postoperatively.

The Operative Procedure

The surgeries were all performed by a single surgeon with more than 500 similar cases of experience. Of the 38 ACL reconstructions, 18 were performed with ipsilateral autologous double-strand PLT and 20 cases were performed

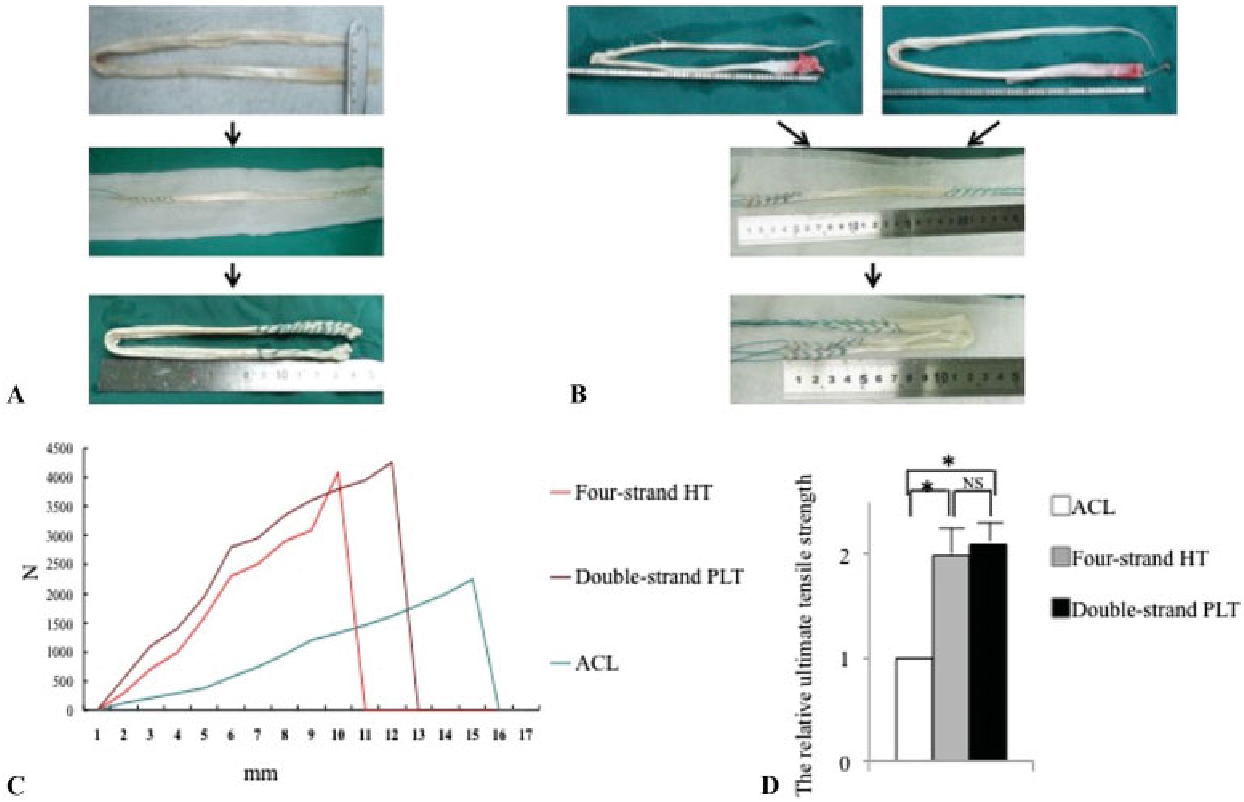

Fig. 1 Biomechanical testing of human peroneus longus tendon (PLT), hamstring tendon (HT), and anterior cruciate ligament (ACL) in vitro. (**A**) Preparation of double-strand PLT: the two ends of PLT were sutured, and then folded in half for two-strand thickness. (**B**) Preparation of four-strand HT: the gracilis tendon and semitendinosus tendon were combined, and then folded in half for four-strand thickness. (**C**) Representative graph of the ultimate tensile strength (unit: Newton, N) and maximum deformation curve (unit: mm) of PLT (double strand), HT (four- strand), and ACL. (**D**) The relative ultimate tensile strength of PLT (double strand), HT (four- strand) with that of ACL as control. Results are expressed as mean ± standard deviation (SD) ($n = 16$). $^{*}p < 0.05$. NS, no significant difference.

