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Tibial tunnel expansion does not correlate with four-strand graft maturation after ACL reconstruction using adjustable cortical suspensory fixation

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Abstract

Purpose Anterior cruciate ligament reconstruction (ACLR) using a short, quadrupled semitendinosus (ST-4) autograft, fixed with an adjustable suspensory fixation (ASF), has several potential advantages. However, the construct is suspected to generate micromotion, tunnel widening and poor graft maturation. The aim of this study was to evaluate post-operative tibial tunnel expansion, graft maturation and clinical outcomes for this type of ACLR.

Methods One-hundred and forty-nine patients were reviewed at a minimum of 2 years following 4-ST ACLR, mean 25.6 ± 3.5 months [24–55], with clinical follow-up and MRI scans. Graft maturity of the intra-articular part of the graft and the tibial tunnel portion was assessed using Signal-to-Noise Quotient (SNQ) and Howell score. Tibial tunnel expansion, bone–graft contact and graft volume in the tibial tunnel were calculated from the MRI scans.

Results Mean tibial tunnel expansion was 13 ± 16.5% [12–122]. Mean SNQ for graft within the tibial tunnel was 3.8 ± 7.1 [−7.7 to 39] and 2.0 ± 3.5 [−14 to 17] for the intra-articular portion of the graft. The Howell score for graft within the tibial tunnel was 41% Grade I, 37% Grade 2, 20% Grade 3, 2% grade 4, and for the intra-articular part 61% Grade 1, 26% Grade 2, 13% Grade 3 and 1% Grade 4. The mean tibial tunnel bone–graft contact was 81 ± 23% [0–100] and mean graft volume was 80 ± 22% [0–100]. No correlation was found between tibial tunnel expansion and graft maturity assessed at both locations. Graft maturity was correlated with higher graft-bone contact and graft volume in the tibial tunnel ($p < 0.05$).

Conclusions ST-4 ACLR with ASF had low levels of tunnel enlargement at 2 years. No correlation was found between graft maturation and tibial tunnel expansion. Graft maturity was correlated with graft–bone contact and graft volume in the tibial tunnel.

Level of evidence Level III.

Keywords Anterior cruciate ligament · ACL · Tunnel enlargement · Tunnel widening · Maturation · SNQ · Signal to noise quotient · ASF · Adjustable suspensory fixation · ST4

Abbreviations

ACL	Anterior cruciate ligament
ASF	Adjustable suspensory fixation
BPTB	Bone patellar tendon bone graft
CT scan	Computerized tomography scan
IKDC	International knee documentation committee
Lat	Lateral
MRI	Magnetic resonance imaging
PA	Posterior–anterior
SNQ	Signal to noise quotient
ST4	Quadrupled semitendinosus graft
STG	Semitendinosus and gracilis graft
XR	X-ray

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Introduction

Anterior cruciate ligament (ACL) reconstruction with hamstring tendon autograft is a common and reliable treatment for ACL injury [15, 45, 50]. Several graft configurations and fixation options exist, of which, the use of a quadrupled semitendinosus (4-ST) autograft with adjustable suspensory cortical fixation (ASF) has become increasingly popular [19]. The configuration is mechanically strong [10, 36] and may afford improved stability and lower rates of failure compared to four-strand, semitendinosus and gracilis autografts using aperture fixation [3, 44]. Although the 4-ST autograft is relatively short, studies have shown that as little as 5 mm of graft within the bone tunnels is adequate for healing at the bone–graft interface [5, 51]. Additionally, cortical suspensory fixation may facilitate revision surgery, with the hardware being relatively more accessible compared to aperture fixation [29].

Following surgery, ACL grafts undergo an approximate 24 months process of "ligamentization" and synovialisation whilst also healing to the bone tunnel walls via Sharpey's fibers [31, 42, 46]. Graft micromotion may occur with cortical fixation as a result of "bungee cord" and "windshield wiper" effects [23, 52]. This may potentially lead to tunnel widening and be deleterious for ACL graft maturation [30, 49, 53]. Additionally, graft maturation in the tunnels may be slower than for the intra-articular portion of the graft [26]. Magnetic resonance imaging (MRI) may be used to evaluate graft ligamentization using signal-to-noise quotient (SNQ) [17, 48] and Howell Score [24]. MRI has also been validated for the measurement of tunnel enlargement, with the advantage of being non-irradiating compared with computerized tomography (CT) and plain radiographs [16, 17, 23, 25].

