ARTICLE IN PRESS

Journal of ISAKOS xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of ISAKOS

journal homepage: www.elsevier.com/locate/jisakos

Current Concepts Review

Short graft anterior cruciate ligament reconstruction: Current concepts

Jessica Thor, MBBS, MRCS [a], Lee Yee Han Dave, MBBS, FRCS (Ortho), MMed(Ortho) [b,*], Sachin Tapasvi, MD [c], Tahsin Beyzadeoglu, MD [d]

[a] *Department of Orthopaedic Surgery,Changi General Hospital, Singapore*
[b] *Department of Orthopaedic Surgery, National University Hospital, Singapore*
[c] *The Orthopaedic Speciality Clinic, Pune, India*
[d] *Professor of Orthopedics & Traumatology Halic University & Beyzadeoglu Clinic Istanbul, Turkey*

ARTICLE INFO

Keywords:
Short graft
Anterior cruciate ligament reconstruction

ABSTRACT

Short graft anterior cruciate igament reconstruction is increasing in popularity for performing a primary ACLR. The short graft coupled with the all-inside technique using closed sockets and suspensory fixation at both femoral and tibial ends are its defining features. The outcomes of this technique have been comparable to well established transportal ACLR techniques. It has the benefits of preserved hamstring strength and less pain attributed to transtibial drilling. However, there is a learning curve involved and will require time before mastery of the technique. Furthermore, in combined osteotomy or multiligament surgery, the use of short graft anterior cruciate ligament reconstruction with sockets preserve bone stock and the single tendon harvest spares the other tendons for use in other ligament reconstruction.

Current concepts

- Short graft anterior cruciate ligament reconstruction (ACLR) is increasingly popular, with more surgeons practising all-inside ACLR techniques.
- The outcomes of short graft ACLR thus far are comparable to the transportal ACL reconstruction technique, but with additional benefits.
- The technique can be performed with soft tissue grafts only.
- The familiarity with the surgical technique, understanding of optimal graft fixation and biology are all paramount to success.

Future perspectives

- Prospective clinical studies are required to determine which patient is best suited for short graft anterior cruciate ligament reconstruction and the ideal graft source.
- Biomechanical and clinical data are required on the most appropriate short graft to be used with this technique.
- Methods to improve healing of osseous graft interface with the use of biologics or scaffolds should be studied.
- The most time and cost-efficient as well strongest graft short graft anterior cruciate ligament reconstruction preparation technique should be determined to allow reproducibility amongst surgeons.

Introduction

The short graft anterior cruciate ligament reconstruction (SG ACLR), as the name implies, is the use of a shorter graft length to perform an ACLR. Hence, there will be less graft length passed in both the femur and tibia tunnels. The proposed benefit is a larger ACL graft diameter with the same graft tissue [1,2] and isolated harvest of the semitendinosus tendon. Now, the use of all soft tissue quadriceps tendon (QT) graft has also been increasingly suggested. With the sparing of the gracilis tendon, there is less pain [3–5], less donor site morbidity and better knee flexion strength compared to when both hamstring tendons are harvested [6,7].

The all-inside ACLR (AI ACLR) is the most performed SG ACLR technique. This technique involves the unique preparation method of a short graft, the use of femoral or tibial sockets instead of complete tunnels and the use of cortical suspensory fixation at both ends. Other SG ACLR options include the more recent Tape Locking Screw (TLS) technique [8]. The TLS technique is more challenging due to the need for precise determination of tunnel length and graft length which will affect the tension in the graft after reconstruction. Pacull et al. has also shown the TLS fixation has lower ultimate load to failure than other femoral fixation options [8].

Most authors describe the use of a quadrupled semitendinosus (ST4) or QT in the SG ACLR [9]. This review looks at the current state of SG

* Corresponding author. Department of Orthopaedic Surgery, National University Hospital, 5 Lower Kent Ridge Road, 119074, Singapore.
E-mail addresses: jessicathor221@gmail.com (J. Thor), davelyh@singnet.com.sg, dave_yh_lee@nuhs.edu.sg (L.Y. Han Dave), stapasvi@gmail.com (S. Tapasvi), tbeyzade@superonline.com (T. Beyzadeoglu).

https://doi.org/10.1016/j.jisako.2022.09.002
Received 31 May 2022; Received in revised form 14 September 2022; Accepted 23 September 2022
Available online xxxx

Please cite this article as: Thor J et al., Short graft anterior cruciate ligament reconstruction: Current concepts, Journal of ISAKOS, https://doi.org/10.1016/j.jisako.2022.09.002

ACLR to discuss the biology, biomechanics, surgical techniques and outcomes of this technique.

Body

Classic technique

The classical AI ACLR technique was described by Lubowitz, Amhad and Anderson [10]. They described a ST4 graft with both ends looped over two adjustable loop cortical suspension devices for the femoral and tibial sockets. High strength ultra-high molecular weight polyethylene sutures are used during special graft preparation. The graft diameter is sized and then marked to the lengths of the tibial and femoral sockets (usually 20–25 mm) for guiding the surgeon during graft passage.

The femoral and tibial sockets are prepared independently. The femoral tunnel is reamed in either an anterograde or retrograde fashion to create a socket, usually between 20 and 25 mm [10]. The tibial socket is created using a retrograde reamer. The prepared graft is shuttled into the knee joint through the anteromedial portal with the proximal sutures entering the femoral socket initially. After the cortical suspensory device engages on the lateral femoral cortex, the graft is then advanced into the femoral socket. This process is then repeated on the tibial side. Finally, the graft is tensioned with the knee in near full extension. Several tips and technical considerations that should be taken into account when performing the SG ACLR are shown in Table 1.

Discussion

SG ACLR graft choice

The ST4 is the most used autograft for SG ACLR [9,11,12]. Females generally have smaller hamstring tendons than their male counterparts [1]. ACL graft diameter has also been found to be critical. A graft of smaller than 8 mm leads to poorer outcomes and increased risk of graft rupture, especially in young athletes [2]. ST4 grafts have an approximate diameter of 8–9.5 mm [6,13], compared to about of 7.2–8.5 mm in a four-strand hamstring graft [13]. Additionally, ST4 SG ACLR also allows for the sparing of the gracilis tendon, which leads to the improved recovery of knee flexion strength and less donor site morbidity [6,7]. Koulomentas et al. [6] and Monaco et al. [7] both reported better knee flexion strength with the AI ACLR reconstruction than the standard ACL reconstruction.

