

Medium-Term (Least 5 Years) Comparative Outcomes in Anterior Cruciate Ligament Reconstruction Using 4SHG, Allograft, and LARS Ligament

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Abstract

Objective: To compare the clinical efficacy of anterior cruciate ligament (ACL) reconstruction with 4-strand hamstring tendon autograft (4SHG), allograft and the Ligament Advanced Reinforcement System (LARS) ligament, and to find the causes of cumulative failure or nonreturn to sport. **Design:** Retrospective case series. **Setting:** Department of Orthopedic Surgery, the second affiliated hospital of Soochow University, Suzhou, Jiangsu, China. **Patients:** Three hundred six patients with isolated ACL deficiency were included. Two hundred twenty-nine patients met the inclusion/exclusion criteria, and finally, 185 of these patients participated in this study. **Interventions:** Anterior cruciate ligament reconstruction using 4SHG, allograft, and LARS. **Main Outcome Measures:** Objective knee function, subjective knee function, and information regarding return to sport, cumulative failure, and complications. Secondary: distribution of tunnel position and tunnel enlargement. **Results:** There were no statistically significant differences between the 3 groups regarding all the clinical objective and subjective results, return to sport, complications, or cumulative failures ($P > 0.05$). One hundred twenty-eight patients (69.2%, 128/185) returned to sport. Preoperative (after injury) Tegner scores were inferior to postoperative Tegner scores, and postoperative Tegner scores were inferior to preinjury Tegner scores ($P < 0.01$). The femoral tunnel malposition was significantly associated with cumulative failure ($P < 0.05$). **Conclusions:** There were no statistically significant differences among the 4SHG, allograft, and LARS ligament in terms of the clinical outcomes after ACL reconstruction (ACLR) at 5-years follow-up. Interestingly, ACLR could improve the functional and motorial level of the knee, but patients had great difficulty in regaining the level of preinjury movement. In addition, the malposition of the femoral tunnel was an important cause of cumulative failure.

Key Words: autograft, allograft, LARS, ACL reconstruction, cumulative failure, return to sport

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This article does not contain any studies with animals performed by any of the authors. Studies with human participants contain routine physical examinations of the knee joint and routine medical imaging including MRI and x-ray, which do not cause injury or discomfort to the human body. This study has been approved by the ethics committee of the second hospital affiliated by Soochow University.

All patients' anonymity has been carefully protected, and informed consent was obtained from all individual participants included in the study.

The data will be available as outlined in the International Committee of Medical Journal Editors policy (www.icmje.org).

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is common in knee ligament injuries, especially among teenagers and people who participate in sports. The annual incidence of ACL rupture is usually between 30 and 78 per 100 000 persons.¹ Ruptures of ACL can result in joint loosening and impaired function without prompt and effective treatment. Gradually, it can evolve into articular degeneration, accelerating meniscus tears, and articular cartilage damage,² as well as expediting the development of traumatic osteoarthritis. Anterior cruciate ligament reconstruction (ACLR) plays a significant role in restoring knee stabilization.³ The commonly used reconstruction materials include autograft (autologous ligament), allograft (allogeneic ligament), and synthetic graft (artificial ligament).

Autografts have been widely adopted for ACLR because of reliable graft stability and favorable return to high-level sports. In clinical practice, the bone–patella tendon–bone autograft was historically taken as the “gold standard” despite the drawback of donor site morbidity.⁴ Subsequently, hamstring autograft received popularity due to easier harvesting, less donor site morbidity, and satisfying clinical results.⁵

Allografts were introduced to avoid donor site morbidity caused by tissue harvesting. Combined with the

advantages of shorter operation time and less postoperative pain, the utilization of the allograft has progressively increased over the past 2 decades.⁶ But, allograft use also causes a series of problems including delayed graft incorporation, possible immunogenicity, and risk of disease transmission.⁷

Synthetic grafts became popular since the late 1970s for providing immediate tensile strength and fast rehabilitation without the risks of disease transmission and immunological rejection. Several considerable problems have appeared during a long and tortuous development of synthetic materials, such as high failure rates (prosthetic components breakage, fixation loss, etc.) and serious complications (sterile effusions, synovitis, etc.).^{8,9} With the loss of rigorous surgeons' trust, there was a depressed market for synthetic devices in ACLR by the end of the 1990s. In the past 15 years, third-generation synthetics such as the Ligament Advanced Reinforcement System (LARS; Surgical Implants and Devices, Arc-sur-Tille, France) have aroused the medical community's new interest following modified designs, refined biomaterials, and more accurate surgical techniques.¹⁰ LARS grafts have gradually become the most widely accepted synthetics in the field of sports medicine in China due to the early return to sports and impressive clinical effects.^{11–13}

At present, there is still no consensus regarding the optimal graft tissue choice in ACLR.¹⁴ Up to now, rare relatively available research literature on the transverse comparative study of the clinical curative effect has been performed in mid long-term comparison among 3 different grafts. It is worth emphasizing that return to sport after ACLR has been widely discussed in various publications in recent years,^{15–17} likely because this is closely related to the social participation-based outcomes of the injured after ACL reconstructive surgery.¹⁸

We report here a comparative study of ACLR using 4-strand hamstring tendon autograft (4SHG),^{19,20} allograft, or the LARS artificial graft with the purpose of contrasting the objective and subjective clinical results, outcomes of return to sport, and cumulative failure reasons by 3 kinds of different grafts. It was hypothesized that performing an ACLR with LARS ligament would exhibit superior clinical results, along with a lower rate of complications or cumulative failures and a closer return to the level of preinjury movement, compared with 4SHG or allograft at least 5-year follow-up. Several discoverable factors, including femoral or tibial tunnel positions, could reasonably bring about cumulative failure or nonreturn to sport.