Whilst previous studies have suggested that 4-ST ACL reconstructions using tibial and femoral ASF are associated with less tunnel expansion at 6 months post-operative follow-up than similar grafts fixed with interference screws [9]. The relationship between the appearances of 4-ST autografts (using tibial and femoral ASF fixation) at 2 year post-operative follow-up and the relationship with tibial tunnel expansion has not been previously investigated. While Zhang et al. [53] showed a correlation between graft maturation and femoral tunnel expansion with femoral suspensory fixation, tibial tunnel widening and its relationship with graft maturity and tibial ASF is used has not been evaluated. The aim of this study was to analyse the correlation between MRI measured graft maturity (using SNQ and Howell scores) and tibial tunnel expansion. It was hypothesized that poorer graft maturation was associated with tunnel enlargement. Additionally, the relationship between graft maturity and the proportion of graft in contact with the bone, the volume of graft in the tibial tunnel and with clinical outcomes at 2-year post-operative follow-up was investigated.

Materials and methods

This study was approved by the institutional review board (CE Clinique du Sport, Mérignac – 12–2019-04). One-hundred and forty-nine patients, who had undergone 4-ST autograft primary ACL reconstruction, with tibial and femoral ASF, between 2014 and 2017, underwent MRI scans and clinical evaluation at a minimum of 2-year post-operative follow-up. Patients were excluded if the ACL reconstruction was performed as part of a multi-ligament injury or if they had sustained an ACL graft rupture between surgery and the MRI scan. All ACL reconstructions were performed by the senior author (initials blinded for review) at the same institution. Clinical evaluation was undertaken at post-operative follow-up appointments in clinic.

Surgical procedure

Under general anaesthesia, patients were placed in supine position. A pneumatic tourniquet was applied to the leg and inflated to a pressure of 300 mmHg. The semitendinosus tendon was harvested using a tendon harvester (Linvatec, Largo, FL, USA). The 4-ST graft was prepared on a Graft-Tech board (SBM, Lourdes, France) with an ASF device at both ends: Pullup® (SBM, Lourdes, France) on the femoral side and Pullup XL® (SBM, Lourdes, France) on the tibial side [8]. The graft diameter was calibrated using a closed sizing tube. The tubes were progressively down-sized in 0.5 mm increments until the graft would not pull into the sizing tube with manual force.

The intercondylar notch was prepared and the capsular line reflection was used to guide tunnel placement [11]. The femoral tunnel was drilled inside-out through the anteromedial (AM) portal. A 20 mm length femoral socket corresponding to the graft diameter was reamed with a drill, the diameter of which corresponded to the graft diameter measured by the sizing tube. The tibial tunnel (corresponding to the graft diameter) was drilled outside-in to the centre of the native tibial ACL footprint. The graft was then pulled retrograde through the tibial tunnel into the femoral socket. With 15–20 mm of graft in the femoral tunnel, final graft tensioning was applied via the ASF devices at both ends.

Patient characteristics

MRI scans were performed for the cohort of 149 patients at an average of 25.6 ± 3.5 months (range from 24 to 55) postoperatively (Table 1).

Post-operative rehabilitation

All patients followed a non-aggressive rehabilitation protocol. Weight bearing was allowed immediately after surgery with the use of crutches and an un-restricted range-of-motion knee brace. Cycling and swimming were commenced at 6 weeks and jogging at 3 to 4 months. Return to sport was allowed from 6 months after surgery, following successful

Table 1 Patient demographics

	Value
No. of patients	149
Age	31.6 ± 12 years (range 11–65)
Sex	
Female	37.6%
Male	62.4%
Sport activity	
Pivot (contact)	44%
Pivot (no contact)	23%
Non-pivoting	26%
No sport	7%
Sport level	
Competition	33%
Leisure	53%
Active	9%
Sedentary	5%
Return to sport	8.7 ± 4.9 months (range 2–28)
Return to work	3.1 ± 4.1 months (range 0–31)

completion of a return to sport criteria assessment (including isokinetic testing).