with ipsilateral autologous four-strand HT. Both groups had arthroscopic-assisted single-bundle ACL reconstruction procedures with an Endobutton (Smith & Nephew) for fixation. Of note, prior to 2008, a transtibial drilling technique was utilized. After 2008, separate anterior-medial drilled femoral tunnels were used. Meniscal pathology and cartilage damage was also assessed and addressed at the time of surgery. The representative images of the ACL reconstruction with autologous ipsilateral double-strand PLT are presented in ►**Fig. 2A–E**. For the PLT harvest, care was taken to distinguish the PLT from the peroneus brevis tendon (PBT). The PBT was identified at its insertion site and was isolated from the PLT. The PLT was completely transected 1 to 1.5 cm proximal to its insertion, and harvested proximally with a tendon stripper (as seen in ►**Video 1**). The graft was prepared for routine ACL reconstruction. The PBT and remaining PLT stump were sutured together to maintain some function of the PLT. TWINFIX (Smith & Nephew) suture devices were used for direct repair of the MCL tear. Radiographs were performed for all patients on postoperative day 3 to ensure there were no early hardware complications. Group B (autologous HT) ACL reconstructions were performed as routine. An accessory medial portal was used for drilling of the femoral tunnels for both groups. No complications were encountered in any of the surgical procedures.

Video 1

The video shows a tendon stripper used to harvest the peroneus longus tendon autograft. Online content including video sequences viewable at: https://www.thieme-connect.com/ejournals/html/doi/10.1055/s-0038-1669951

Postoperatively, the patients were all placed in articulating knee braces. Active knee extension and quadriceps contraction exercises along with ankle plantar and dorsiflexion exercises were started on postoperative day 2. Eight days after the surgery, active knee flexion was permitted to 30°. Knee flexion was increased to 90 and 120 degrees 4 and 6 weeks postoperatively, respectively. The patients weaned off the crutches by 6 weeks, and resumed most daily activities by 3 months and full physical activity by 1 year. The rehabilitation was guided by the surgeon who performed the reconstructive surgery.

Evaluation on the Effects of the Surgeries

Knee stability and function were evaluated clinically with the Lachman test and KT-2000 arthrometer (MEDmetric Corporation, San Diego, CA) and subjectively with Tegner–Lysholm