MATERIALS AND METHODS

This study retrospectively evaluated 306 patients who underwent ACLR for isolated ACL deficiency between August 2006 and December 2012 (Figure 1). An ACL rupture was diagnosed by anterior drawer test, Lachman test, Pivot-Shift test, and magnetic resonance imaging (MRI)²¹ and confirmed by arthroscopic surgery. Exclusion criteria of the study incorporated multiligament injury (except medial collateral ligament injury with nonsurgical treatment), revision surgery, contralateral knee trauma history, previous knee surgery history, arthroscopic cartilage lesion or degeneration greater than grade 3 (Outerbridge classification), and preoperative knee osteoarthritis greater than grade 2 (Kellgren and Lawrence grading scale²²). This study was approved by our

ethics committee and institutional review committee. Participants were informed of the purpose and procedures of the investigation and signed informed consent.

In total, 185 patients met our criteria and were enrolled in this study. According to graft materials and surgical methods, the patients were divided into 3 groups: 67 patients received the 4-strand hamstring tendon autograft (4SHG), 47 patients received allografts, and 71 patients received LARS during arthroscopic ACLR.

The groups were comparable with respect to sex, age at operation, side of knee injury, cause of injury, and time between injury and surgery. After informing patients of the pros and cons of 3 different grafts, the choice of which graft material to reconstruct was multifactorial and mainly dependent on the patient's degree of symptoms, requirements, and preferences. All patients were aware of the disease details and the operative procedures as explained to them by the same team of surgeons. The postoperative follow-up was performed by 3 independent, clinically experienced doctors who were not involved in the operation.

Surgical Technique

An arthroscopically assisted reconstructive surgery of ACL was performed on each patient. After a successful anesthesia, standard anterolateral and anteromedial portals were introduced under arthroscopic control.

Diagnostic arthroscopy was performed to visually confirm the extent of the ligament tear, to identify meniscus or cartilage injuries, and to conduct further arthroscopic debridement. All the ACLR procedures were performed by the same group of surgeons on the basis of a standardized surgical technique.

In the 4SHG group, both the semitendinosus tendon and gracilis tendon were harvested and disconnected. The remaining muscular tissue was debrided from the tendons using a tendon stripper. The tendons were folded into 4 strands and then sutured to each other. The quadruple-stranded graft was 8-mm wide and 12-cm long.²³ For the tibial tunnel placement, a tibial drill guide was adjusted to a sagittal angle of 50 degrees; the intra-articular guide tip was centered within the native ACL tibial footprint, and then a cannulated drill was used to create a tibial tunnel under direct visualization. The femoral tunnel was prepared through a transtibial portal and marked at the 1:00 to 1:30 clock (left) or 10:30 to 11:00 clock (right) position. Then, a femoral tunnel was established to 30-mm deep using a cannulated drill. The tunnel diameter was 8 to 9 mm, identical to the diameter of the graft. The tendon was firmly secured with a cortical fixation button (Endobutton; Smith & Nephew, London, United Kingdom) on the femoral side and a bioabsorbable interference screw (Biosure HA; Smith & Nephew) on the tibial side.

In the allograft group, all the grafts were made from nonirradiated fresh-frozen hamstring tendon and obtained from a certified tissue bank (Shanxi Bone Tissue Bank, Taiyuan, China) or the Musculoskeletal Transplant Foundation. On the same day of surgery, the fresh-frozen allograft was prepared by thawing to 37°C for 30 minutes²⁴ in sterile saline before surgery. After harvest, the constructs for allograft were woven in the similar fashion as that for autograft. The intra-articular tunnels were created in the same way as that described for the 4SHG technique. The fixation of