MRI and image analysis

ACL graft maturation was assessed using sagittal and axial planes fat-saturated MRI sequences. 2 mm slices were obtained using a 1.5-T superconducting magnet (Signa; GE Healthcare) with a dedicated surface coil. Proton density-weighted images were acquired with the standard spin echo technique (1000-ms repetition time and 20-ms echo time). All graft measurements were taken with the RadiAnt DICOM Viewer 1.9.16 (Medixant). The sagittal view showing maximum section of the graft was selected. All MRI's were evaluated by a senior surgeon, different from the operator he was blind to the clinical and operative data. SNQ is the gold standard for MRI analysis of the graft [21]. The different measurements were made to two decimal places, the values retained were to one decimal rounded to the higher unit if necessary.

The diameter of the part of the tibial tunnel with graft within it was measured on the axial sequences. The largest diameter was recorded. This was compared to the diameter of the drill used intra-operatively making it possible to assess tunnel expansion using the formula: [7]

$$\text{Tunnel expansion} = \frac{\text{Follow up diameter} - \text{Intial diameter}}{\text{Intial diameter}}$$

Graft maturity was assessed at two sites: within the tibial tunnel and the intra-articular portion of the graft [34, 41]. The Signal-To-Noise (SNQ) score was used to compare ACL graft signal with posterior cruciate ligament (PCL) signal, subtracting background noise (with a lower SNQ reflecting greater graft maturity) [48] (Fig. 1). The graft Howell score [24] was also recorded at the two sites, the signal was analysed on PD-weighted and T2-weighted images and evaluated as Grade I = normal signal (similar to posterior cruciate ligament), Grade II > 50% of the total volume of the graft having a normal signal, Grade III < 50% of the graft having a normal signal, and Grade IV 100% of the graft having an increased signal.

As in previous studies [9, 16], the proportion of graft in contact with bone in the tibial tunnel (percentage bone–graft contact) and the volume occupied by the graft in the tunnel (percentage tibial graft volume) (Fig. 2) was analysed. The appearance of the tibial tunnel was categorized as: unfilled, partially filled or completely filled [1, 9]

Clinical post-operative assessment

Clinical outcomes were evaluated at final follow-up using the International Knee Documentation Committee (IKDC) and the Lysholm scores. The Tegner score and any delay in return to work or sport was also recorded (Fig. 3).

Statistical analysis

Descriptive statistics were used to describe patient characteristics. Continuous variables were expressed as mean, standard error (SE) and range. The results of the different clinical outcome (Lysholm, IKDC) were reported as mean and standard deviation except for Tegner score were the median and range values at the 1st and 3rd quartile were expressed. Correlations between tibial tunnel enlargement, bone–graft contact, tibial graft volume, bone filling, clinical outcomes and graft maturation were assessed using the Spearman product moment correlation (r) for mean SNQ score and the Kruskal–Wallis test, with a Dunn test and Bonferroni correction, for the Howell score. In the analysis of Howell scores, grades III and IV was combined to have a group size of more than five cases. The results are displayed with one decimal rounded up if necessary. All calculations were made using Addinsoft 2020 (XLSTAT, Paris, France). Results were considered statistically significant when the 95% confidence interval did not include the null value (1.00) or when $p < 0.05$.

Results

Graft maturation

At final follow-up, graft SNQ was positively correlated with the Howell score for the tibial and intra-articular