The choice of ACL graft should be tailored to each individual patient, such as their sporting demand, gender or the presence of ligamentous laxity. There is now an increasing use of the QT as the graft of choice for ACL reconstruction. The ACL registry data from New Zealand show a rise in the use QT grafts since 2019 but they still account for only 6.5% of all primary ACL reconstructions [14]. The advantages of the QT graft include consistently sufficient length compatible with SG ACLR. It often has a wide diameter of 10 mm [15,16] and can be harvested with or without a bone plug [16]. The reported problems with QT harvest include weakness of knee extension, donor site pain and patella fractures [16].

The QT can be prepared via a proprietary Graft Link technique using cortical suspensory buttons [15]. Galan et al. [17] found good to excellent results at 5 years with QT graft AI ACLR in young athletes. The QT graft is considered an option especially in the female athlete, with increased ligamentous laxity and smaller hamstring tendons [1]. It exhibits less post-operative pivot shift laxity and can be harvested with reliable dimensions [16]. Traditionally, bone patella tendon bone (BPTB) grafts have been considered as the gold standard in ACL reconstruction [6]. Recent literature comparing QT to BPTB grafts has shown that QT grafts have similar properties to BPTB, but with better ultimate load to failure rates and less anterior knee pain [17,18].

The peroneus longus (PL) tendon has also been considered as an alternative to the hamstring graft for AI ACLR [19]. He et al. [19] in their meta-analysis comparing AI ACLR using PL grafts versus hamstring grafts reported donor site morbidity with the use of PL grafts, with a decrease in American Orthopaedic Foot and Ankle Scores (AOFAS). More studies are required before PL grafts can be considered a regular graft option in the SG ACLR.

Table 1
Tips when performing a SG ACLR.

If a graft diameter of less than 8.5 mm or a graft length less than 25 mm is obtained after harvesting only the semitendinosus tendon, consider harvesting the gracilis tendon as well
Measure the graft length accurately. Add 5 mm when reaming femoral and tibial tunnel socket lengths to avoid bottoming out of the graft, leading to a lax graft
Leave a small amount of muscle on the graft during graft preparation for better healing as it has been shown to contain pluripotential cells
Use outside-in femoral drilling in adolescent anterior cruciate ligament reconstruction to avoid physeal damage
Short Graft ACL with concurrent high tibial osteotomy or Short graft ACL in multiligament reconstruction should be considered.

Graft preparation

The SG ACLR technique demands a unique method of preparation. These grafts are recommended to be a maximum length of 70–75 mm after tensioning [10], for fear of bottoming out and the grafts becoming slack when sockets are used. The popular methods of graft preparation include the buried-knot method described by Lubowitz [20] and the continuous loop method [21] as seen in Fig. 1. Others have also described alternative methods, for example the Sommerfeldt configuration [22] and the Quad Link technique [15].

The buried-knot method has consistently shown in biomechanical studies to be able to withstand sufficient forces in the post-surgery ACL period [23], with an ultimate failure load range of 908 N [24]. Biomechanical studies have shown that the mode of failure with SG ACLR sutured constructs to mostly be at the cortical suspensory fixation loop [21,25,26]. Richardson et al. [26] reported majority of failures at the button loop with the buried-knot technique. This demonstrates the adequate strength of the graft/button implant construct strength via the buried-knot method.

The considerations for optimal SG ACLR graft preparation are:

1) choice of a strong graft preparation method such as the buried-knot method, which has greater ultimate failure loads and less elongation as compared to the continuous loop method [21];
2) secure fixation at the terminal ends of the graft to improve ultimate failure loads, stiffness and elongation [22,27];
3) use of 4 instead of 2 cerclage sutures to around the graft at the tibial and femoral ends which protects against graft elongation [25];
4) use of a larger suture diameter for graft preparation is recommended to gain better load to failure rates; a Fibrewire No 2 had a mean load to failure of 731 N versus a load to failure of 610 N using Fibrewire No 0 [28];
5) consideration for graft augmentation with suture or suture tapes, to achieve load sharing, better ultimate failure loads and to protect from graft elongation [29].

Grafts fashioned from the use of two separate tendons such as the semitendinosus and gracilis do not fare better than the methods of QT4 graft preparation. However, the use of two separate tendons can be considered if there is insufficient final graft length or diameter, such as due to accidental graft transection during harvesting. Wichern et al. [24] and Richardson et al. [26] have demonstrated increased displacement and lower mean ultimate failure loads with different tendon preparation methods for two tendons, in both the four-strand and six-strand constructs.

Graft length, size and healing

There are various studies performed to determine a minimum graft length in both the femoral and tibial ACL tunnel. Zantop et al. [30] using goat tendons showed no differences between 15 mm and 25 mm grafts in the femoral tunnel at 12 weeks with regards to stiffness and ultimate