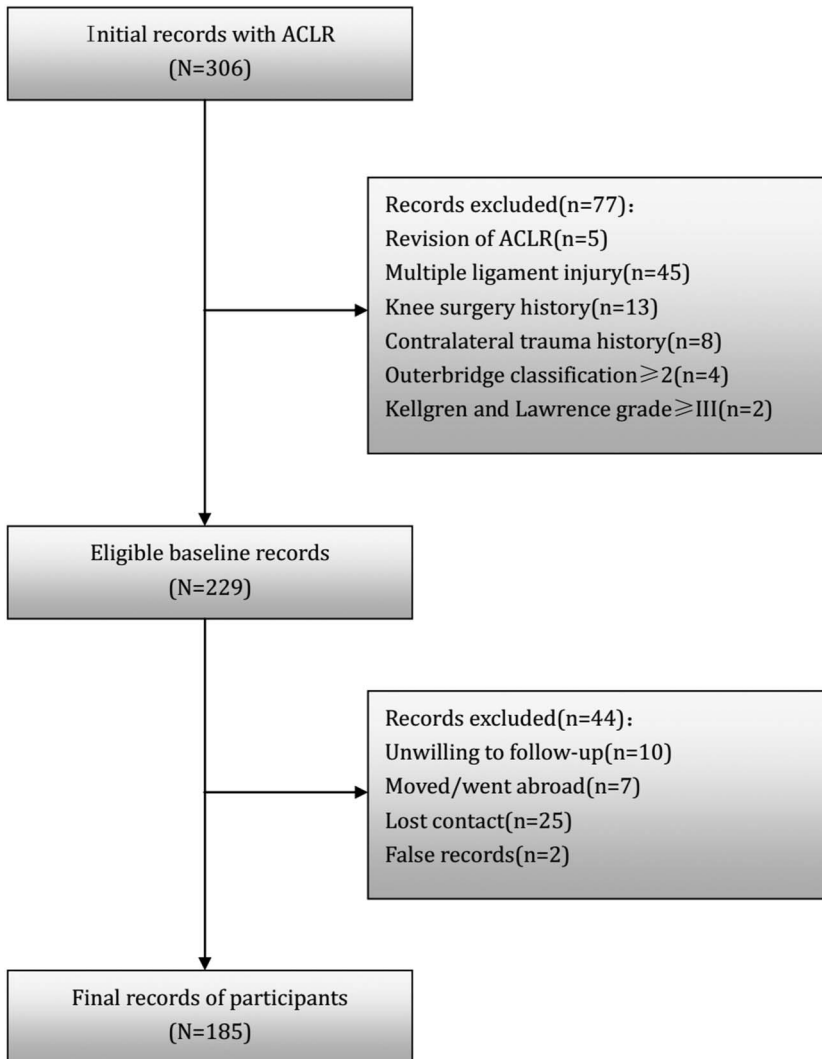


Figure 1. Patient enrollment flow diagram.

allograft and 4SHG on the bones was performed as described above.

In the LARS group, the epibiotic ACL stump was preserved as much as possible, and isometric surgical principles were followed during the reconstruction process. The point of the tibial tunnel was placed at the central part of the ACL stump (50% of the distance between the most anterior edge and the most posterior edge of the tibial plateau²⁵) between the medial and lateral tibial intercondylar tubercles. After a Kirschner wire was inserted, the tibial tunnel was created with a 7.5-mm-diameter drill bit. The femoral tunnel was confirmed by the transtibial technique at the 1:00 to 1:30 clock (left) or 10:30 to 11:00 clock (right) position. From the tibial portal, the Kirschner wire was passed through the tibial tunnel and into the knee joint, then through the femoral tunnel and out from the skin of the anterolateral thigh. Guided by the Kirschner wire, the 7.5-mm-diameter drill bit was drilled out of the femoral tunnel. The bone tunnel size was appropriate for the diameter of the graft. The graft was introduced into the knee joint by a guide wire and then tension was adjusted by a motion of the knee. Both tibial and femoral fixations were

achieved with titanium interference screws (Surgical Implants and Devices; LARS).

Postoperative Rehabilitation

Rehabilitation guidance was initiated under the direction of a physical therapist within 1 week after reconstruction. Ankle pump movements, quadriceps isometric exercises, and straight leg raises were started from the first day after surgery to strengthen the quadriceps. All patients underwent knee flexion exercises from the third day after surgery and gradually increased the flexion angle. We noticed that the range of motion should be achieved 90 degrees within 1 week postoperatively for the LARS group and 4 weeks for the 4SHG and the allograft group. Unlocked functional braces were used to aid walking 6 weeks postoperatively for all patients after ACLR. For the LARS reconstruction, crutches were discarded after 2 weeks. For the 4SHG or allograft reconstruction, crutches were used for 6 weeks; the lower extremity with non-weight-bearing was permitted for the first few weeks followed by moderate weight-bearing after 4 weeks

postoperatively when using crutches. Walking without crutches was allowed according to the recovery individually. Swimming and cycling was allowed 6 to 8 weeks postoperatively in the LARS group but 4 months in the 4SHG and the allograft group. Patients gradually returned to non-competitive sports activities and even competitive sports as was deemed appropriate by each individual.

Clinical Assessment

For the evaluation of postoperative knee joint stability, objective assessments were obtained with physical examinations, covering Kneelax 3 (Monitored Rehab Systems, Haarlem, the Netherlands) at 70 to 90 degrees of flexion and 132 N of force,²⁶ the anterior drawer test, the Lachman test, and the Pivot-Shift test. Each indicator of knee stability with accurate evaluation was based on comparison with contralateral knee stability. Muscular atrophy of thigh muscles was estimated by measuring the difference in bilateral thigh circumference at 10 cm above the upper border of the patella, which was graded as follows: grade A (no difference), grade B (0 to ≤ 1 cm), grade C (1 to ≤ 2 cm), and grade D (> 2 cm).²⁷ To evaluate the subjective holistic level of living quality and motor function, we simultaneously received the 2000 International Knee Documentation Committee (IKDC) subjective score,²⁸ Lysholm knee scoring scale,²⁹ Tegner activity level, and the Knee injury³⁰ and Osteoarthritis Outcome Score (KOOS)³¹ as subjective judgments by filling out patient-reported questionnaires.