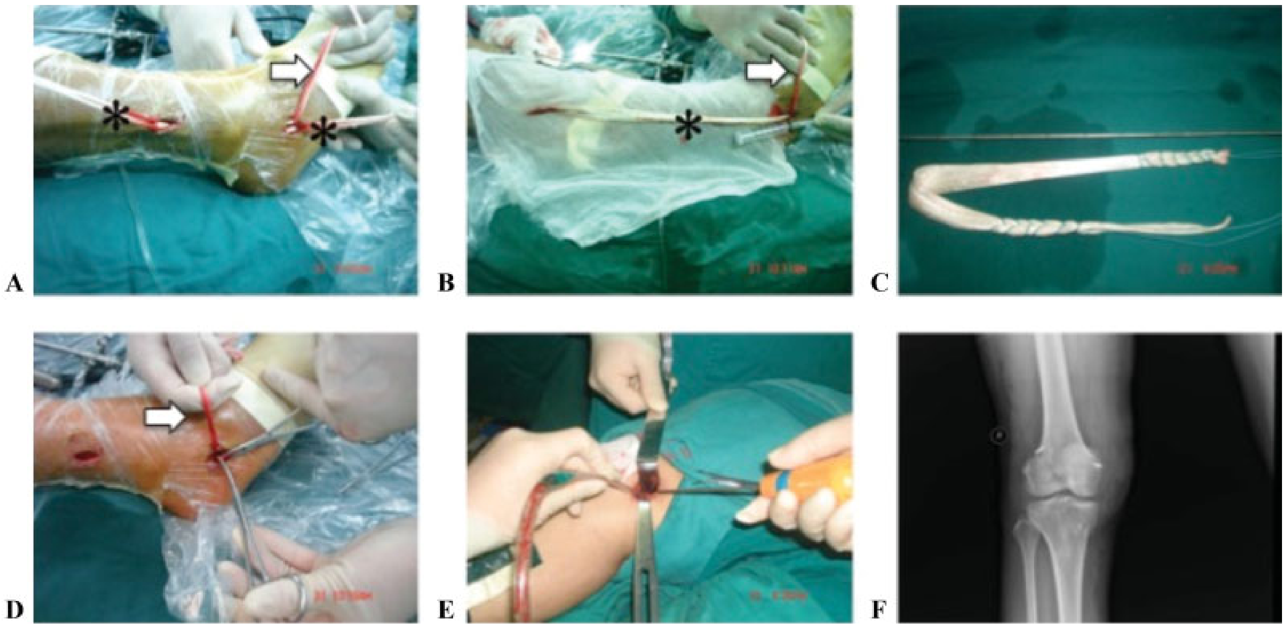

Fig. 2 Reconstruction of anterior cruciate ligament (ACL) with autologous ipsilateral double-strand peroneus longus tendon (PLT) for acute ACL ruptured patients accompanied by grade III injury of the medial collateral ligament (MCL). (**A–E**) The representative images of surgical operation. (**A**) Discriminating between PLT and peroneus brevis tendon (PBT). Asterisk indicates PLT, arrow indicates PBT. (**B**) The length of PLT is generally approximately 30 cm. The diameter is generally 8 to 9 mm. The PLT was resected 1 to 1.5 cm proximal to its distal insertion. (**C**) The two ends of the PLT were sutured for ACL reconstruction. (**D**) The retention of PLT and PBT were sutured. (**E**) The injured MCL was repaired by TWINFIX. (**F**) X-ray images of the patient 3 days postoperatively.

Knee Scoring Scale and the International Knee Documentation Committee (IKDC) Subjective Knee Form at 6, 12, and 24 months postoperatively. The Lachman test was given a grade (I, II, or III) depending on the amount of anterior translation (3–5, 5–10, $>$ 10 mm, respectively) of the tibia on the femur. This was verified with the more objective KT-2000 machine at 24 months postoperatively. The MCL repair integrity was evaluated clinically at each follow-up visit with valgus stress of the knee at 0 degrees and 30 degrees of flexion to verify that there was no pathological laxity and that there were firm endpoints.

Statistical Analysis

Statistical analysis was performed using SPSS 12.0. One-way analysis of variance was used to analyze group differences. The results of the Lachman tests and subjective index appraisal were analyzed using the chi-square test. A *p*-value of < 0.05 was considered to indicate a statistically significant difference.

Results

The Ultimate Tensile Strength of Double-Strand PLT is Comparable with Four-*Strand* HT In Vitro

To find more suitable transplant material for the acute ACL ruptured patient with grade III MCL injury, the biomechanical characters of PLT, HT, and ACL were compared in vitro in this study. The fresh PLT, HT, and ACL specimens were obtained from 16 patients with transfemoral amputation above the lower third of the thigh. ►**Fig. 1A** and **B** show the preparation of the doubled PLT (►**Fig. 1A**) and quadrupled HT (►**Fig. 1B**) for biomechanical testing. As shown in ►**Table 1**, the ultimate tensile strengths of doubled PLT, quadrupled HT, and native ACL were 4,268 $\pm$ 285, 4,090 $\pm$ 265, and 2,020 $\pm$ 264 N, respectively. The data showed that the ultimate tensile strengths of both doubled PLT and quadrupled HT were significantly higher than that of the native ACL ($p < 0.05$), whereas the ultimate tensile strength of double-strand PLT was comparable with four-strand HT in vitro (►**Fig. 1C** and **D**). From a strength standpoint, the doubled PLT should be considered as a comparable substitute material of quadrupled HT for the combined ACL–MCL injury patient.