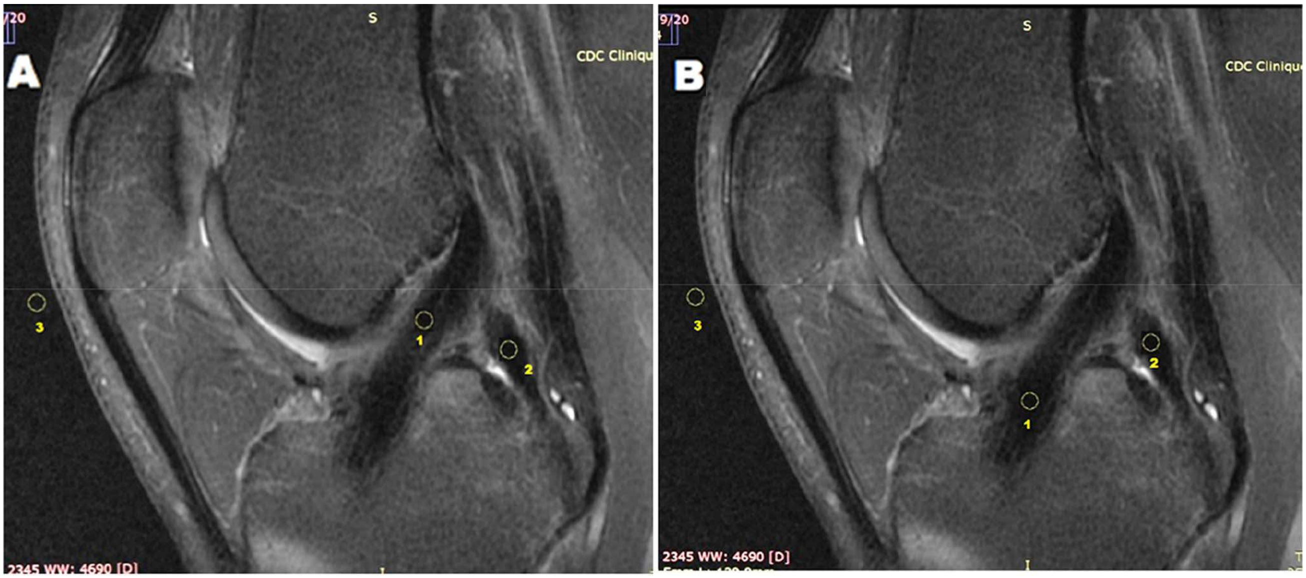

Fig. 1 Method of Signal to Noise Quotient (SNQ) measurement on sagittal T2 MRI scans. **A** A 25 pixels diameter region interest (ROI) was evaluated in the mid-substance of the intra-articular part of the ACL graft (articular SNQ) and (**B**) in the mid-substance of the graft in the tibial tunnel (tibial SNQ). The PCL signal was measured with the ROI (2) placed in the mid-substance of the ligament. For background noise measurement, the ROI (3) was selected anterior to the patellar tendon