After the end of the final follow-up, overall IKDC grade C or D, such as an overall IKDC objective score of C or D, Pivot-Shift test $\geq 2+$, Lachman test or Kneelax 3 > 5 mm, limited range of motion (ROM) (ie extension deficit > 5 degrees or flexion deficit > 15 degrees), was regarded as clinical failure. Notably, cumulative failure was defined as clinical failure plus graft rerupture by Crawford et al.³² The physical examination was based on the 2000 IKDC knee examination form. Infection, synovitis, and fixation failure were defined as complications. The athletic levels for returning to sport were measured by the Tegner activity level. We defined returning to sport at preinjury level if the postoperation Tegner scores equaled or exceeded preinjury Tegner scores. Complication incidence, cumulative failure rate, and return rate were included as important comparison items. Hospital stay and expenses were collected as reference variables at the time of hospitalization. The data from the preinjury, preoperative, and the final follow-up evaluations were also compared.

Radiographic Assessment

X-radiography of the knee joint was taken to determine the position of intra-articular apertures of the tibia and femoral tunnels.^{33–35} The clock-face reference was used in describing femoral tunnel position in the coronal plane. With the midpoint of the intercondylar notch defined as the center of the clock-face, the 1:00 to 1:30 clock for left knees or 10:30 to 11:00 clock for right knees corresponded to the femoral tunnel orientation when the knee was at 90 degrees of flexion. The tibial tunnel position was located at the area of the ACL footprint on the intercondylar eminence in the coronal plane radiograph. In the sagittal plane, the quadrant method described by Bernard et al³⁶ was adopted with the help of Blumensaat's line in regard to the tunnel measurement of the

femoral side. The Blumensaat's line stopped at the 2 points of intersection across the anterior and posterior aspects of the femoral condyles, which constituted an outline border of the rectangle grid. An isometric tangent to the distal contour of the femoral condyle parallel to Blumensaat's line formed an opposite outline border. The rectangular grid system was produced to fit over the lateral femoral condyle combining the remaining 2 rectangle boundaries. The position of the femoral tunnels was confirmed in the middle of the elliptical region containing the locations of anteromedial (AM) and posterolateral (PL) bundles on the lateral femoral roentgenogram, which is illustrated in Figure 2. The sagittal-plane tibial point according to the anatomical position of the ACL footprint was defined by Colombet et al.³⁷ The center of the AM bundle was situated at 36%, and the center of the PL bundle was situated at 52%, referring to Amis and Jakob's line³⁸ with a percentage of the length. Then, the placement of tibial tunnels was determined in the center region of AM and PL bundle points with measurements performed from the sagittal plane (Figure 3).

Femoral and tibial bone tunnel enlargement was assessed by x-ray as well. The intra-articular aperture diameters of femoral and tibial tunnels was recorded as tunnel diameter, which was measured at each tunnel opening point in anteroposterior and lateral (AP and LAT) x-ray image using a linear measuring tool perpendicular to the tunnel axis (Figure 4). The evaluation of tunnel location is based on radiographic analysis.^{39–41} The measurements were acquired independently by 3 different technicians with clinical experience, and the results were averaged. The initial diameter of tunnel intra-articular aperture was recorded as the size of the drill bit through reviewing the surgical records. Tunnel enlargement of femoral and tibial from radiographs was represented as a percentage calculation as follows: (current diameter – initial diameter)/initial diameter $\times 100\%$.²⁷

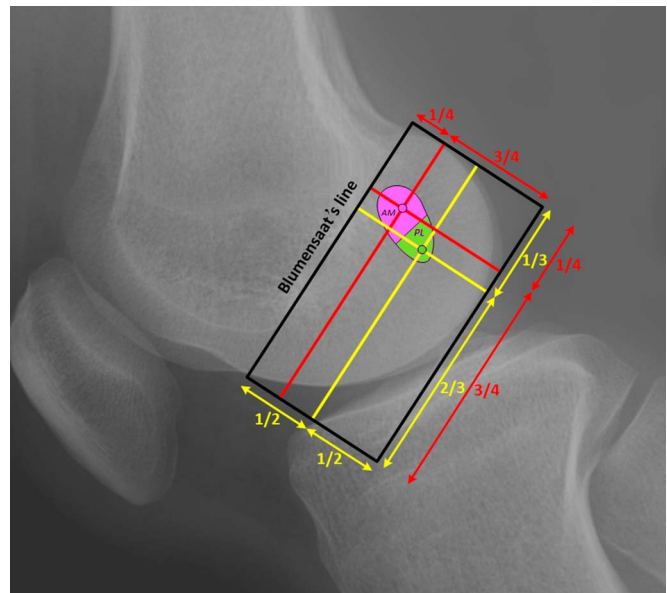


Figure 2. The sagittal plane measurement for the femoral tunnel position referencing the location of the femoral insertion of the AM and PL bundles with the method of Bernard et al.³⁶ The oval area represents the area of the femoral tunnel site.