Table 1 Mechanical test results of tendons and ligaments

	Ultimate tensile strength (N)	Max deformation (mm)
Anterior cruciate ligament	2,020 $\pm$ 264	14.98 $\pm$ 4.35
Posterior cruciate ligament	2,168 $\pm$ 458	15.18 $\pm$ 3.46
Hamstring[a]	4,090 $\pm$ 265	12.27 $\pm$ 2.78
Peroneus longus tendon[b]	4,268 $\pm$ 285	13.36 $\pm$ 2.35

[a]Quadrupled hamstring tendon.
[b]Doubled peroneus longus tendon.

Table 2 Knee Lachman tests at 6, 12, and 24 months after surgery

	6 months after surgery			12 months after surgery			24 months after surgery		
Indicators	**0**	**I**	**II–III**	**0**	**I**	**II–III**	**0**	**I**	**II–III**
Group A (cases)	16	2	0	15	3	0	14	4	0
Group B (cases)	17	3	0	17	1	2	16	2	2
p-Values	0.817			0.872			0.875		

Note: $p < 0.05$ was considered statistically significant.

Application of Autologous Ipsilateral Double-strand PLT for ACL Reconstruction in Acute ACL Ruptured Patients with III Degree MCL Injury

A total of 38 acute ACL ruptures with concomitant grade III MCL injuries were selected. Eighteen patients were randomized into the double-strand PLT (group A) and 20 patients were randomized into the four-strand HT (group B) for autologous grafts for the ACL reconstruction portion of the surgery.

Postoperative Effect Evaluation by Lachman Test, KT-2000 Arthrometer, and Subjective Index Appraisal

Knee stability and function were evaluated in both group A and B clinically with the Lachman test (►**Table 2**), KT-2000 arthrometer (►**Table 3**), and subjectively with Tegner–Lysholm Knee Scoring Scale and the IKDC Subjective Knee Form (►**Table 4**) at 6, 12, and 24 months postoperatively. There was no statistically significant difference between the two groups at 6 months postoperatively ($p = 0.817$). Similarly, there was no statistically significant difference ($p = 0.872$ at 1 year, $p = 0.875$ at 2 years) between the two groups at 12 or 24 months postoperatively. More objectively, a KT-2000 machine was used to test anterior drawer laxity difference 24 months postoperatively (►**Table 3**) and verify the more subjective findings on the Lachman test. A uniform anterior force of 134 N was used. The results correlated with our Lachman test exam findings and were not statistically different between the two groups ($p = 0.798$).

Table 3 KT-2000 measurements 24 months postoperatively

Anterior translation	Group A	Group B	*p*-Value
0–2 mm	15 (83.33%)	16 (80.00%)	0.798
3–5 mm	3 (16.67%)	3 (15.00%)	
> 6 mm	0 (0%)	1 (5%)	

Note: $p < 0.05$ was considered statistically significant.

For the results of subjective index appraisal at 6 months postoperatively, there were no significant differences of Tegner scores between group A (6 ± 0.46) and group B (6 ± 0.57), Lysholm scores between group A (94 ± 6.02) and group B (95 ± 2.35), nor was there a statistical difference of IKDC knee functional score (group A: 89.45 ± 2.89, group B: 90.12 ± 4.56). For the results of subjective index appraisal at 12 months, there were no significant differences of Tegner scores between group A (5 ± 0.96) and group B (6 ± 0.03), Lysholm scores between group A (94 ± 6.67) and group B (95 ± 3.55), nor was there a statistical difference IKDC knee functional score (group A: 90.48 ± 2.36, group B: 90.17 ± 4.32). For the results of subjective index appraisal at 24 months, there were no significant differences of Tegner scores between group A (5 ± 0.89) and group B (6 ± 0.12), Lysholm scores between group A (92 ± 6.81) and group B (93 ± 5.22), nor was there a statistical difference IKDC knee functional score (group A: 90.13 ± 3.01, group B: 89.22 ± 3.83). In addition, there were no cases of excess laxity observed with valgus stress tests during postoperative follow-up thereby confirming the integrity of the MCL repair.