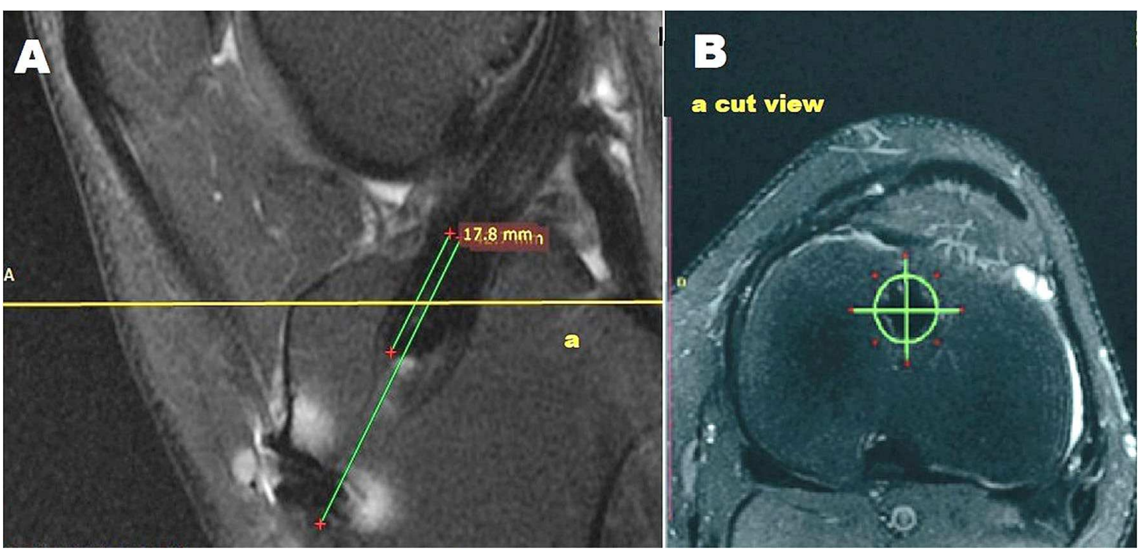

Fig. 2 Method of analysis of bone–graft contact and tibial graft volume. **A** Sagittal T2 MRI section through the tibial tunnel with line a showing the cut level of the axial T2 section (**B**). The tibial tunnel was divided in four parts to calculate tibial graft volume and bone–graft contact [1, 8]

parts of the graft: $r = 0.2$ for both ($p < 0.001$). The size of the graft (initial and at 2 years) was not correlated with the tibial SNQ maturation score (n.s.).

The maturation scores and their statistical analysis are presented in Table 2.

Tibial tunnel expansion

The mean tibial tunnel diameter drilled during surgery was 8.7 ± 0.6 mm (range from 7.5 to 10.5). At final follow-up, the mean tibial tunnel diameter was 9.8 ± 1.6 mm

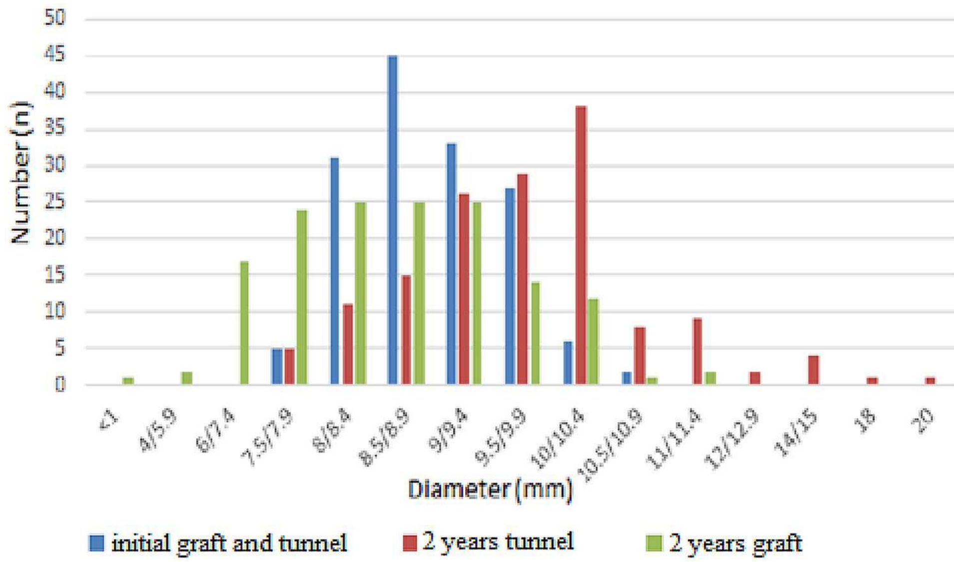

Fig. 3 Diagrams showing the diameter of the tibial tunnel and tibial graft initially and at 2 years

(range from 7.5 to 20): a mean enlargement of 13 ± 16.5% (range from 12 to 122).

No correlations were found between tibial tunnel expansion and age (n.s.).

Characteristics of the graft in the tibial tunnel

Both the bone–graft contact ratio means 81 ± 23% (range from 0 to 100) and the tibial graft volume means 80 ± 22% (range from 0 to 100) were found to be correlated with graft SNQ and Howell scores of both the tibial and intra-articular portions of the graft ($p < 0.05$) (Table 3).

At final follow-up, the distal part of the tibial tunnel, not containing graft, was completely filled with bone in 109 cases (73%), partially filled in 35 cases (23%) and not filled in 5 cases (3%). Statistical analyses of tunnel characteristics and graft maturation are presented in Table 3.

Clinical outcomes

At 2 year post-operative follow-up, mean clinical outcome scores were: IKDC = 86.7 ± 11.7 (range from 50.6 to 100), Lysholm = 90 ± 10.4 (range from 52 to 100), the median of Tegner's score was 6 [Q1 = 5; Q3 = 7].