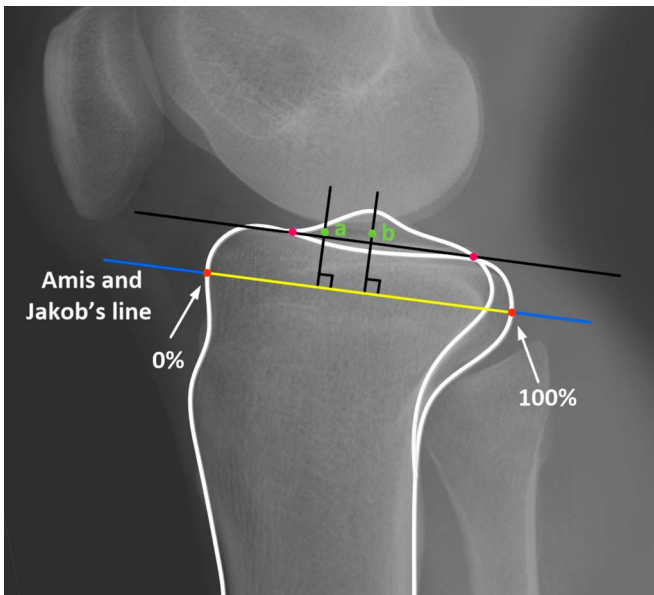


Figure 3. Illustration showing the anchor point of tibia tunnel on the sagittal plane. The Amis and Jakob's line was defined as a line passing through the most posterior edge of the tibial plateau and parallel to medial tibial plateau surface. A percentage-term measurement generated from the Amis and Jakob's line intersecting the anterior border (0%) and posterior border (100%) of the tibia plateau. (a) The center of the AM bundle lay at 36% orthogonally projected onto this line. (b) The center of the PL bundle lay at 52% orthogonally projected onto this line. The bony reference points defining the position of the tibia tunnel were in the center region of a and b.

Meanwhile, MRI of the knee joint was performed to discern the continuity and shape of ligaments and to observe the condition in the articular cavity (eg, other ligament damage, synovial lesions, articular cartilage injury, meniscus injury, joint degenerative changes, etc.). The relationship between

intra-articular tunnel malposition and cumulative failure was subsequently evaluated.

Statistical Analysis

All statistical analyses of data were performed using SPSS 22.0 (SPSS, Armonk, NY) software. The continuous arguments, including time between injury and surgery, Lysholm score, Tegner score, KneeLax3 measurement, tunnel enlargement, hospital stay, and expenses were normally distributed and analyzed with the paired analysis of the variance test and Kruskal–Wallis test among 3 groups. The categorical variables, including the complication incidence, cumulative failure rate, and return rate, were compared using the χ^2 test and Fisher exact test. Concerning patient-reported questionnaires, the difference between the 3 groups was analyzed using the Kruskal–Wallis test, and the outcomes at different time points were analyzed using the Friedman test. The χ^2 test was calculated to assess the relevancy between tunnel malposition and cumulative failure. The level of statistical significance was set to $P < 0.05$.

RESULTS

General Results

In total, of 306 patients of initial records with ACLR, 229 met the inclusion and exclusion criteria, and 185 were available for follow-up and eventually enrolled in the research, covering 135 male patients (73.0%) and 50 female patients (27.0%) (Table 1). Therefore, the complete lost rate of follow-up was 19.2%. The average age was 31.5 years old (range, 13-57 years), and the median time of follow-up was 86.4 months (range, 60-132 months). The mean period between the primal injury and surgery was 74.6 weeks (range 1-566 weeks). The highest hospitalization expenses were observed in the LARS group, showing significantly more spending than the other 2 groups. The 4SHG group cost the least ($P < 0.01$). There was

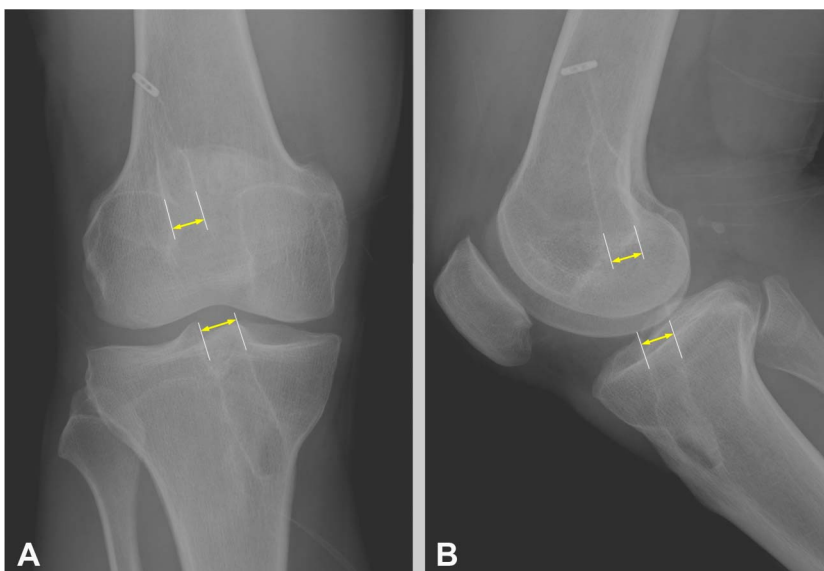


Figure 4. Intra-articular aperture diameters of femoral and tibial tunnels on (A) anteroposterior and (B) lateral radiographs. The diameter measurements are perpendicular to the tunnel axis. The yellow arrows illustrate diameters of tunnel portals.