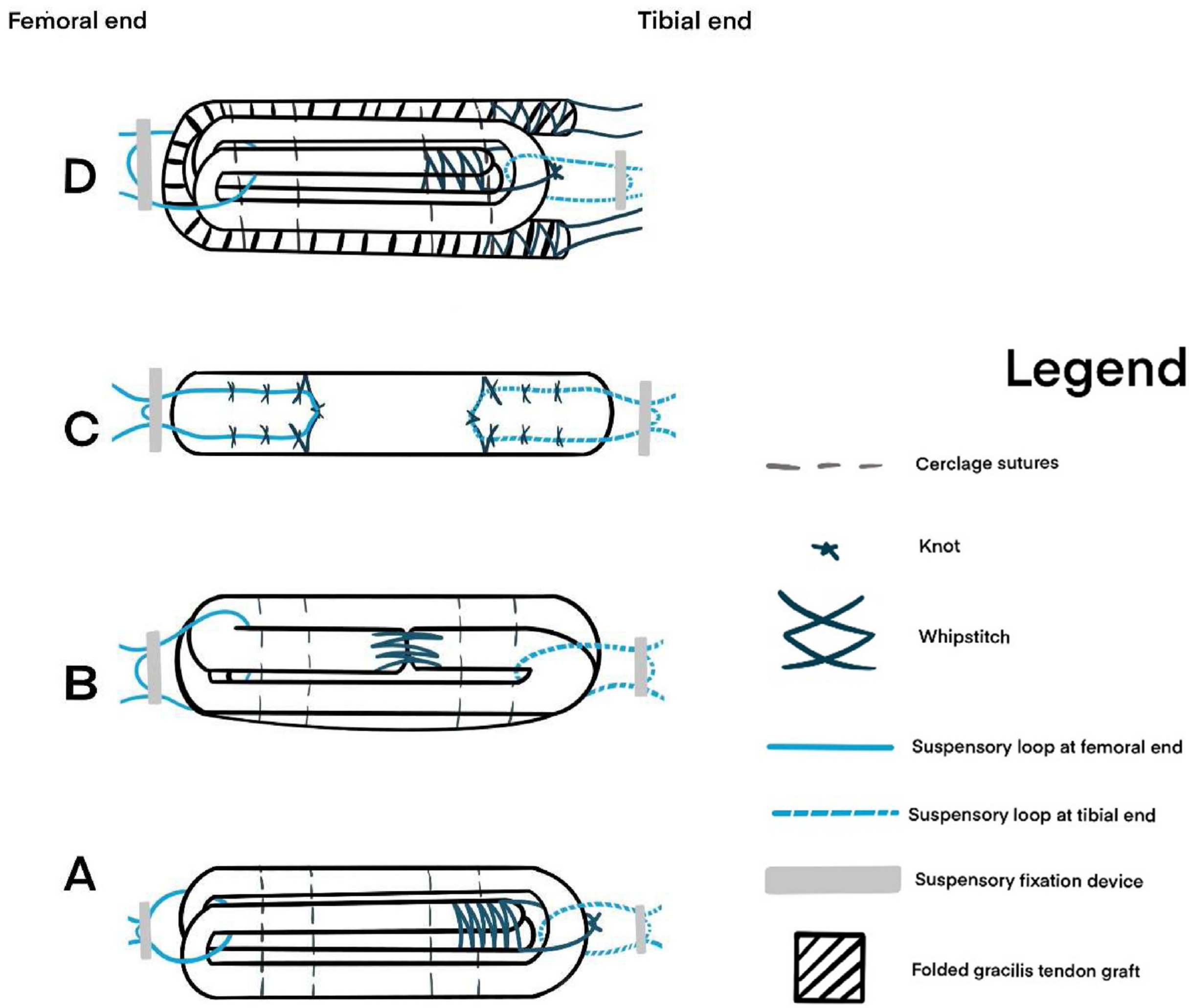

Fig. 1. A – Buried-knot technique of a quadrupled semitendinosus graft preparation described by Lubowitz [10], with the dotted lines as cerclage sutures, and both ends of the tendon are whipstitched together and then secured to the tibial loop. B – continuous loop method of a quadrupled semitendinosus graft [21]. C – the quad link method as described by Sprowls using an all-soft tissue quadriceps tendon graft [15]. D – use of both a folded gracilis tendon and quadrupled semitendinosus graft (prepared in the same fashion as described by Lubowitz) to form a 6-strand graft in the event that a quadrupled semitendinosus graft is of insufficient thickness.

failure loads. Yang et al. [31] have showed an intraosseous tibial tunnel graft length of 20 mm in a porcine model (compared to 40 mm) had no significant differences in graft slippage or graft movement. They recommended a 20 mm intraosseous graft length to be sufficient for rehabilitation after ACL reconstruction.

The healing and integration of an ACL soft tissue graft depends on the formation of Sharpey fibres, signalling incorporation. These fibres are found closer to the joint [13,30], suggesting that perhaps an increased graft in tunnel length does not aid significantly in graft healing. Short grafts should therefore not be biomechanically inferior to conventional ACL reconstruction methods. A widely accepted guideline is a minimum socket length of 20 mm.

The MOON cohort compared patients with between femoral tunnel grafts lengths more than 25 mm versus patients with between femoral tunnel grafts lengths less than 25 mm [32]; reported that there were no differences in the follow up KOOS and IKDC scores. Gupta et al. [33] in a recent study revealed no differences between clinical and radiological outcomes for patients with grafts more than 20 mm in the tunnel and patients with grafts less than 20 mm in the tunnel. Moon et al. [34] compared 3 patient cohorts based on the length of graft in the tunnel: less than15mm, 15–20 mm and more than 20 mm. They found no significant differences in post-surgery knee laxity, VAS scores, Lysholm and IKDC scores.

Tunnel preparation–femur

In AI ACLR, the femoral tunnel is prepared independently from the tibia; it can be reamed through the anteromedial portal or via outside-in drilling. The additional benefit of drilling the femoral tunnel outside-in is that it can be reamed without the need for knee hyperflexion, therefore requiring less assistance for the surgeon during surgery.

On the tibia side in AI ACLR, the sockets are usually prepared using a retrograde reaming technique [20]. Various companies have retrograde reamers to perform sockets preparation. These retrograde reamers require a learning curve [35] to familiarise and also add additional cost to the ACL surgery. In addition, when a socket is reamed on the tibia side, the graft passage will have to be through the arthroscopic portals, rather than the usual passage from the tibia side externally.

Alternatively, in a variation of the classical technique, even with the use of short grafts, a full tibial tunnel has been proposed. This allows the graft to be passed as usual from the tibia side externally. Comparing the AI ACLR and this technique with complete tibia tunnels, Lubowitz, Schwartzberg and Smith [3] as well as Desai et al. [35] have shown excellent physical examination findings and outcomes at 2 years follow up, with no significant differences in the clinical outcomes of both groups.

Table 2
Studies of the all-inside technique.

