Current Concepts Review

Short graft anterior cruciate ligament reconstruction: Current concepts

Jessica Thor, MBBS, MRCS, Lee Yee Han Dave, MBBS, FRCS (Ortho), MMed(Ortho), Sachin Tapasvi, MD, Tahsin Beyzadeoglu, MD

A R T I C L E  I N F O

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- Short graft
- Anterior cruciate ligament reconstruction

A B S T R A C T

Short graft anterior cruciate ligament 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.

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

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.
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 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 wider 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 liga-mentous laxity and smaller hamstring tendons [1]. It exhibits less post-operative pivot shift laxity and can be harvested with reliable dimensions [16]. Traditionally, bone patellar 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], Heetel. [19] in their meta-analysis comparing AIACL R 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.

Graft preparation

The SG ACLR technique demands a unique method of preparation. These grafts are recommended to be a maximum length of70–75mm after tenosioning [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 length.
the femoral tunnel at 12 weeks with regards to stiffness and ultimate 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.

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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>
<thead>
<tr>
<th>Author</th>
<th>Journal Year</th>
<th>Number of patients</th>
<th>Mean age (range if any), years</th>
<th>Follow up (range), months</th>
<th>Graft and techniques</th>
<th>Complications</th>
<th>Post-operative clinical results</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubowitz et al. [3]</td>
<td>Arthroscopy 2013</td>
<td>148</td>
<td>A: 39.3 Standard: 41.1</td>
<td>24</td>
<td>A: 2-strand tibialis tendon allograft Standard: 2-strand tibialis tendon allograft</td>
<td>NR</td>
<td>A: 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</td>
<td>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</td>
</tr>
<tr>
<td>Volpi et al. [41]</td>
<td>Muscles, Ligaments and Tendons Journal 2014</td>
<td>40</td>
<td>A: 38.4 Standard: 32.6</td>
<td>24</td>
<td>A: doubled/tripled ST tendon autograft Standard: ST&amp;G</td>
<td>NR</td>
<td>A: Lysholm 90.9 IKDC A 11 (55%) IKDC B 8 (40%) IKDC C 1 (5%) Tegner 5.2 VAS 81.7</td>
<td>No significant differences between both groups in IKDC, Lysholm, Tegner and VAS scores.</td>
</tr>
<tr>
<td>Schurz et al. [4]</td>
<td>Arthroscopy 2016</td>
<td>79</td>
<td>Male 53 Female 26</td>
<td>29 (18–54) 30.4 (24.3–44.8)</td>
<td>Quadrupled ST</td>
<td>Deep infection – 2 Numbness – 9</td>
<td>A: Lysholm 93.1 IKDC 89.7 Tegner 6 KT-2000 1.7 mm VAS score 0.14</td>
<td>Significant improvements in IKDC, Lysholm, Tegner and VAS scores compared to baseline, p &lt; 0.0001 12.7% ACL graft ruptures</td>
</tr>
<tr>
<td>Yasen et al. [11]</td>
<td>The Knee 2016</td>
<td>108</td>
<td>Male 81 Female 27</td>
<td>30.9 (15–61) 49.8 (30–66)</td>
<td>Quadrupled ST</td>
<td>Superficial infection – 1</td>
<td>A: Lysholm score 88.1 Tegner score 5.1 KOOS 87.9 KT-1000 2.20 mm</td>
<td>Significant improvements in KOOS, Lysholm and Tegner scores as compared to baseline, p &lt; 0.001 Significantly improved knee flexion compared to baseline (p &lt; 0.001) 6.5% ACL graft failure</td>
</tr>
<tr>
<td>Baldassarri et al. [42]</td>
<td>Muscles, Ligaments and Tendons Journal 2018</td>
<td>40</td>
<td>A: 38.4 Standard: 32.6</td>
<td>24</td>
<td>A: doubled or tripled ST tendon autograft Standard: ST&amp;G</td>
<td>NR</td>
<td>A: Lysholm 90.9 IKDC A 11 (55%) IKDC B 8 (40%), IKDC C 1 (5%) Tegner 5.2 VAS 81.7</td>
<td>No significant differences between both groups in IKDC, Lysholm, Tegner and VAS scores.</td>
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<tr>
<td>Monaco et al. [43]</td>
<td>KSSTA 2018</td>
<td>44</td>
<td>A: 32.5 Standard: 31.7</td>
<td>24</td>
<td>A: quadrupled ST tendon autograft Standard: doubled ST&amp;G</td>
<td>Nil</td>
<td>A: Lysholm 94.9 IKDC A 10 (50%) IKDC B 9 (45%) IKDC C 1 (5%) Tegner 6.4 VAS 84.6</td>
<td>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.</td>
</tr>
<tr>
<td>Colombet et al. [44]</td>
<td>The Orthopaedic Journal of Sports Medicine 2018</td>