TABLE 1. Preoperative Demographics in Autograft, Allograft, and LARS Groups

	4SHG (n = 67)	Allograft (n = 47)	LARS (n = 71)	P
Age, yr	31.1 (17-56)	30.1 (16-55)	32.8 (13-57)	0.347
Sex (male/female), n	52/15	35/12	48/23	0.402
Body mass index, kg/m ²	24.5 (18.9-31.1)	25.2 (20.3-29.3)	25.8 (19.1-42.0)	0.319
Laterality (right/left), n	38/29	20/27	36/35	0.330
Time to surgery, wk	73.7 (1-566)	76.0 (2-514)	74.5 (1-540)	0.995
Follow-up time, mo	84.3 (60-129)	89.7 (61-131)	86.1 (60-132)	0.752
Meniscus injury, n				
None	17	17	22	0.167
Medial	27	10	16	
Lateral	11	8	10	
Both	12	12	23	
Cause of injury, n				0.966
Traffic	9	8	12	
Sports	44	29	46	
Fall	14	10	13	

Values are presented as mean (range) unless otherwise noted.

no statistically significant difference between the 3 groups regarding the length of stay ($P > 0.05$) (Table 2).

Cumulative Failures and Complications

Until the last follow-up, complications were observed in 5 patients (2.7%) with no significance among 3 ligaments (4SHG: n = 1; allograft: n = 2; LARS: n = 2). Three patients (1 in the 4SHG group and 2 in the allograft group) suffered from a superficial surgical site infection, which were treated with antibiotics after a disturbed period of wound healing. Synovitis occurred in 2 patients who were only discovered in the LARS group after 5 and 6 years. In this cohort, a total of 21 patients (11.4%) revealed graft cumulative failures, 6 patients (9.0%, 6/67) with 4SHG, 8 patients (17.0%, 8/47) with allografts, and 7 patients (9.9%, 7/71) with LARS synthetics, respectively ($P = 0.360$). To be specific, clinical failure was observed in 5 patients with 4SHG, 8 patients with allografts, and 6 patients with LARS synthetics, while a graft rerupture was observed in 1 patient with 4SHG and 1 patient with LARS synthetics. There was no rerupture discovered in the allograft group. In 2 patients, graft reruptures were diagnosed by MRI 5 and 8 years after surgery respectively in the 4SHG and LARS groups. The broken grafts were separately replaced by 4SHG and LARS ligament during revision. We found no statistical

significance with respect to complications or cumulative failures among 3 groups ($P > 0.05$).

Return to Sport

One hundred twenty-eight (69.2%, 128/185) patients returned to sport, in which 87 (47.0%, 87/185) patients returned to the competitive sport, and 41 (22.2%, 41/185) patients returned to the recreational sport. Eighty-four (45.4%, 84/185) patients returned to sport at preinjury level. Of the 57 cases in which patients could not go back to sports practice, 53 cases (93.0%, 53/57) reported feeling anxiety over return to sport. When comparing the occurrence of returning to sport among 3 groups, which included a total of 49 patients in the 4SHG group, 31 in the allograft group, and 48 in the LARS group, there was no statistically significant difference ($P = 0.669$).

Patient-Reported Questionnaires and Physical Examinations

Similar results were obtained when comparing the 3 groups regarding the subjective and objective evaluation, for the anterior drawer test, Lachman test, Pivot-Shift test, Lysholm scores, and Tegner scores at the final follow-up ($P > 0.05$) (Table 3). In regard to the subjective evaluation, preoperative (after injury) Lysholm scores were inferior to postoperative

TABLE 2. Comparison of Hospitalization, and Complication, Cumulative Failure, and Return Rates

	4SHG (n = 67)	Allograft (n = 47)	LARS (n = 71)	P Value
Hospital stay, d	9.0 ± 3.4	9.7 ± 2.9	9.8 ± 3.3	0.312
Hospital cost, CNY	20 721 ± 4767	32 889 ± 4784	37 506 ± 3390	0.000
Complication rate, %	1.5 (1/67)	4.3 (2/47)	2.8 (2/71)	0.668
Cumulative failure rate, %	9.0 (6/67)	17.0 (8/47)	9.9 (7/71)	0.360
Return rate, %	73.1 (49/67)	66.0 (31/47)	67.6 (48/71)	0.669

Values are presented as mean ± SD. n, number; CNY, Chinese Yuan.

TABLE 3. Physical Examination Outcomes at 5-Year Follow-up

	4SHG				Allograft				LARS				P
	A	B	C	D	A	B	C	D	A	B	C	D	
Effusion	67	0	0	0	47	0	0	0	70	1	0	0	0.448
Flexion	58	7	2	0	41	5	1	0	63	7	1	0	0.917
Extension	66	1	0	0	47	0	0	0	71	0	0	0	0.415
Anterior drawer test	54	13	0	0	32	15	0	0	56	14	1	0	0.271
Lachman test	56	11	0	0	33	14	0	0	59	11	1	0	0.162
Pivot-Shift test	59	6	2	0	43	3	1	0	65	5	1	0	0.742
Overall IKDC score	50	15	2	0	30	16	1	0	52	18	1	0	0.437
Thigh muscle atrophy	50	10	8	3	31	10	5	1	49	13	5	0	0.641

Values are presented as n.