This subjective functional data indicated that the therapeutic effects of ACL reconstruction surgery with double-strand PLT and ACL reconstruction surgery with four-strand HT are comparable.

Preoperative and Postoperative Effect Evaluation by Ankle Functional Testing

For the results of ankle functional testing at 12 and 24 months, there were no significant differences in ankle dorsiflexion strength preoperatively (80.92 ± 0.26 N) and postoperatively (80.00 ± 0.57 N at 12 months and 81.46 ± 0.48 N at 24 months postoperatively) of the PLT resected donor ankle, and no marked differences in ankle plantar flexion strength preoperatively (147.96 ± 0.38 N) and postoperatively (147.76 ± 0.25 N at 12 months and 150.22 ± 0.35 N) of the donor ankle (►**Table 5**).

Using a robotic dynamometer, the amount of torque that the ankle was able to generate in inversion and eversion was measured and is shown in ►**Tables 6–9**. The torque force generated was measured in the donor ankle prior to tendon harvest, 24 months postoperatively, as well as to the contralateral ankle 24 months postoperatively. Both eccentric and concentric muscle contraction was measured. The

Table 4 Subjective index appraisal at 6, 12, and 24 months after surgery

	6 months after surgery			12 months after surgery			24 months after surgery		
Indicators	Tegner	Lysholm	IKDC	Tegner	Lysholm	IKDC	Tegner	Lysholm	IKDC
Group A	6 ± 0.46	94 ± 6.02	89.45 ± 2.89	5 ± 0.96	94 ± 6.67	90.48 ± 2.36	5 ± 0.89	94 ± 6.81	90.13 ± 3.01
Group B	6 ± 0.57	95 ± 2.35	90.12 ± 4.56	6 ± 0.03	95 ± 3.55	90.17 ± 4.32	6 ± 0.12	93 ± 5.22	89.22 ± 3.83
p-Values	0.4134	0.3215	0.2368	0.4215	0.3267	0.2674	0.4153	0.4276	0.4298

Abbreviation: IKDC, International Knee Documentation Committee.
Note: $p < 0.05$ was considered statistically significant.

Table 5 Ankle biomechanical testing of double-strand PLT (group A) at preoperative visit, 12, and 24 months after operation (N)

	Preoperative	12 months after surgery	*p*-Values	Preoperative	24 months after surgery	*p*-Values
ADF	80.92 ± 0.26	80.00 ± 0.57	0.826	80.92 ± 0.26	81.46 ± 0.48	0.828
APF	147.96 ± 0.38	147.76 ± 0.25	0.858	147.96 ± 0.38	150.22 ± 0.35	0.855

Abbreviations: ADF, ankle dorsiflexion; APF, ankle plantar flexion; PLT, peroneus longus tendon.

Table 6 Torque comparison of concentric contraction for donor ankle and contralateral ankle at 24 months after operation by Biodex System 4 ($\bar{x}$ ± s)

	30 deg/s (CON) (Nm)			*p*-Values
	Healthy side	Donor side	Percentage loss	
Inversion	36.70 ± 22.21	34.32 ± 13.64	6.05 ± 4.72	0.425
Eversion	17.03 ± 12.82	16.12 ± 14.98	7.56 ± 10.37	0.368
	180 deg/s (CON) (Nm)			*p*-Values
	Healthy side	Donor side	Percentage loss	
Inversion	22.04 ± 16.32	21.07 ± 15.86	6.82 ± 7.33	0.489
Eversion	11.35 ± 9.05	10.03 ± 8.54	7.89 ± 8.03	0.392

Abbreviations: CON, concentric; Nm, Newton meters.