Author	Journal Year	Number of patients	Mean age (range if any), years	Follow up (range), months	Graft and techniques	Complications	Post-operative clinical results		Comments
Lubowitz et al. [3]	Arthroscopy 2013	148 AI: 76 Standard: 72	AI: 39.3 Standard: 41.1	24	AI: 2-strand tibialis tendon allograft Standard: 2-strand tibialis tendon allograft	NR	<u>AI</u> IKDC subjective 86.5 KSS pain 93.3 KSS function 97.6 VAS -2.5 SF-12 physical 53.3 SF-12 mental 56.8	<u>Standard</u> IKDC subjective 84.0 KSS pain 95.9 KSS function 98.8 VAS -1.7 SF-12 physical 52.5 SF-12 mental 55.3	No significant difference between both groups in IKDC, KSS, SF-12 scores, femoral and tibial widening, or narcotics consumption Significantly lower VAS in AI group No significant differences in operative times
Volpi et al. [41]	Muscles, Ligaments and Tendons Journal 2014	40 AI: 20 Standard: 20	AI: 38.4 Standard: 32.6	24	AI: doubled/tripled ST tendon autograft Standard: ST&G	NR	<u>AI</u> Lysholm 90.9 IKDC A 11 (55%) IKDC B 8 (40%) IKDC C 1 (5%) Tegner 5.2 VAS 81.7	<u>Standard</u> Lysholm 94.9 IKDC A 10 (50%) IKDC B 9 (45%) IKDC C 1 (5%) Tegner 6.4 VAS 84.6	No significant differences between both groups in IKDC, Lysholm, Tegner and VAS scores.
Schurz et al. [4]	Arthroscopy 2016	79 Male 53 Female 26	29 (18–54)	30.4 (24.3–44.8)	Quadrupled ST AI	Deep infection – 2 Numbness – 9	Lysholm 93.1 IKDC 89.7 Tegner 6 KT-2000 1.7 mm VAS score 0.14		Significant improvements in IKDC, Lysholm, Tegner and VAS scores compared to baseline, $p < 0.0001$ 12.7% ACL graft ruptures
Yasen et al. [11]	The Knee 2016	108 Male 81 Female 27	30.9 (15–61)	49.8 (30–66)	Quadrupled ST AI	Superficial infection – 1 Superficial haematoma – 1Hemarthrosis – 1	Lysholm score 88.1 Tegner score 5.1 KOOS 87.9 KT-1000 2.20 mm		Significant improvements in KOOS, Lysholm and Tegner scores as compared to baseline, $p < 0.001$ Significantly improved knee flexion compared to baseline ($p < 0.001$) 6.5% ACL graft failure
Baldassarri et al. [42]	Muscles, Ligaments and Tendons Journal 2018	40 AI: 20 Standard: 20	AI: 38.4 Standard: 32.6	24	AI: doubled or tripled ST tendon autograft Standard: ST&G	NR	<u>AI</u> Lysholm 90.9 IKDC A 11 (55%) IKDC B 8 (40%), IKDC C 1 (5%) Tegner 5.2 VAS 81.7	<u>Standard</u> Lysholm 94.9 IKDC A 10 (50%) IKDC B 9 (45%) IKDC C 1 (5%) Tegner 6.4 VAS 84.6	No significant differences between both groups in IKDC, Lysholm, Tegner and VAS scores.
Monaco et al. [43]	KSSTA 2018	44 AI: 22 Standard: 22	AI: 32.5 Standard: 31.7	24[a] (21–27)	AI: quadrupled ST tendon autograft Standard: doubled ST&G	Nil	<u>AI</u> Lysholm[a] 95 Tegner[a] 6 IKDC[a] 91 KSS pain[a] 96 KSS function[a] 100 KT-1000 1.7 mm	<u>Standard</u> Lysholm[a] 90 Tegner[a] 6 IKDC[a] 94 KSS pain[a] 95 KSS function[a] 100 KT-1000 2.1 mm	No significant differences between both groups in IKDC, KSS, Lysholm, Tegner and KT-1000 side-to-side. Significantly larger increase in tibial tunnel widening in the standard technique.
Colombet et al. [44]	The Orthopaedic Journal of Sports Medicine 2018	97 Male – 64, Female – 33	30.9 (14.8–56.1)	24	Quadrupled ST AI	Nil	Lysholm 90.8 Tegner 6.6 IKDC 87.6 Laxity side-to-side 0.8 mm		Significant improvements in Lysholm, Tegner and IKDC scores compared to baseline 2.1% ACL graft failure
Kouloumentas et al. [6]	European Journal of Orthopaedic Surgery & Traumatology 2019	90 AI: 45 Standard: 45	AI: 27.6 Standard: 29.7	24	AI: quadrupled ST tendon autograft Standard: 4-strand ST&G	Nil	<u>AI</u> Lysholm 97.7 IKDC: 83.6 KOOS 95.3 KSS 83.9	<u>Standard</u> Lysholm 96.6 IKDC: 78.5 KOOS 95.8 KSS 96.6	No significant differences between both groups in IKDC, KSS, Lysholm and KOOS scores. AI group had better flexor peak torque, time-to-peak and isometric flexor/extensor ratio at 90°.

(*continued on next page*)

Table 2 (*continued*)

Author	Journal Year	Number of patients	Mean age (range if any), years	Follow up (range), months	Graft and techniques	Complications	Post-operative clinical results		Comments
									AI: 2.2% ACL graft failure Standard: 4.4% ACL graft failure
Mayr et al. [45]	KSSTA 2020	30 AI: 16 Standard: 14	AI: 25 Standard: 29	24	AI: quadrupled ST tendon autograft Standard: 4-strand ST&G	AI: intraoperative button mislocation and button loop rupture, septic arthritis, 3 early reruptures Standard: intraoperative screw breakage	AI Lysholm 94 IKDC subjective 88 Tegner 6 KT-1000 2.9 mm Single leg hop 97	Standard Lysholm 94 IKDC subjective 89 Tegner 6 KT-1000 1.4 mm Single leg hop 99	No significant differences in IKDC, Tegner, Lysholm scores and KT-1000 measurements between both groups. Significantly larger tibial tunnel widening in standard group with screw fixation
Roger et al. [46]	KSSTA 2020	60 AI: 33 Standard: 27	AI: 30.5 Standard: 30.3	24	AI: quadrupled ST tendon autograft Standard: 4-strand ST&G	Cyclops lesion requiring revision – AI group (3%), STG group (3.7%)	AI IKDC subjective 80.2	Standard IKDC subjective 83.6	No statistically significant differences between AI and full tunnel groups for subjective IKDC score, laxity, morbidity, hamstring strength recovery or knee flexion. Less tourniquet time in AI group ($p < 0.001$).
Galan et al. [17]	Journal of Experimental Orthopaedics 2020	291 Male – 64, Female – 33	23.2 (17–42)	60	QT with bone block	Harvest site pain – 3 Patellofemoral syndrome-type pain – 12 Intraoperative patella fractures – 2 Postoperative infection – 1 Haematoma – 5	Lysholm 91 IKDC A 174 (59.79%), B 102 (35.4%), C 14 (4.81%) Tegner[a] – 8 KT-1000 1 mm		Low complication rate of 5.15% anterior knee pain Graft rerupture rate 10.7%
Smith et al. [18]	Arthroscopy 2020	64 AI: 32 Standard: 32	17.7 (13–24)	24	AI: quadrupled ST tendon autograft Standard: BPTB graft	AI: Graft failure – 2 Standard: Removal of tibia iscrew	AI IKDC subjective 94.8 KOOS function 92.5 KOOS QoL 83.3 KOOS symptoms 89.7 KT-1000 0.3 mm Marx 13.3 SF-12 physical 55.5 SF-12 mental 58.0	Standard IKDC subjective 89.4 KOOS function 84.5 KOOS QoL 82.4 KOOS symptoms 86.6 KT-1000 0.0 mm Marx 13.1 SF-12 physical 56.4 SF-12 mental 58.7	No statistically significant between both groups in terms of side-to-side difference in laxity, IKDC, KOOS, Marx, SF-12 mental and physical and return to preoperative sporting level. Standard group had higher post operative pain on post operative day 2, 3 and 7.
Desai et al. [35]	The Orthopaedic Journal of Sports Medicine 2021	136 AI: 82 Standard: 54	AI: 25.8 Standard: 21.1	24	AI: ST&G tendons or ST only Standard: ST&G tendons or ST only	AI: 1 infection, 1 arthrofibrosis, 3 revision meniscal surgery, 2 chondral defects Standard: 1 arthrofibrosis, 2 revision meniscal surgery	AI Lysholm 93.8 IKDC 93.5 Tegner 6.4	Standard Lysholm 94.4 IKDC 93.3 Tegner 6.8	No significant differences in IKDC and Lysholm scores between both groups. Longer return to sport in AI group as compared to standard group. AI: 9.8% ACL reconstruction failure Standard: 18.5% ACL reconstruction failure
Kyriakopoulos et al. [5]	Cureus 2021	44 AI: 22 Standard: 22	AI: 27.5 Standard: 26.6	36	AI: ST Standard: ST&G	AI: postoperative haematoma requiring surgery	AI Lysholm 87 KT-1000 1.92 mm	Standard Lysholm 86.1 KT-1000 2.41 mm	Statistically significant improvements in Lysholm scores in both groups AI group had statistically significant lower VAS scores in early postoperative period at 2 weeks. No graft failures in either group,
Kulshrestha et al. [47]	European Journal of Orthopaedic Surgery &	80 AI: 40 Standard: 40	30 AI: 29.3 Standard: 33	24	AI: quadrupled ST&G	AI: Superficial infection – 1 Laxity ≥ 5 mm–3	AI Tegner 5.9 KSS objective	Standard Tegner 5.3 KSS objective 65.3	Statistically significant improvement in Tegner activity score in the AI group