Lysholm scores; in addition, preoperative (after injury) Tegner scores were inferior to postoperative Tegner scores, while postoperative Tegner scores were inferior to preinjury Tegner scores ($P < 0.01$) (Table 4).

Knee Balance Measurement and Radiographic Examination

Four patients showed limitation of motion range, where flexion angle of the affected knee was over 15 degrees smaller than that of the uninjured side. According to KneeLax3 measurements, the mean side-to-side difference was 2.4 ± 2.3 mm (range, -3 to 5 mm) in patients with 4SHG, 3.2 ± 2.8 mm (range, -3 to 7 mm) in patients with allografts, and 2.7 ± 2.2 mm (range, -1 to 8 mm) in patients with LARS synthetic grafts ($P = 0.157$). The femoral tunnel malposition was significantly associated with the cumulative failure ($P < 0.05$), but the tibial tunnel malposition was not significantly

associated with the cumulative failure ($P > 0.05$) (Table 5). These analyses showed no significant difference in the case of tunnel widening (Table 6) and position distribution among 3 groups ($P > 0.05$).

DISCUSSION

The orthopedic community has debated about the choice of ideal graft for ACLR for more than 30 years.⁴² With good outcomes, autograft is still very popular and is the mainstream in ACLR. A randomized controlled trial verified that allografts can also be achieved satisfactorily with comparable outcomes compared with autografts at average 7.8-year follow-up.⁴³ But, autografts could not completely avoid the occurrence of donor site morbidity, and early return to sport was not allowed due to the long time for graft revascularization.^{44,45} Longer vascularization time of graft

TABLE 4. Subjective Preinjury, Preoperation, and Postoperation Evaluated Outcomes

	4SHG (n = 67)	Allograft (n = 47)	LARS (n = 71)	P
Tegner score				
Preinjury	5.6 ± 1.4	5.8 ± 1.4	5.8 ± 1.3	0.447
Preoperative	3.1 ± 1.8	2.9 ± 1.8	3.1 ± 1.7	0.682
Postoperative	4.8 ± 1.3	4.9 ± 1.4	4.8 ± 1.4	0.947
P value	< 0.01	< 0.01	< 0.01	
Lysholm score				
Preoperative	60.7 ± 12.1	58.3 ± 15.4	61.9 ± 13.2	0.363
Postoperative	84.0 ± 15.2	84.0 ± 14.6	84.1 ± 14.4	0.983
P value	< 0.01	< 0.01	< 0.01	
IKDC				
Preoperative	43.6 ± 11.0	44.5 ± 9.5	46.7 ± 8.5	0.139
Postoperative	71.6 ± 11.8	74.8 ± 10.2	74.2 ± 9.2	0.224
P value	< 0.01	< 0.01	< 0.01	
KOOS at 5 years				
Pain	90.5 ± 11.7	89.0 ± 11.6	89.4 ± 12.4	0.795
Symptoms	86.7 ± 13.5	85.6 ± 12.8	88.1 ± 10.5	0.528
Activities of daily living	86.4 ± 8.2	86.8 ± 7.7	88.5 ± 7.0	0.233
Sport and recreation function	81.6 ± 12.3	80.3 ± 10.8	82.3 ± 12.0	0.684
Knee-related quality of life	77.6 ± 15.3	77.2 ± 15.4	77.0 ± 15.4	0.969

Values are presented as mean \pm SD.

TABLE 5. Distribution of Tunnel Position With Graft Success or Failure

	Graft Failure	Graft Success	P
4SHG			
Femoral side			0.013
Malposition	5 (22.7)	17 (77.3)	
Normal position	1 (2.2)	44 (97.8)	
Tibial side			0.142
Malposition	3 (18.8)	13 (81.2)	
Normal position	3 (5.9)	48 (94.1)	
Allograft			
Femoral side			0.047
Malposition	6 (31.6)	13 (68.4)	
Normal position	2 (7.1)	26 (92.9)	
Tibial side			0.539
Malposition	1 (25.0)	3 (75.0)	
Normal position	7 (16.3)	36 (83.7)	
LARS			
Femoral side			0.012
Malposition	7 (18.9)	30 (81.1)	
Normal position	0 (0.0)	34 (100.0)	
Tibial side			0.682
Malposition	3 (12.5)	21 (87.5)	
Normal position	4 (8.5)	43 (91.5)	

Values are presented as n (%).

and the potential risks including immune rejection and disease transmission might be fatal weaknesses for allografts.^{46,47} Patients hope to return to work and sport earlier without self-tissue sacrifice and the risk of disease transmission. Therefore, LARS as the new synthetics has been used for more than 10 years in China amid skepticism from many surgeons. Chen et al²⁷ reported that new-generation synthetics might acquire earlier symptom relief and function restoration than hamstring autografts. Newman et al⁴⁸ pointed out that LARS ligament reconstruction generates comparable outcomes to autograft; the complication incidences of LARS ligament transplantation were low and similar to autograft over a short-to medium-term follow-up. This study indicated that there was no significant difference among 4SHG, allograft, and LARS ligaments in terms of the clinical outcomes, the rate of complications, or cumulative failures of ACLR. The price of synthetics is more expensive than the other 2 kinds of nonsynthetic grafts. Each of 3 grafts has certain advantages

and weaknesses, so that an absolutely perfect graft does not exist with respect to ACLR. Along with the popularity of precision medicine and personalized treatment, surgeons must master all varieties of ACLR technique with different grafts for the sake of giving every patient the most appropriate choice according to their personal willingness and economic condition.