Table 7 Torque comparison of concentric contraction for donor ankle at preoperative visit and 24 months after operation by Biodex System 4($\bar{x}$ ± s)

	30 deg/s (CON) (Nm)			*p*-Values
	Before harvesting	After harvesting	Percentage loss	
Inversion	37.53 ± 19.15	34.32 ± 16.35	8.92 ± 9.65	0.478
Eversion	18.26 ± 11.32	16.12 ± 14.98	6.12 ± 11.45	0.336
	180 deg/s (CON) (Nm)			*p*-Values
	Before harvesting	After harvesting	Percentage loss	
Inversion	23.01 ± 15.68	21.07 ± 15.86	8.24 ± 7.22	0.414
Eversion	12.31 ± 10.32	10.03 ± 9.22	9.78 ± 8.67	0.319

Abbreviations: CON, concentric; Nm, Newton meters.

Table 8 Torque comparison of eccentric contraction for donor ankle and contralateral ankle at 24 months after operation by Biodex System 4 ($\bar{x}$ ± s)

	30 deg/s (ECC) (Nm)			*p*-Values
	Healthy side	Donor side	Percentage loss	
Inversion	44.78 ± 20.33	41.59 ± 21.53	9.45 ± 8.99	0.491
Eversion	28.69 ± 21.53	26.77 ± 23.14	8.73 ± 11.13	0.382
	180 deg/s (ECC) (Nm)			*p*-Values
	Healthy side	Donor side	Percentage loss	
Inversion	30.21 ± 23.12	28.01 ± 19.36	9.34 ± 12.37	0.405
Eversion	31.75 ± 18.69	28.02 ± 11.32	8.47 ± 14.86	0.394

Abbreviations: ECC, eccentric; Nm, Newton meters.

Table 9 Torque comparison of eccentric contraction for donor ankle at preoperative visit and 24 months after operation by Biodex System 4 ($\bar{x} \pm s$)

	30 deg/s (ECC) (Nm)			*p*-Values
	Before harvesting	After harvesting	Percentage loss	
Inversion	43.61 ± 21.63	41.59 ± 21.53	9.37 ± 8.13	0.402
Eversion	27.92 ± 16.43	26.77 ± 23.14	7.39 ± 7.05	0.398
	180 deg/s (CON) (Nm)			***p*-Values**
	Before harvesting	**After harvesting**	**Percentage loss**	
Inversion	29.51 ± 17.37	28.01 ± 19.36	8.64 ± 4.35	0.411
Eversion	29.22 ± 16.32	28.02 ± 11.32	9.03 ± 8.64	0.390

Abbreviations: ECC, eccentric; Nm, Newton meters.

amount of torque lost after tendon harvesting or compared with the nondonor contralateral after 2 years after surgery was not statistically different.

Based on these results, there does not appear to be any obvious functional impairment in these motions after harvesting the PLT to reconstruct the ACL in the donor ankle.

Discussion

In recent years, HT has been widely utilized as an autograft in ACL reconstruction.[19–21] However, there is significant variability in HT diameter and an undersized graft is a potential risk factor for ACL reconstruction failure.[17] It has been recommended that the cross-sectional diameter of the graft for reconstruction be at least 8 mm which can be difficult with HTs alone while maintaining enough length. Moreover, if there is a concomitant grade III injury of MCL, medial-sided soft tissue damage will increase the risk of wound complication and infection with a medial hamstring harvest. Also, harvesting HT could potentially lead to instability of the medial knee joint, though more definitive data should be collected to prove this assertion. Lastly, such a high-energy injury to the medial side of the knee to cause grade III MCL injury should bring the structural reliability of the medial HTs into question. In addition, in revision multiligament knees or pediatric knee reconstructions, sources of adequate autograft can be sparse. Past literature has suggested the feasibility of using PLT autograft as an alternative to HT.

The ultimate tensile strengths of both the double-strand PLT and four-strand HT were found to be significantly higher than that of a native ACL, and the ultimate tensile strength of double-strand PLT was comparable with four-strand HT. Our findings are consistent with previously described load to failure test results. Strictly biomechanically speaking, the double-strand PLT is a suitable graft source with enough strength for ACL reconstruction.