(*continued on next page*)

Table 2 (*continued*)

Author	Journal Year	Number of patients	Mean age (range if any), years	Follow up (range), months	Graft and techniques	Complications	Post-operative clinical results	Comments
	Traumatology 2021				Standard: quadrupled ST&G	Standard: Superficial infection – 2 Laxity $\geq$ 5 mm–5	66.6 KSS symptoms 13.6 KSS satisfaction 31.5 KSS expectation11.3 KSS function 83.9 KSS symptoms 15.2 KSS satisfaction 27.9 KSS expectation 9.4 KSS function 84.7	Satisfaction component in KSS better in the AI group than the standard group
Pautasso et al. [48]	European Journal of Orthopaedic Surgery & Traumatology 2021	157 AI: 51 Standard HS: 53 Standard BPTB: 53	23.4 (16–30) AI: 18.1 Standard HS: 23.0 Standard BPTB: 25.3	AI: 36.5 Standard HS: 38.8 Standard BPTB: 41.2	AI: quadrupled ST Standard HS: HS Standard BPTB: BPTB	Nil	AI: Lysholm 92.4 KOOS 89.5 Tegner 5.5 KT-1000 3.1 mm Standard: Lysholm 91.2 KOOS 89.2 Tegner 6.1 KT-1000 3.3 mm Standard BPTB: Lysholm 91.8 KOOS 88.8 Tegner 5.9 KT-1000 2.5 mm	Statistically significant improvement in preoperative and postoperative Lysholm, KOOS, Tegner scores in all 3 surgical techniques No statistical difference in KT-1000 values, postoperative Tegner, Lysholm and KOOS scores between both knees for all 3 surgical techniques Significantly longer surgery duration ($p < 0.001$) in AI technique as compared to the other 2
Lowenstein et al. [12]	Arthroscopy 2021	100 Male – 38 Female – 62	31.3 (14–58)	24	Quadrupled ST autograft (54%) or allograft (46%)	Nil	VAS pain 1.07 Marx scale 8.75 KOOS pain 89.03, KOOS symptoms 80.79 KOOS ADL 95.4, KOOS sports 81.25 KOOS quality of life 71.56 WOMAC pain 92.65, WOMAC stiffness 84.13 WOMAC function 95.4	Patients who had autograft had better Marx activity scores, KOOS Sport and KOOS ADL scores No significant differences in outcomes scores of males and females Better Marx scores in males at 1 year, and greater KOOS ADL scores in females at 1 year
Greif et al. [49]	Arthroscopy 2022	124 Suspensory fixation: 62 Interference screw fixation: 62	Suspensory fixation: 27.74 Interference screw fixation: 31.21	Suspensory fixation: 31.70 Interference screw fixation: 31.29	All soft tissue QT autograft	Suspensory fixation: 4 arthrofibrosis, 1 button removal due to infection, 7 anterior knee/kneeling pain Interference screw fixation: 1 arthrofibrosis, 13 anterior knee/kneeling pain	Suspensory fixation: IKDC subjective 92.08 Lysholm 93.87 Tegner 6.91 Interference screw fixation: IKDC subjective 90.12 Lysholm 90.34 Tegner 6.77	3 graft failures in interference screw fixation 1 graft failure in suspensory fixation No significant difference in anterior knee/kneeling pain ($p = 0.22$) Significantly better Lysholm scores in suspensory fixation group ($p = 0.04$)
Goyal et al. [2]	European Journal of Orthopaedic Surgery & Traumatology 2022	80 AI: 40 Standard: 40	28.3 AI: 28.3 Standard 28.4	24	AI: quadrupled ST Standard: doubled ST&G	AI: late infection at tibial side Standard: 1 implant failure with tunnel widening	AI Lysholm 98.8 IKDC subjective 914 VAS 0.1 Quad power 40.9bs HS power 25.8bs Standard Lysholm 97.5 IKDC subjective 90.8 VAS 0.2 Quad power 40.5lbs HS power 23.5lbs	Lower VAS score in the AI group at the 2 and 6 weeks follow up mark. No significant differences in Tegner, IKDC and Lysholm scores between both groups. No significant differences in quadriceps powerSignificant difference in HS power ($p = 0.002$) between both groups

ACL – anterior cruciate ligament, AI – all-inside; BPTB – bone patella tendon bone graft, HS – hamstrings; KOOS – Knee Injury and Osteoarthritis Outcome Score; KSS – Knee Society Score; KSSTA – Knee Surgery, Sports Traumatology, Arthroscopy; IKDC – International Knee Documentation Committee score; KT-1000 – KT-1000 knee arthrometer, Lysholm – Lysholm scores, Marx–Marx scale, NR – not recorded, QT – quadriceps tendon; SF-12 – 12-item short form survey; ST – semitendinosus; ST&G – semitendinosus and gracilis; Tegner–Tegner activity scale, VAS – visual analogue scale; WOMAC – Western Ontario and McMaster Universities Osteoarthritis Index.

[a] Median values.

Fixation devices

Graft fixation is important for the success of ACL reconstruction. With the use of sockets in SG ACLR, cortical suspensory devices have become the choice of fixation for short grafts. The benefits of using cortical suspension fixation in ACL reconstruction are the high load to failure strength of cortical fixation and less risk of graft fixation compared to interference screw fixation [36]. A randomised controlled trial by Lubowitz et al. [37] compared suspensory cortical fixation to aperture screw fixation and found no significant differences in knee anteroposterior stability or other outcomes. A recent meta-analysis by Fu et al. [38] comparing cortical suspensory fixation in short grafts to aperture fixation also showed no significant differences between knee outcome scores in both groups.