No correlations were found between clinical outcomes and maturation score or tunnel expansion (Table 3).

Post-operative complications

During the follow-up period, there were three post-operative complications. One patient developed intra-articular infection 2 weeks following surgery, requiring arthroscopic lavage and 6 weeks of antibiotic therapy. At final follow-up, mean clinical scores for this patient were IKDC = 96.6 and Lysholm = 94. The tibial part of the graft had SNQ = 16.5 and articular part SNQ = 2.5. One patient developed a cyclops lesion requiring arthroscopic debridement 13 months following the primary surgery. One patient developed a tibia tunnel cyst with 122% tunnel widening,

Table 2 Graft maturation scores

	ACL graft within the tibial tunnel	Intra-articular ACL graft	Comparison ACL tibial graft maturation vs articular
SNQ	Mean = 3.8 ± 7.1 (Range from −7.7 to 39)	Mean = 2.0 ± 3.5 (Range from −14 to 17)	SNQ tibial vs SNQ articular: $p < 0.001$ $r^2 = 0.4$
Howell score, % (*n*):			Howel score tibial vs articular: $p < 0.001$
Grade I	41% (61)	61% (91)	
Grade II	37% (55)	26% (38)	
Grade III	20% (30)	13% (19)	
Grade IV	2% (3)	1% (1)	

SNQ signal-to-noise quotient

Table 3 Correlations between the ACL graft appearance with for tibial tunnel expansion, bone–graft contact ratio, graft volume occupancy, bone filling and clinical outcomes

		Tibial tunnel expansion	Bone–graft contact	Tibial graft volume	Bone filling	IKDC	Lysholm	Tegner
Tibial graft portion	SNQ [a]	(n.s.) $r^2<0.1$	$p=0.006$ $r^2<-0.1$	$p<0.001$ $r^2<-0.1$	(n.s.) $r^2<0.1$	(n.s.) R < 0.1	(n.s.) $r^2<0.1$	(n.s.) $r^2<0.1$
	Howell score [b]	(n.s.)	p < 0.001	p < 0.001	p = 0.007	(n.s.)	(n.s.)	(n.s.)
Intra-articular graft portion	SNQ [a]	(n.s.) $r^2<0.1$	p = 0.005 $r^2<-0.1$	p = 0.026 $r^2<-0.1$	(n.s.) $r^2<0.1$	(n.s.) R < 0.1	(n.s.) $r^2<0.1$	(n.s.) $r^2<0.1$
	Howell score[b]	(n.s.)	$p<0.001$	$p<0.001$	(n.s.)	(n.s.)	(n.s.)	(n.s.)
Tibial tunnel expansion	/	/	/	/	(n.s.) $r^2=-0.1$	(n.s.) $r^2=-0.1$	(n.s.) $r^2<-0.1$	

[a]Spearman correlation product / [b]Kruskal–Wallis test with Dunn Test Bonferroni correction /

requiring bone grafting and removal of the tibial fixation 15 months after primary surgery. At final follow-up, mean clinical scores for this patient were IKDC = 79.3, Lysholm = 73. The SNQ for the tibial part of the graft was 6.2 and 6 for the articular part.

Discussion

The most important finding of this study was that there was minimal tibial tunnel enlargement following 4ST autograft reconstruction using tibial and femoral ASF. Second, graft maturity at 2-year post-operative follow-up was correlated with bone–graft contact and graft volume in the tibial tunnel but was not correlated with clinical outcomes or tunnel enlargement.