The therapeutic effects of ACL reconstruction surgery with double-strand PLT and ACL reconstruction surgery with four-strand HT are comparable as suggested by our subjective functional scores. Of note, one of the patients in the four-strand HT group presented with a grossly positive anterior drawer test at 6 months postsurgery without premature strenuous exercise or another injury. An MRI showed that the transplant had resorbed. There was no similar complication in the PLT group, perhaps partly because the diameter of double-strand PLT is consistently larger than four-strand HT.

Previous literature has suggested that harvesting the PLT will have little to no effect on foot and ankle function.[16] Our findings support that assertion. The peroneus longus' main function is to evert the foot and plantar flex the first ray. There is concern that removal of the peroneus longus will, in addition to decreasing eversion strength and plantar flexion, will increase ankle instability. Our study, however, showed similar strength and range of motion of the ankle pre- and postgraft harvest. The PLT has a minor, if any, and redundant, if at all, effect on maintenance of the arch of the foot. The function of the abductor hallucis, posterior tibial tendon, and flexor pollicis longus are mainly to maintain the medial longitudinal arch. The peroneus brevis, and abductor digiti minimi maintain lateral longitudinal arch. The adductor pollicis muscle and posterior tibial tendon are the most important structures to maintain the foot transverse arch. Therefore, the literature has suggested that harvesting the PLT has no obvious influence on the stability of the foot.[16]

In our experience, we found the diameter of a double-strand PLT to typically be between 8 to 9 mm and the length of PLT is approximately 30 cm from its myotendinous junction to its insertion, making it a clinically effective width and length. There was no postoperative difference in ankle strength in inversion or eversion suggesting that PLT harvest has minimal influence on the ankle functions tested due to the compensatory and redundant mechanisms of other tendons around the ankle.

Given the difficulty in the management of an ACL–MCL combined knee, there has been much controversy over its most appropriate treatment, including the most efficacious graft source. Our study finds good short-term results with the use of ipsilateral autologous double-strand PLT without any significant detriment to subjective or objective outcomes. To our knowledge, this is the first paper of comparison for double-strand PLT and four-strand HT in arthroscopic-assisted ACL reconstruction accompanied with grade III MCL in the international literature.

There are several limitations of this article. First, this study is a cohort study with a relatively homogenous patient population with a limited number of patients and, given the relative rarity of this injury pattern, may be underpowered to detect certain clinical differences between the two groups. Although no power analysis was performed, this study represents all available patients at the time of the publication and patients are continuing to be registered. Longer follow-up would also better identify later onset complications of ACL reconstruction as well as longer-term effects of harvesting the PLT. With that being said, this study with at least 2 years of follow-up serves as a preliminary data set, the largest and most extensive of its kind, and the patients will continue to be followed to assess for long-term complications. The surgeries were also performed over 9 years and various techniques and equipment changed over that time, making the surgical results susceptible to confounding bias. Specifically, all surgeries performed prior to 2008 utilized a transtibial technique, while all surgeries after 2008 were performed with a separate anterior-medial portal for the femoral tunnel. There is no "gold standard" approach for femoral tunnel drilling, and both are accepted approaches with equivalent outcomes seen in our study. Additionally, while cartilage and meniscal damage was treated at the time of surgery, there was not a clear distinction in the amount of damage for each case which could theoretically be a source of confounding. The postoperative rehabilitation protocol remained the same for all patients regardless of articular cartilage or meniscal damage noted during surgery. More in-depth ankle-specific biomechanical testing than what was performed in this study, including analysis of the medial arch on radiographs, gait analysis, and foot pressure studies may have found subtle differences in the PLT donor group ankles. In addition, the inclusion of subjective ankle-specific functional scores to more definitively prove the safety of this graft would be beneficial.

Conclusion

In conclusion, this article demonstrates the structural capabilities of a PLT and its safety and effectiveness as a graft choice in ACL reconstruction with a concomitant grade III MCL tear with 2 years of follow-up data. Establishing the PLT as a feasible autograft would be useful in revision situations or as a supplement to other autograft choices. Familiarity with utilizing the PLT as an autograft would be helpful to have in a surgeon's armamentarium.