Adjustable loop cortical suspension devices are the mainstay of SG ACLR technique. They enable further tightening after insertion to achieve maximum amount of graft in tunnel and do not require precise calculations prior to tunnel reaming. However, there are concerns with regards to lengthening of the adjustable loop devices, with differences observed with cyclic displacement between fixed and adjustable loop ACL fixation devices [23,39]. Barrow et al. [23] reported that adjustable length fixation devices experienced a clinically significant increase in loop lengthening during cyclic testing, caused by suture slippage into the adjustable length loop. Noonan et al. [39] proposed that re-tensioning and knot tying after initial reduction of the tendon graft with an adjustable loop fixation device may help to reduce loop slippage and displacement. These concerns in biomechanical studies are, however, not translated in clinical studies. Boyle et al. [40] showed no significant differences in short-term knee stability and graft failure rates between adjustable and fixed loop femoral cortical suspension in their study of 188 ACL reconstruction patients.

Outcomes

The results of SG ACLR have consistently shown similar outcomes compared to standard techniques with no significant differences across various papers, summarised in Table 2. There are a total of 19 studies included, with multiple high-quality studies comparing different techniques of ACL reconstruction [2] [–] [6,11,12,17,18,35,41] [–] [49]. A total of 1812 patients were included in the studies. All the studies have shown a significant improvement in outcome scores with SG ACLR compared to the baseline. Graft ruptures ranged across different studies from 2.1% to 12.7% in the SG ACLR technique (Table 2). SG ACLR can be considered as a good, viable alternative to the standard technique.

Lowenstein et al. [12] reported that anatomic ST4 AI ACLR had improved functional outcomes at 1 and 2 years post-operatively and is comparable in both male and female patients alike. Smith et al. [18] showed that ST4 AI ACLR had equivalent KT-1000 stability testing when compared to gold standard BPTB ACL reconstruction in young athletes. Both groups had similar retear rates. Comparing different graft choices in SG ACLR, Galan et al. [17] achieved similar IKDC outcomes with the QT graft as the ST4 AI ACLR group shown by Volpi [41] et al. Galan et al. achieved 59.79% IKDC A, 35.4% IKDC B and 4.81% IKDC C, whereas Volpi et al. obtained scores of 55%, 40%, and 5%, respectively, in their cohort. Greif et al. [49] also had good outcomes in their experience with QT grafts in terms of IKDC scores and low rates of graft failure.

Benefits

Studies have shown that the AI technique is associated with less pain when compared to standard techniques [2,3,5,6,9]. This has been postulated to be due to less bone loss with tibial sockets and less tibial periosteal irritation [9]. This allows for earlier rehabilitation and faster recovery as well.

The benefit of SG ACLR with ST4 with the preservation of the gracilis or QT, leads to improved recovery of knee flexion strength [6,7]. This is ideal in female athletes, as it may be difficult to reliably obtain a graft of the required diameter for ACLR.

Mayr et al. reported less tibial tunnel enlargement in AI ACLR with button fixation compared to screw fixation [45]. The preservation of bone stock with the use of sockets as compared to full tunnels in the SG ACLR can also be helpful in the event of revision surgery or even in complex combined osteotomy surgery. ST4 or QT SG ACLR which spare the other tendons were used to reconstruct the other ligaments in multiligament surgery.

SG ACLR is also versatile in the skeletally immature younger athletes. The physeal sparing AI ACLR technique can be used [50]. This allows an anatomical ACL to be performed without crossing the physis to avoid growth arrest. An ST4 SG ACLR is ideal in such patients.

Conclusion

To summarise, short grafts have become a popular option these days and should be considered for use in a primary ACL reconstruction, especially in the younger athletes. Outcomes of the short graft are reproducible and consistent, with good biomechanical properties desired in ACL reconstruction.

Authors contribution

DL and JT designed the layout of the text and was involved in writing the manuscript and review of the completed paper. DL and JT performed the literature search and wrote the manuscript. ST and TB contributed to writing the manuscript and review of the completed paper.

Funding

The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Matzkin EG, Lowenstein NA. Optimizing outcomes of anterior cruciate ligament (ACL) reconstruction in female athletes: from graft choice to return to sport criteria. Annals of Joint 2021;6. https://doi.org/10.21037/AOJ-20-31.

[2] Goyal T, Das L, Paul S, Choudhury AK, Sethy SS. Outcomes of retro-drilled all-inside tibial tunnel vs complete tibial tunnel techniques in anterior cruciate ligament reconstruction—a comparative study. Eur J Orthop Surg Traumatol 2022;32: 523–32. https://doi.org/10.1007/s00590-021-03011-2.

[3] Lubowitz JH, Schwartzberg R, Smith P. Randomized controlled trial comparing all-inside anterior cruciate ligament reconstruction technique with anterior cruciate ligament reconstruction with a full tibial tunnel. Arthrosc J Arthrosc Relat Surg 2013;29:1195–200. https://doi.org/10.1016/j.arthro.2013.04.009.

[4] Schurz M, Tiefenboeck TM, Winnisch M, Syre S, Plachel F, Steiner G, et al. Clinical and functional outcome of all-inside anterior cruciate ligament reconstruction at a minimum of 2 Years' follow-up. Arthrosc J Arthrosc Relat Surg 2016;32:332–7. https://doi.org/10.1016/j.arthro.2015.08.014.

[5] Kyriakopoulos G, Manthas S, Vlachou M, Oikonomou L, Papadakis SA, Kateros K. Anterior cruciate ligament reconstruction with the all-inside technique: equivalent outcomes and failure rate at three-year follow-up compared to a doubled semitendinosus-gracilis graft. Cureus 2021;13. https://doi.org/10.7759/cureus.20508.

[6] Kouloumentas P, Kavroudakis E, Charalampidis E, Kavroudakis D, Triantafyllopoulos GK. Superior knee flexor strength at 2 years with all-inside short-graft anterior cruciate ligament reconstruction vs a conventional hamstring technique. Knee Surg Sports Traumatol Arthrosc 2019;27:3592–8. https://doi.org/10.1007/s00167-019-05456-9.

[7] Monaco E, Redler A, Fabbri M, Proietti L, Gaj E, Daggett M, et al. Isokinetic flexion strength recovery after ACL reconstruction: a comparison between all inside graft-link technique and full tibial tunnel technique. Physician Sportsmed 2019;47: 132–5. https://doi.org/10.1080/00913847.2018.1537535.

[8] Pacull R, Kalk E, Rongieras F, Bertani A, Gras L-L. Anterior cruciate ligament reconstruction with short hamstring grafts: the choice of femoral fixation device matters in controlling overall lengthening. Knee Surg Sports Traumatol Arthrosc 2021. https://doi.org/10.1007/s00167-021-06783-6.

