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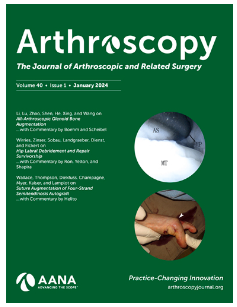

Primary All-Soft Tissue Quadriceps Tendon Autograft Anterior Cruciate Ligament Reconstruction with Suture Tape Augmentation Resulted in Satisfactory Patient Outcomes and a Low Graft Failure Rate in High School and Collegiate Athletes

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Running Title: Primary ASTQ ACLR with STA in Athletes

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IRB: Protocol SOS #1 – Orthopaedic sports medicine, arthroscopy, and related surgery registry using web-based OrthoIllustrated Surgical Outcomes System (SOS)

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Primary ASTQ ACLR with STA in Athletes

ABSTRACT

Purpose: To evaluate ≥ 2-year patient outcomes following primary all-soft tissue quadriceps tendon autograft (ASTQ) anterior cruciate ligament reconstruction (ACLR) with suture tape augmentation (STA) in skeletally mature high school and collegiate athletes. **Methods:** All high school and collegiate athletes who underwent primary ASQT ACLR with STA with a minimum of 2-year follow-up were analyzed retrospectively. Patients were administered validated PROMs pre- and postoperatively. The minimal clinically important difference (MCID) was calculated for each PROM based on this study population and applied to the individual patient. Return to sport (RTS), subsequent surgical intervention including contralateral ACLR, and KT-1000 arthrometer measurements for knee laxity were collected. Complications were assessed by physical examination, radiological studies, or obtained via telephone. **Results:** There were a total of 60 patients included in final data analysis with a mean age of 16.8-years-old (95% CI, 16.2-17.4) and mean final follow-up of 37.1 months (95% CI, 33.1-41.1). Twelve patients (20%) necessitated subsequent surgery on the ipsilateral knee which included seven patients having a subsequent meniscal procedure and three patients underwent arthrolysis. 0% sustained a graft failure and six patients sustained a contralateral ACL injury necessitating surgery. All PROMs improved at final follow-up ($p < 0.001$). Additionally, KT-1000 arthrometer measurements significantly improved postoperatively at 1-year clinical follow-up ($p < 0.001$). A majority of patients obtained the MCID thresholds for each PROM at final follow-up. There were 48 patients (80%) who participated in pivoting sports. The RTS rate at same level was 54 patients (90%) with six patients (10%) not returning to same level due to graduation. **Conclusion:** ASQT ACLR with STA in a young athletic patient population may result in a low graft failure rate while maintaining satisfactory patient outcomes at short-term follow-up, including a return to sport at the same level of 90%. **Level of Evidence:** Retrospective Case Series, IV.

INTRODUCTION

The incidence of anterior cruciate ligament (ACL) injuries has increased in recent years as there has been an increase in competitive sport participation in the adolescent and young-adult patient populations.[1-3] Additionally, the rate of graft failure following primary ACL reconstruction (ACLR) in these younger and more active patients remains high, especially in those who returned to sport following their initial surgery.[4] The overall risk of an ACL reinjury in young patients who return to sport—with adolescent patients being the most vulnerable—is 9-23%, with a majority of the graft failures occurring within two years following the initial procedure.[4-6] Furthermore, Salmons et al noted graft failure to approach 39% at a final follow-up of 20 years following primary hamstring tendon autograft ACLR.[6] There are multiple factors that can increase the risk of reinjury such as the type of sport played (eg, pivoting sports such as soccer, basketball, football, volleyball, etc.), and patient-specific factors such as younger patient age, knee hyperextension, gender, and type of graft used.[3,6-8] Furthermore, revision ACL surgery has been associated with worse patient outcomes.[6,9-11]

A potential solution that may decrease this rate of ACL graft retear is augmenting the primary ACLR with suture tape. [12-20] ACLR with suture tape augmentation (STA) has been shown biomechanically to increase construct strength while decreasing graft elongation by decreasing the peak loads experienced by the graft.[11,12] There have been a few clinical studies attempting to elucidate the benefit of STA, with a majority consisting of augmented quadrupled semitendinosus grafts.[14,17-21] There is a paucity of clinical literature describing all-soft tissue quadriceps tendon autograft (ASQT) ACLR with STA.[19,21] Of note, the revision ACLR rate in those undergoing non-augmented ASQT ACLR is as high as 18% (n = 8/45) in athletes that participated at a high level of competition.[5]

The purpose of this study was to evaluate ≥ 2-year patient outcomes following primary all-soft tissue quadriceps tendon autograft (ASTQ) anterior cruciate ligament reconstruction (ACLR) with suture tape augmentation (STA) in skeletally mature high school and collegiate athletes. We hypothesized that ASTQ ACLR with STA will lead to a low complication rate—including a low subsequent revision ACLR while maintaining satisfactory patient-reported outcome measures (PROMs).