Concerns about tibial tunnel enlargement with the use of ACL graft cortical fixation have been previously reported, with graft micromotion in the longitudinal axis ("bungee cord effect") and the “windscreen wiper effect" in the transverse axis being proposed as mechanisms [12, 23, 49]. Clatworthy et al. [7] and Buelow et al. [4] defined tunnel “ballooning” as enlargement of greater than 50%, this occurred in 5 tibial tunnels (3%) in this series. Others authors have defined “ballooning” as expansion of more than 2 mm from the original diameter [14, 39], 23 tunnels (15%) in this study fell into this category. Colombet et al. [9] compared ACL graft fixation with interference screws against the same ASF device that was used in this study and found more tunnel expansion in patients with interference screws fixation at 6-months post-operative follow-up. The mean 13 ± 16.5% [12–122] tunnel expansion reported in the present study is also less than reported in several other studies which used interference screws [4, 38, 40, 43], bi-cortical post screws [33] and closed loop suspensory fixation [28] for graft fixation (Table 4). The insertion of tibial interference screws has been shown to both compress the graft and enlarge the tunnel at the time of implantation due to the greater compressive stiffness of the screw compared to the graft and cancellous bone [7, 43, 49]. The disparity between suspensory fixation systems may be attributable to differing construct stiffness. The ASF device that was used in this present study was compared favourably with that used by Mayr et al. [39], they found 18% of patients had more than 10 mm post-operative tibial tunnel enlargement using the TightRope ASF device (Arthrex, Naples, FL, USA). This variation might again explained by the different stiffness of the two ASF systems used [13]; a comparative biomechanical study comparing the different extra-cortical fixations would be necessary to explore this hypothesis.

The results of the present study showed that tibial tunnel expansion was not correlated with ACL graft maturity of either the intra-articular or tibial tunnel parts of the graft (as measured by SNQ or Howell score). In contrast, Zhang et al. [53] did find a significant correlation between femoral tunnel enlargement, and graft SNQ score, for hamstring autograft reconstructions fixed using a closed loop extra-cortical fixation device (Endobutton CL®, Smith and Nephew, Andover, MA). The study by Zhang et al. [53], however, evaluated only 22 patients, compared with 149 in this present cohort.

However, graft maturity in the tibia was significantly correlated with the bone–graft contact and graft volume in the tibial tunnel. Furthermore, initial graft size did not correlate with tibial SNQ maturation score. Improved MRI features of graft maturity in the tibial tunnel has been previously shown with ASF compared to interference screws [9]. This is consistent with animal studies that show better maturation for grafts in close contact with bone [20]. Interference screw fixation, particularly if placed eccentrically alongside the graft, may tend to reduce the contact surface between the bone and the graft compared to ASF, which allows the graft to occupy the entire volume of the tunnel improving bone–graft contact.

Table 4 Studies assessing post-operative tibial tunnel enlargement and the fixations used

Study	Graft	Tibial fixation methods	Tibial enlargement	Patients (*n*)	Measures
Current study	ST4 autograft	ASF—Pullup®	13%	149	MRI
Robinson et al. [42]	STG autograft	Bioabsorbable interference screws			
		PLLA	46%	21	CT scan
		PLLA + HA	29.9%	13	
Jansson & Al. [26]	STG autograft	Suspensory Cortical Fixation (Endobutton CL)	23%	14	XR & MRI
L'insalata et al. [31]	ST4 or STG autograft	Bi-cortical screw and washer	20.9% (PA view)		
			25.5% (Lat view)	30	XR
	BPTB group	Interference screw	9.7% (PA view)		
			14.4% (lat view)	30	
Buelow et al. [4]	STG autograft	Extracortical fixation	49%	30	XR & MRI
		Bioabsorbable interference screw (Arthrex, Karlsfeld)	94%	30	
Moisala et al. [39]	STG autograft	Bioabsorbable interference screw (Hexalon, Inion Co., Finland)	48%	20	MRI
		Metal screw (Timoni Co., Finland)	41%	22	
Mayr et al. [37]	STG autograft	Bioabsorbable interference screw (biocomposite, arthrex)	> 10 mm: 100% / > 12 mm: 35.7%	14	CT scan
		Adjustable length loop cortical button (TightRope, arthrex)	> 10 mm: 18.8% / > 12 mm: 0%	16	

ST4 short quadrupled semitendinosus, *STG* semitendinosus and gracilis, *PLLA* Poly-L-lactic-acid, *HA* Hydroxyapatite, *BPTB* Bone patellar tendon bone

ASF Adjustable suspensory fixation, *XR* X-ray, *PA* Posterioranterior, *Lat* Lateral, *MRI* magnetic resonance imaging, *CT* computerized tomography