[9] de Sa D, Shanmugaraj A, Weidman M, Peterson DC, Simunovic N, Musahl V, et al. All-inside anterior cruciate ligament reconstruction-A systematic review of techniques, outcomes, and complications. J Knee Surg 2018;31:895–904. https://doi.org/10.1055/s-0038-1627446.

[10] Lubowitz JH, Amhad CH, Anderson K. All-inside anterior cruciate ligament graft-link technique: second-generation, no-incision anterior cruciate ligament reconstruction. Arthrosc J Arthrosc Relat Surg 2011;27:717–27. https://doi.org/10.1016/j.arthro.2011.02.008.

[11] Yasen SK, Borton ZM, Eyre-Brook AI, Palmer HC, Cotterill ST, Risebury MJ, et al. Clinical outcomes of anatomic, all-inside, anterior cruciate ligament (ACL) reconstruction. Knee 2017;24:55–62. https://doi.org/10.1016/j.knee.2016.09.007.

[12] Lowenstein NA, Haber DB, Ostergaard PJ, Collins JE, Matzkin EG. All-inside anterior cruciate ligament reconstruction using quadrupled semitendinosus: comparable 2-year outcomes in male and female patients. Arthrosc J Arthrosc Relat Surg 2021;37:3140–8. https://doi.org/10.1016/j.arthro.2021.03.077.

[13] Cavaignac E, Marot V, Faruch M, Reina N, Murgier J, Accadbled F, et al. Hamstring graft incorporation according to the length of the graft inside tunnels. Am J Sports Med 2018;46:348–56. https://doi.org/10.1177/0363546517733472.

[14] New Zealand ACL registry annual report 2021. NZ ACL Registry; 2021. p. 1–16. https://www.aclregistry.nz/.

[15] Sprowls GR, Robin BN. The quad link technique for an all-soft-tissue quadriceps graft in minimally invasive, all-inside anterior cruciate ligament reconstruction. Arthrosc Techniques 2018;7:e845–52. https://doi.org/10.1016/j.eats.2018.04.004.

[16] Diermeier T, Tisherman R, Hughes J, Tulman M, Baum Coffey E, Fink C, et al. Quadriceps tendon anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2020;28:2644–56. https://doi.org/10.1007/s00167-020-05902-z.

[17] Galan H, Escalante M, della Vedova F, Slullitel D. All inside full thickness quadriceps tendon ACL reconstruction: long term follow up results. J Exp Orthop 2020;7. https://doi.org/10.1186/s40634-020-00226-w.

[18] Smith PA, Cook CS, Bley JA. All-inside quadrupled semitendinosus autograft shows stability equivalent to patellar tendon autograft anterior cruciate ligament reconstruction: randomized controlled trial in athletes 24 Years or younger. Arthrosc J Arthrosc Relat Surg 2020;36:1629–46. https://doi.org/10.1016/j.arthro.2020.01.048.

[19] He J, Tang Q, Ernst S, Linde MA, Smolinski P, Wu S, et al. Peroneus longus tendon autograft has functional outcomes comparable to hamstring tendon autograft for anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2021;29:2869–79. https://doi.org/10.1007/s00167-020-06279-9.

[20] Lubowitz JH. All-inside anterior cruciate ligament graft link: graft preparation technique. Arthrosc Tech 2012;1:e165–8. https://doi.org/10.1016/j.eats.2012.06.002.

[21] Tiefenboeck TM, Hirtler L, Winnisch M, Binder H, Koch T, Komjati M, et al. The buried knot technique for all inside graft link preparation leads to superior biomechanical graft link stability. Sci Rep 2019;9:1–8. https://doi.org/10.1038/s41598-018-38150-w.

[22] Graf-Alexiou L, Karpyshyn J, Baptiste JJ, Hui C, Sommerfeldt M, Westover L. Biomechanical strength of all-inside ACL reconstruction grafts using side-to-side and backup fixation. Orthop J Sports Med 2021;9:1–6. https://doi.org/10.1177/23259671211006521.

[23] Barrow AE, Pilia M, Guda T, Kadrmas WR, Burns TC. Femoral suspension devices for anterior cruciate ligament reconstruction: do adjustable loops lengthen? Am J Sports Med 2014;42:343–9. https://doi.org/10.1177/0363546513507769.

[24] Wichern CR, Skoglund KC, O'Sullivan JG, Burwell AK, Nguyen JT, Herzka A, et al. A biomechanical comparison of all-inside cruciate ligament graft preparation techniques. J Exp Orthop 2018;5. https://doi.org/10.1186/s40634-018-0158-0.

[25] Mayr R, Heinrichs CH, Eichinger M, Smekal V, Schmoelz W, Attal R. Preparation techniques for all-inside ACL cortical button grafts: a biomechanical study. Knee Surg Sports Traumatol Arthrosc 2016;24:2983–9. https://doi.org/10.1007/s00167-015-3605-9.

[26] Richardson MW, Tsouris ND, Hassan CR, Elbayar JH, Qin YX, Komatsu DE, et al. A biomechanical comparison of alternative graft preparations for all-inside anterior cruciate ligament reconstruction. Arthrosc J Arthrosc Relat Surg 2019;35:1547–54. https://doi.org/10.1016/j.arthro.2018.11.065.

[27] Bowes J, Mohamed N, Baptiste JJ, Westover L, Hui C, Sommerfeldt M. Biomechanical comparison of graft preparation techniques for all-inside anterior cruciate ligament reconstruction. Orthop J Sports Med 2020;8:1–7. https://doi.org/10.1177/2325967120938039.

[28] Tiefenboeck TM, Hirtler L, Winnisch M, Joestl J, Koch T, Komjati M, et al. A bigger suture diameter for anterior cruciate ligament all-inside graft link preparation leads to better graft stability: an anatomical specimen study. Knee 2018;25:427–33. https://doi.org/10.1016/j.knee.2018.03.010.

[29] Bachmaier S, Smith PA, Argintar EH, Chahla J, Higgins LD, Wijdicks CA. Independent suture augmentation with all-inside anterior cruciate ligament reconstruction reduces peak loads on soft-tissue graft. A biomechanical full-construct study. Arthrosc J Arthrosc Relat Surg 2022;38:88–98. https://doi.org/10.1016/j.arthro.2021.09.032.

[30] Zantop T, Ferretti M, Bell KM. Effect of tunnel-graft length on the biomechanics of anterior cruciate ligament-reconstructed knees: intra-articular study in a goat model. Am J Sports Med 2008;36:2158–66. https://doi.org/10.1177/0363546508320572.