Conflict of Interest
None.

References

1 Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. Am J Sports Med 1994;22(02):211–217
2 Bonamo JJ, Krinick RM, Sporn AA. Rupture of the patellar ligament after use of its central third for anterior cruciate reconstruction. A report of two cases. J Bone Joint Surg Am 1984;66(08): 1294–1297
3 Fahey M, Indelicato P. Bone tunnel enlargement after ACL allograft reconstruction. Orthop Trans 1993;17:231
4 Fulkerson JP, Langeland R. An alternative cruciate reconstruction graft: the central quadriceps tendon. Arthroscopy 1995;11(02): 252–254
5 Sachs RA, Daniel DM, Stone ML, Garfein RF. Patellofemoral problems after anterior cruciate ligament reconstruction. Am J Sports Med 1989;17(06):760–765
6 Thompson W, Harner C, Jamison J. Immunologic response to fresh frozen patellar tendon allograft anterior cruciate ligament reconstruction. Trans Orthop Res Soc 1994;19:624
7 Atkinson TS, Atkinson PJ, Mendenhall HV, Haut RC. Patellar tendon and infrapatellar fat pad healing after harvest of an ACL graft. J Surg Res 1998;79(01):25–30
8 Christen B, Jakob RP. Fractures associated with patellar ligament grafts in cruciate ligament surgery. J Bone Joint Surg Br 1992;74 (04):617–619
9 Kartus J, Ejerhed L, Sernert N, Brandsson S, Karlsson J. Comparison of traditional and subcutaneous patellar tendon harvest. A prospective study of donor site-related problems after anterior cruciate ligament reconstruction using different graft harvesting techniques. Am J Sports Med 2000;28(03):328–335
10 Ahn JH, Lee SH. Risk factors for knee instability after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2016;24(09):2936–2942
11 Figueroa D, Calvo R, Vaisman A, Campero M, Moraga C. Injury to the infrapatellar branch of the saphenous nerve in ACL reconstruction with the hamstrings technique: clinical and electrophysiological study. Knee 2008;15(05):360–363
12 Nelissen E, van Arkel ER, Hazelbag HM. Traumatic neuroma of the infrapatellar branch of the saphenous nerve after hamstring harvesting. J Knee Surg 2010;23(04):233–236
13 Bates NA, McPherson AL, Rao MB, Myer GD, Hewett TE. Characteristics of inpatient anterior cruciate ligament reconstructions and concomitant injuries. Knee Surg Sports Traumatol Arthrosc 2016;24(09):2778–2786
14 Duncan JB, Hunter R, Purnell M, Freeman J. Meniscal injuries associated with acute anterior cruciate ligament tears in alpine skiers. Am J Sports Med 1995;23(02):170–172
15 Yoon KH, Yoo JH, Kim KI. Bone contusion and associated meniscal and medial collateral ligament injury in patients with anterior cruciate ligament rupture. J Bone Joint Surg Am 2011;93(16): 1510–1518
16 Kerimoğlu S, Aynaci O, Saraçoğlu M, Aydin H, Turhan AU. Anterior cruciate ligament reconstruction with the peroneus longus tendon [in Turkish]. Acta Orthop Traumatol Turc 2008;42 (01):38–43
17 Zhao JZ, Huangfu XQ. The biomechanical and clinical application of using the anterior half of the peroneus longus tendon as an autograft source. AM J Sports Med 2012;40(3):662–671
18 Nazem K, Barzegar M, Hosseini A, Karimi M. Can we use peroneus longus in addition to hamstring tendons for anterior cruciate ligament reconstruction? Adv Biomed Res 2014;3:115
19 Brown CH Jr, Steiner ME, Carson EW. The use of hamstring tendons for anterior cruciate ligament reconstruction. Technique and results. Clin Sports Med 1993;12(04):723–756
20 McKernan D, Weiss J, Deffner K, Greenwald R. Tensile properties of gracilis, semitendinosus and patellar tendons from the same donor. Trans Orthop Res Soc 1995;20:39
21 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(03): 344–352