In recent years, people pay more attention to return to sport after ACLR. But, Ardern et al⁴⁹ reported less than 50% of the patients returned to the preinjury level, or to competitive sport participation during the 2 to 7 years after ACLR. Hamrin et al⁵⁰ found that single-bundle ACLR did not significantly improve subjective knee function through the KOOS evaluation after 2 consecutive annual clinic visits. This study also found that preoperative (after injury) subjective scores were lower than postoperative subjective scores and postoperative subjective scores were lower than preinjury subjective scores as measured with Tegner activity level. The results were

TABLE 6. Enlargement of Femoral and Tibial Tunnel

	4SHG (n = 67)	Allograft (n = 47)	LARS (n = 71)	P
Femoral tunnel widening, %				
Anteroposterior	26.3 ± 12.2	23.6 ± 12.5	22.2 ± 10.7	0.245
Lateral	23.7 ± 13.4	22.1 ± 11.9	19.2 ± 10.6	0.111
Tibial tunnel widening, %				
Anteroposterior	24.2 ± 12.0	21.3 ± 10.5	20.9 ± 14.4	0.089
Lateral	21.5 ± 13.4	19.4 ± 9.8	19.5 ± 11.7	0.343

Values are presented as mean ± SD.

consistent across 4SHG, allograft, and LARS ligaments. It followed that ACLR could significantly improve the functional and motorial level of the knee, but it was difficult to help patients regain the level of preinjury movement. The probable reasons for this effect were inferred to be: (1) anatomical structures of ACL were difficult to be fully recovered by surgery, and tendon–bone biological healing was impeded. (2) Proprioceptive sensation and static postural control were impaired after ACLR,^{51,52} that is, injury and surgery caused loss of mechanical receptors, leading to decrease of neuromuscular control of knee stability. (3) Biomechanical structure and symmetrically mechanical steadiness were destroyed.⁵³ (4) Preoperative and postoperative knee-joint immobilization caused quadriceps atrophy as a result that the muscle strength was insufficient to support the stability of knee joint. (5) Postoperative complications such as infection and synovitis generated adverse effects. (6) Specially, psychological factors concerning fear of reinjury prevented patients from returning to original preinjury states. Psychological effects in ACL injury and reconstruction may be underrated for the importance of returning to exercise.^{54,55} Positive psychological intervention could be offered, such as preoperative psychological screening and postoperative counseling.⁵⁶ In the study, psychological barriers seemed to be a non-negligible reason leading to a relatively lower return rate. Besides these reasons, returning to sport related to age, sex, family, and social responsibility. Most patients who have undergone ACLR desire for knee stabilization or even future participation in cutting or pivoting sports.⁵⁷ Future advances in ligament reconstruction and postoperative restoration should focus on how to scientifically and effectively return to physical exercises and recover the preinjury athletic level. It was noted in this study that the average Tegner scores in this study were lower than that reported in European and American studies. Tegner activity score was summarized and used based on the western playing level as a result that it might not perfectly apply to the Chinese exercise mode, especially referring to high-score competitive or recreational sports (eg, ice hockey, alpine skiing, motor-cross, handball, etc.).

The third finding of this study revealed that femoral tunnel malposition had a significant effect on cumulative failure. The failure of ACLR can be ascribed to 3 causes: technical errors, biological failures (eg infection or graft rejection), and trauma. Reconstruction failure usually occurred because of technical mistakes within 6 months after surgery.⁵⁸ Technical errors are the most important factors responsible for the cumulative failure, and the caothesis of the femoral tunnel is the most frequent technical error.^{59,60} It should be noted that synthetics lack malleability, which makes them susceptible to malposition of femoral tunnel compared with autografts or allografts. Nevertheless, the expansion of bone tunnels did not lead to postoperative functional changes in this study. The relationship between the enlargement degree of the bone tunnel and the success or failure of the graft surgery remains to be further researched.

Several limitations associated with the study were indicated. As a retrospective study, it could have introduced patient selection bias. There was a potential confounder for transfer bias with only 80.8% follow-up, and the comparatively short 5-year follow-up time might be considered a study limitation. Comprehensive studies comprising prospective long-term follow-up of more than

10 years and more systematic clinical assessments should be considered in the future.

CONCLUSIONS

No statistically significant differences were found among 4SHG, allograft, and LARS ligaments in terms of the clinical objective and subjective results, the rate of complications, cumulative failures, or return to sport after ACLR at 5-years follow-up. It was worth noting that ACLR could improve the functional and motorial level of the knee, but patients had great difficulty in regaining the level of preinjury movement. In addition, the malposition of femoral tunnel position was one of the important causes of cumulative failure.

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