[31] Yang DL, Cheon SH, Oh CW, Kyung HS. A comparison of the fixation strengths provided by different intraosseous tendon lengths during anterior cruciate ligament reconstruction: a biomechanical study in a porcine tibial model. Clin Orthop Surg 2014;6:173–9. https://doi.org/10.4055/cios.2014.6.2.173.

[32] Mariscalco MW, Magnussen RA, Mitchell J, Pedroza AD, Jones MH, Andrish JT, et al. How much hamstring graft needs to be in the femoral tunnel? A MOON cohort study. Eur Orthop Traumatol 2015;6:9–13. https://doi.org/10.1007/s12570-014-0275-x.

[33] Gupta PK, Acharya A, Khanna V, Mourya A. Intra-femoral tunnel graft lengths less than 20 mm do not predispose to early graft failure, inferior outcomes or poor function. A prospective clinico-radiological comparative study. Musculoskelet Surg 2022. https://doi.org/10.1007/s12306-022-00740-3.

[34] Moon HS, Choi CH, Yoo JH, Jung M, Lee TH, Choi KH, et al. The graft insertion length in the femoral tunnel during anterior cruciate ligament reconstruction with suspensory fixation and tibialis anterior allograft does not affect surgical outcomes but is negatively correlated with tunnel widening. Arthrosc J Arthrosc Relat Surg 2021;37:2903–14. https://doi.org/10.1016/j.arthro.2021.03.072. e1.

[35] Desai VS, Anderson GR, Wu IT, Levy BA, Dahm DL, Camp CL, et al. Anterior cruciate ligament reconstruction with hamstring autograft: a matched cohort comparison of the all-inside and complete tibial tunnel techniques. Orthop J Sports Med 2019;7:1–7. https://doi.org/10.1177/2325967118820297.

[36] Lee D, Nyland J, Kendzior M, Nawab A, Caborn DNM. Intratunnel versus extratunnel fixation of hamstring autograft for anterior cruciate ligament reconstruction. Arthrosc J Arthrosc Relat Surg 2012;28:1555–66. https://doi.org/10.1016/j.arthro.2012.02.021.

[37] Lubowitz JH, Schwartzberg R, Smith P. Cortical suspensory button versus aperture interference screw fixation for knee anterior cruciate ligament soft-tissue allograft: a prospective, randomized controlled trial. Arthrosc J Arthrosc Relat Surg 2015;31:1733–9. https://doi.org/10.1016/j.arthro.2015.03.006.

[38] Fu CW, Chen WC, Lu YC. Is all-inside with suspensory cortical button fixation a superior technique for anterior cruciate ligament reconstruction surgery? A systematic review and meta-analysis. BMC Muscoskel Disord 2020;21:1–13. https://doi.org/10.1186/s12891-020-03471-3.

[39] Noonan BC, Dines JS, Allen AA, Altchek DW, Bedi A. Biomechanical evaluation of an adjustable loop suspensory anterior cruciate ligament reconstruction fixation device: the value of retensioning and knot tying. Arthrosc J Arthrosc Relat Surg 2016;32:2050. https://doi.org/10.1016/j.arthro.2016.02.010. –9.

[40] Boyle MJ, Vovos TJ, Walker CG, Stabile KJ, Roth JM, Garrett WE. Does adjustable-loop femoral cortical suspension loosen after anterior cruciate ligament reconstruction? A retrospective comparative study. Knee 2015;22:304–8. https://doi.org/10.1016/j.knee.2015.04.016.

[41] Volpi P, Bait C, Cervellin M, Denti M, Prospero E, Morenghi E, et al. No difference at two years between all inside transtibial technique and traditional transtibial technique in anterior cruciate ligament reconstruction. Muscles, Ligaments Tendons J 2014;4:95–9. https://doi.org/10.32098/mltj.01.2014.18.

[42] Baldassarri M, Perazzo L, Ghinelli D, Ricciarelli M, Pilla F, Buda R. Return to sport after ACL surgery: a comparison between two different reconstructive techniques. J Knee Surg 2019;32:513–8. https://doi.org/10.1055/s-0038-1653948.

[43] Monaco E, Fabbri M, Redler A, Gaj E, de Carli A, Argento G, et al. Anterior cruciate ligament reconstruction is associated with greater tibial tunnel widening when using a bioabsorbable screw compared to an all-inside technique with suspensory fixation. Knee Surg Sports Traumatol Arthrosc 2019;27:2577–84. https://doi.org/10.1007/s00167-018-5275-x.

[44] Colombet P, Saffarini M, Bouguennec N. Clinical and functional outcomes of anterior cruciate ligament reconstruction at a minimum of 2 Years using adjustable suspensory fixation in both the femur and tibia: a prospective study. Orthop J Sports Med 2018;6:1–11. https://doi.org/10.1177/2325967118804128.

[45] Mayr R, Smekal V, Koidl C, Coppola C, Eichinger M, Rudisch A, et al. ACL reconstruction with adjustable-length loop cortical button fixation results in less tibial tunnel widening compared with interference screw fixation. Knee Surg Sports Traumatol Arthrosc 2020;28:1036–44. https://doi.org/10.1007/s00167-019-05642-9.

[46] Roger J, Bertani A, Vigouroux F, Mottier F, Gaillard R, Have L, et al. ACL reconstruction using a quadruple semitendinosus graft with cortical fixations gives suitable isokinetic and clinical outcomes after 2 years. Knee Surg Sports Traumatol Arthrosc 2020;28:2468–77. https://doi.org/10.1007/s00167-020-06121-2.

[47] Kulshrestha V, Sood M, Kumar S, Kawale A. Original study: early patient-reported functional outcome of all-inside ACL reconstruction as compared to anteromedial portal technique. Eur J Orthop Surg Traumatol 2021;31:1477–83. https://doi.org/10.1007/s00590-021-02912-6.

[48] Pautasso A, Capella M, Barberis L, Drocco L, Giai Via R, Bistolfi A, et al. All-inside technique in ACL reconstruction: mid-term clinical outcomes and comparison with AM technique (Hamstrings and BpTB grafts). Eur J Orthop Surg Traumatol 2021;31:465–72. https://doi.org/10.1007/s00590-020-02798-w.

[49] Greif DN, Shallop BJ, Allegra PR, Cade WH, Minesinger KE, Luxenburg D, et al. A comparison of two-year anterior cruciate ligament reconstruction clinical outcomes using all-soft tissue quadriceps tendon autograft with femoral/tibial cortical suspensory fixation versus tibial interference screw fixation. Arthrosc J Arthrosc Relat Surg 2022;38:881–91. https://doi.org/10.1016/j.arthro.2021.06.024.

[50] Lee Yee Han D, Nawab A. Anatomic physeal-sparing ACL reconstruction: a modified technique. Tech Knee Surg 2012;11:210–3. https://doi.org/10.1097/BTK.0b013e318278abe3.