In 73% of cases the distal part of the tunnel, not occupied by graft, was completely re-filled by bone on the post-operative MRI scans. Re-filling of the tunnel with bone did not influence graft maturation of the intra-articular portion of the graft but was correlated with improved graft maturity in the tibia as measured by the Howell score (although there was no correlation with SNQ). The findings of minimal tunnel enlargement in the part of the tunnel occupied by the graft (13%) and bone re-filling the distal part of the tunnel in 73% of cases at 2-year post-operative follow-up, are encouraging in the context of revision surgery and are likely to indicate a minimal need for tibial tunnel bone grafting and staged revision surgery. Previous studies have also suggested that ASF used for primary ACL reconstruction has advantages for revision surgery including reduced bone cyst formation, and the lack of hardware in the tunnel [10, 13, 36].

As has been previously described [26, 46, 53], that portion of the graft in the tibial tunnel had a significantly higher SNQ than the intra-articular part of the graft. These data reflect two different processes: "the ligamentization" of the intra-articular part of the graft undergoing a graft remodeling with exposure to cytokines and synovial fluid, whilst in the tunnel, incorporation of the graft and adherence to the tunnel walls through the formation of Sharpey's fibers at the graft–bone interface [27, 46]. Although Li et al. [32] reported a link between the level of resumed sports activity and graft maturation, no correlation was found in this present study between the MRI assessment of graft maturity and clinical outcome scores. This is consistent with other studies [2, 31, 35, 54] and a recent systematic review also suggested that graft maturity alone is not the determining factor for clinical outcome [21].

This study is one of the largest analysis of ACL graft maturity measured with conventional MRI [47]. It reenforces previous work demonstrating a lack of correlation between tibial tunnel widening and graft maturity but is the first large study to assess short ST4 autograft ACL reconstruction with tibial and femoral ASF fixation. However, this study has some limitation: although SNQ is frequently used [18] to assess ACL graft maturity, the measure shows variability between studies, which makes it difficult to compare different studies [47]. The Howell score has also been used to provide an additional indicator of maturation, but this score is also subject to variability in interpretation [24]. Tunnel enlargement was calculated by comparing the axial diameter of the tibial tunnel with the diameter used to drill the tunnel during surgery, although a simple method of calculation, other calculation methods have been described such as the tunnel cross-sectional area measurement which takes into account the angle of the graft [7]. MRI is advantageous as a non-invasive tool for measuring bone tunnel expansion and graft maturation, and is frequently used in the study of the native ACL and its reconstruction, however, it may underestimate tunnel expansion compared CT [39]. The results presented in this study must be viewed in the context of the differing methodologies used in previous studies to measure tunnel expansion (MRI vs CT Scan vs Radiographs) and comparisons should be interpreted cautiously. The MRI measurements were performed by a single observer, blind to the other data and different from the primary operator, however, multiple observer measurements to compare intra- and inter-observer variability would have been interesting but was not the focus of the study. A single MRI at 2-year post-operative follow-up was used, intermediate MRIs would have allowed to follow chronology of graft maturity [37]. Additionally although changes in graft maturation are largely complete at 2-years following surgery [6, 22, 37] further changes may still occur [54] and a study assessing the tunnels at longer term follow-up might have different findings.

This study shows that adjustable suspensory fixation does not result in excessive ballooning of the tibial tunnel (13 ± 16.5% [12–122]), and the widening of the tibial tunnel does not seem to have an impact on graft maturation. This method of fixation, therefore, remains a reliable solution for anterior cruciate ligament reconstructions.

Conclusions

This study has shown that 4-ST autograft ACL reconstruction using tibial and femoral ASF is associated with low levels of post-operative tunnel enlargement. Higher bone–graft contact and tibial tunnel graft volume appear to lead to improved graft maturity, but does not appear to effect clinical outcomes.

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Declarations

Conflict of interest N. Bouguennec is a consultant for SBM, N. Graveleau is a consultant for SBM, and P. Colombet has received royalties from SBM, all of which is unrelated to this article.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors

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