METHODS

Patient Population

Following institutional review board approval, all patients who underwent ACLR by the senior author (P.A.S.) from 2016 to 2021 were screened. Patients were included if they underwent primary ASTQ ACLR, were skeletally mature, had a minimum of 2-year follow-up, and participated in competitive sports at either the high school or collegiate level. Patients were still included if they underwent medial collateral ligament (MCL) repair. Patients were excluded if they underwent primary ACLR with a different autograft type, primary allograft ACLR, revision ACLR, pediatric physeal-sparing ACLR, had a previous knee operation, were extra-articularly augmented (i.e., anterolateral ligament reconstruction), or only participated in sports recreationally.

Of note, the senior author slowly transitioned from the bone-patellar tendon-bone (BTB) autograft with STA to the ASTQ with STA at the end of 2018 due to his concern related to anterior knee pain in BTB patients. Furthermore, not only did the switch from BTB with STA to ASQT with STA result in less patients with anterior knee discomfort but resulted in comparable postoperative subjective and objective patient outcomes.

Surgical Technique

Prior to surgery, all patients were assessed using radiographs to determine skeletal maturity. Adolescent patients with open growth plates on knee radiographs were additionally assessed using preoperative hand radiographs via the Greulich and Pyle's atlas to determine bone age along with Tanner staging to determine whether to perform a traditional ACLR or an epiphyseal-sparing procedure.

With the knee flexed at 90°, a minimally invasive quadriceps tendon harvesting system (Quad Tendon Graft Cutting Guide/Stripper Cutter; Arthrex, Naples, FL) was used to harvest the ASTQ.[16,22] All grafts were full thickness. Each graft measured 65-70-mm in length and a width of 9-11-mm dependent on patient size (figure 1). The tendon defect was routinely closed with interrupted #1 horizontal mattress sutures (Coated Vicryl; Johnson & Johnson MedTech, New Brunswick, NJ) with the knee in flexion.

Arthroscopic all-inside ACLR using a suspensory adjustable loop device (ALD) (ACL TightRope; Arthrex, Naples, FL) was performed both proximally and distally in all patients (figure 2).[16,23] A 2-mm by 0.5-mm suture tape (FiberTape; Arthrex, Naples, FL) was looped through the proximal button of the ALD to remain independent of the graft (figure 3).[16] The two free ends of the suture tape were passed distal through the tibial ALD button (figure 4) and fixed using a bioabsorbable anchor (BioComposite SwiveLock; Arthrex, Naples, FL) with the knee held in hyperextension. The knee was then cycled and the graft re-tensioned on both the femoral and tibial side via the ALDs which was also performed with the knee fully hyperextended. The grafts and suture tape were all fixed in hyperextension due to the physiological lengthening of the ACL from flexion to extension evident in all cases with probing of the tape upon completion showing laxity at 90 degrees of flexion.[24] Figure 5 is an arthroscopic photo of the final from the anterolateral portal with the knee flexed at 90° of the final construct, the suture tape can be seen running posteriorly along the ASTQ graft.

MCL repair with STA was performed in all patients with acute ≥ grade 2 MCL sprains that demonstrated intraoperative 2-3+ laxity to valgus stress-testing at 30° of knee flexion and had a positive drive-through sign seen arthroscopically.[25] First, the MCL tear was identified being primarily off the femur or the tibia. A suture with attached suture tape was placed at the isometric attachment site of the superficial MCL under fluoroscopy guidance (Figure 6A & 6B). The tape would then be fixed distally with another anchor approximately 6-cm distal to the medial joint line to the attachment site of the superficial MCL just deep and proximal to the retracted pes tendons, thus further anatomically securing the MCL (Figure 6C). The final step was to utilize the stay suture in either the femoral or tibial anchor as appropriate for additional primary repair fixation of the native torn MCL fibers.

Postoperative Protocol

All patients were placed in a splint (T Scope® Premier Post-Op Knee Brace; Breg, Carlsbad, CA) locked in extension immediately postoperatively. All patients were sent home with a continuous passive motion machine (KinexCONNECT; Kinex Medical Company, Waukesha, WI) to be used for the first two weeks. Patients typically achieved full-weightbearing status in their functional ACL brace by postoperative week 2-4 dependent on quadriceps strength and overall leg control allowing a normal gait and based also on concomitant meniscal repair protocols. Of note, if a patient received an osteochondral allograft transplant (OCAT) then they were to be non-weightbearing for a total of 6 weeks to allow the graft adequate time to heal, similar to what is done for a patient following repair of a complex radial or root meniscus tear. All patients were seen in the clinic postoperatively at two weeks, three months, six months, and one-year. Closed-chain exercises began once the patient achieved full-weightbearing status. Patients were cleared to jog by postoperative month three with agility exercises beginning by postoperative month four, and sport-specific exercises beginning by postoperative month five. Patients may be cleared to return to sport (RTS) by the six-month visit dependent on physical examination (no effusion, full ROM, negative pivot shift, and good quadriceps muscle mass), patient readiness (feeling confident with knee), and RTS functional testing performed in physical therapy (compared to contralateral leg includes strength with dynamometer testing, Y-balance testing, jump-landing posture, and hop testing).