<td>97</td>
<td>Male – 64, Female – 33</td>
<td>30.9 (14.8–56.1)</td>
<td>Quadrupled ST</td>
<td>Nil</td>
<td>A: Lysholm 90.8 Tegner 6.6 IKDC 87.6 Laxity side-to-side 0.8 mm</td>
<td>Significant improvements in Lysholm, Tegner and IKDC scores compared to baseline 2.1% ACL graft failure No significant differences between both groups in IKDC, Lysholm and KOOS scores. AI group had better flexor peak torque, time-to-peak and isometric flexor/extensor ratio at 90°</td>
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</table>
| Kouloumentas et al. [45] | European Journal of Orthopaedic Surgery & Traumatology 2019 | 90 | A: 27.6 Standard: 29.7 | 24 | A: quadrupled ST tendon autograft Standard: 4-strand ST&G | Nil | A: Lysholm 97.7 IKDC: 83.6 KOOS 95.3 KSS 83.9 | No significant differences between both groups in IKDC, 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)
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<th>Post-operative clinical results</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayr et al. [45] KSSTA 2020</td>
<td>30</td>
<td>AI: 25 Standard: 29</td>
<td>24</td>
<td>AI: quadrupled ST tendon autograft Standard: 4-strand ST &amp; G</td>
<td>Al: intraoperative button mislocation and button loop rupture, septic arthritis, 3 early reruptures Standard: intraoperative screw breakage</td>
<td>Al: Lysholm 94 KDC subjective 88 Tegner 6 KT-1000 2.9 mm Single leg hop 97</td>
<td>Standard: Lysholm 94 KDC subjective 89 Tegner 6 KT-1000 1.4 mm Single leg hop 99</td>
<td>AI: 2.2% ACL graft failure Standard: 4.4% ACL graft failure 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</td>
</tr>
<tr>
<td>Roger et al. [46] KSSTA 2020</td>
<td>60</td>
<td>AI: 30.5 Standard: 30.3</td>
<td>24</td>
<td>AI: quadrupled ST tendon autograft Standard: 4-strand ST &amp; G</td>
<td>Al: Cyclops lesion requiring revision – AI group (3%), STG group (3.7%)</td>
<td>AI: IKDC subjective 80.2</td>
<td>Standard: IKDC subjective 83.6</td>
<td>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 &lt; 0.001). Low complication rate of 5.15% anterior knee pain Graft rerupture rate 10.7%</td>
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<td>Galan et al. [17] Journal of Experimental Orthopaedics 2020</td>
<td>291 Male – 64, Female – 33</td>
<td>23.2 (17–42)</td>
<td>60</td>
<td>QT with bone block</td>
<td>Harvest site pain – 3 Patellofemoral syndrome-type pain – 12 Intraoperative patella fractures – 2 Postoperative infection – 1 Haematomata – 5</td>
<td>Lysholm 91 IKDC A 174 (59.79%), B 102 (35.4%), C 14 (4.81%) Tegner4 – 8 KT-1000 1 mm</td>
<td>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.</td>
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<td>Smith et al. [18] Arthroscopy 2020</td>
<td>64</td>
<td>AI: 32 Standard: 32</td>
<td>17.7 (13–24)</td>
<td>24</td>
<td>AI: quadrupled ST tendon autograft Standard: BPTB graft</td>
<td>Al: Graft failure – 2 Standard: Removal of tibia iscrew</td>
<td>Al 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</td>
<td>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</td>
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<td>Desai et al. [35] The Orthopaedic Journal of Sports Medicine 2021</td>
<td>136</td>
<td>AI: 82 Standard: 54</td>
<td>25.8 (21.1)</td>
<td>24</td>
<td>AI: STG tendons or ST only Standard: STG tendons or ST only</td>
<td>Al: 1 infection, 1 arthrofibrosis, 3 revision meniscal surgery, 2 chondral defects Standard: 1 arthrofibrosis, 2 revision meniscal surgery</td>
<td>Al: Lysholm 93.8 IKDC 93.5 Tegner 6.4</td>
<td>Standard: Lysholm 94.4 IKDC 93.3 Tegner 6.8</td>
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<td>Kyriakopoulos et al. [5] Cureus 2021</td>
<td>44</td>
<td>AI: 22 Standard: 22</td>
<td>27.5 (26.6)</td>
<td>36</td>
<td>AI: ST Standard: ST &amp; G</td>
<td>Al: postoperative haematoma requiring surgery</td>
<td>Al: Lysholm 87 KT-1000 1.92 mm</td>
<td>Standard: Lysholm 86.1 KT-1000 2.41 mm</td>
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<tr>
<td>Kulkrestha et al. [47] European Journal of Orthopaedic Surgery &amp; Medicine 2021</td>
<td>80</td>
<td>AI: 40 Standard: 40</td>
<td>30</td>
<td>24</td>
<td>AI: quadrupled ST &amp; G</td>
<td>AI: Superficial infection – 1 Laxity ≤ 5 mm –3</td>
<td>Al Tegner 5.9 KSS objective</td>
<td>Standard: Tegner 5.3 KSS objective 65.3</td>
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Table 2 (continued)

<table>
<thead>
<tr>
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<th>Post-operative clinical results</th>
<th>Comments</th>
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<tr>
<td>Traumatology 2021</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard: quadrupled ST &amp; G</td>
<td>66.6</td>
<td>KSS symptoms 15.2</td>
<td>Satisfaction component in KSS better in the AI group than the standard group</td>
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<tr>
<td>Pautasso et al. [48]</td>
<td>European Journal of Orthopaedic Surgery &amp; Traumatology 2021</td>
<td>157</td>
<td>23.4 (16–30)</td>
<td>24</td>
<td>AI: quadrupled ST</td>
<td>66.6</td>
<td>KSS symptoms 15.2</td>
<td>Statistically significant improvement in preoperative and postoperative Lysholm, KOOS, Tegner scores in all 3 surgical techniques</td>
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<td></td>
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<td></td>
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<td>Standard HS: Standard BPTB:</td>
<td>92.4</td>
<td>KOOS 89.5</td>
<td>No statistical difference in KT-1000 values, postoperative Tegner, Lysholm and KOOS scores between both knees for all 3 surgical techniques</td>
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<td></td>
<td>38.8</td>
<td>Standard BPTB: 41.2</td>
<td></td>
<td>Significantly longer surgery duration (p &lt; 0.001) in AI technique as compared to the other 2</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td>25.3</td>
<td></td>
<td></td>
<td>Patients who had autograft had better Marx activity scores, KOOS Sport and KOOS ADL scores</td>
</tr>
<tr>
<td>Lowenstein et al. [12]</td>
<td>Arthroscopy 2021</td>
<td>100 Male – 38 Female – 62</td>
<td>31.3 (14–58)</td>
<td>24</td>
<td>Quadrupled ST autograft (54%) or allograft (46%)</td>
<td>80.79</td>
<td>KT-1000 91.0</td>
<td>Better Marx scores in males at 1 year, and greater KOOS ADL scores in females at 1 year</td>
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<tr>
<td>Greif et al. [49]</td>
<td>Arthroscopy 2022</td>
<td>124 Suspensory fixation: 62 Interference screw fixation: 62</td>
<td></td>
<td></td>
<td>All soft tissue QT autograft</td>
<td>92.08</td>
<td>Lysholm 93.87</td>
<td>No significant differences in outcomes scores of males and females</td>
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<td>Suspensory fixation: 27.74 Interference screw fixation: 31.21</td>
<td>90.12</td>
<td>Lysholm 90.34</td>
<td>Better KOOS ADL scores in females at 1 year</td>
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<td>Suspenesory fixation: 31.70 Interference screw fixation: 31.29</td>
<td>6.91</td>
<td>Tegner 6.77</td>
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<td>Goyal et al. [2]</td>
<td>European Journal of Orthopaedic Surgery &amp; Traumatology 2022</td>
<td>80</td>
<td>28.3</td>
<td>24</td>
<td>AI: quadrupled ST</td>
<td>94.8</td>
<td>KOOS 98.5</td>
<td>Significantly better Lysholm scores in suspension fixation group (p = 0.04)</td>
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<td></td>
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<td></td>
<td>Standard: doubled ST &amp; G</td>
<td>914</td>
<td>IKDC subjective 90.8</td>
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<td></td>
<td>40.0bs</td>
<td>VAS 0.1</td>
<td>40.5lbs</td>
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<td>HS power 25.8bs</td>
<td>Quad power 40.5lbs</td>
<td>HS power 23.5lbs</td>
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</tbody>
</table>


* 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 suspension 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] [1] [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 physes 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.

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**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.

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