Patient Outcomes

All patients were enrolled in our institution's registry prior to their procedure where they completed patient-reported outcome measures (PROMs) pre- and postoperatively. Preoperative PROMs were gathered 1-2 weeks following the injury. Each patient completed the visual analog scale (VAS) for pain,[26] the Knee Injury and Osteoarthritis Outcome Score (KOOS),[27] the International Knee Documentation Committee (IKDC) survey,[28] the Tegner activity rating scale and the Lysholm knee survey,[29] and the Single Assessment Numeric Evaluation (SANE).[30] The minimal clinically important difference (MCID) was calculated for each PROM and applied to the individual patient. RTS data was collected via patient charts, as all patients were seen in the office by the senior author for examination prior to being medically cleared to return to full-participation which also was dependent on review of strength and functional testing performed in physical therapy, as well as physician assessment of overall patient mental readiness.[31]

The senior author evaluated the stability of all patients prior to RTS and at final follow-up. If a patient was suspected to have a subsequent injury, then they were assessed with physical examination and radiological studies. Of note, graft failure was defined as either a positive pivot shift at any point during the postoperative period or an MRI confirming a graft rupture. Anteroposterior laxity was objectively assessed preoperatively and at 1-year postoperatively via KT-1000 arthrometer (MEDmetric, San Diego, CA) by qualified research personnel who were blinded to the senior author's physical examination findings. KT-1000 measurements were assessed with the knee at approximately 25° of knee flexion.

Complications were determined through physician evaluation in the office and then via telephone. Subsequent operations to the ipsilateral knee as well as contralateral ACLR were collected at final follow-up. Final follow-up was calculated using the date of the last completed PROM or the date of the last office visit. Patients were deemed lost to follow-up following three consecutive attempts to contact them via email or phone with no response.

Statistical Analysis

Continuous variables were represented as mean (95% confidence intervals). Categorical variables were represented as absolute frequency (percentage). For comparison of pre- and postoperative patient outcomes, either the Student-t or the Mann-Whitney U test was used based on the normality of the distribution which was assessed using the Shapiro-Wilk test. Nominal logistic regression and bivariate regression analyses were used to assess relationships between potential predictors and postoperative categorical outcomes and are represented as odds ratio (95% confidence intervals). The MCID was calculated using a distribution-based approach defined as ½ the standard deviation of the mean difference between preoperative baseline and final follow-up scores. Due to the observational nature of the study and due to the inclusion of all available patients, an a priori was not performed. Data analyses were performed using JMP®, Version 17. (SAS Institute Inc., Cary, NC). For statistical analysis in this study, $P < 0.05$ was considered statistically significant.

RESULTS

Patient Selection

There was a total of 164 potentially eligible patients who received QTA ACLR with STA by the senior author from 2016 to 2021. Out of these patients, there was a total of 70 skeletally mature patients that underwent primary QTA ACLR with STA that participated in competitive sports at either the high school or collegiate level. Out of these patients, 60 patients (86%) reported ≥ 2-year follow-up and were included in final data analysis. The ten remaining patients (14%) were deemed lost to follow-up following the 3rd time of being contacted by either phone or email with no response. Figure 7 is a flowchart summarizing the patients that were included and excluded.

Patient Characteristics

Patient characteristics are summarized in table 1. The mean patient age was 16.8-years-old (range, 13-23) and the mean follow-up was 37.1 months (95% CI, 33.1-41.1). This study cohort was 68% female (n = 41). The mean ASTQ width was 10.4-mm (95% CI, 10.2-10.5). A total of 10 patients (17%) received MCL repair with STA. Of the meniscal procedures, 21 (78%) of the lateral meniscal interventions and 19 (87%) of the medial meniscal interventions consisted of all-inside repair with the remainder of the cases consisting of arthroscopic partial meniscectomies. It was noted that one patient received a concomitant osteochondral allograft transplantation (diameter, 10.5-mm).

Postoperative Complications and Subsequent Interventions

Details regarding complications and subsequent interventions are summarized in table 2. Out of the total number of patients, 12 patients (20%) required a subsequent procedure. Out of the patients that underwent a second surgery, three patients (5.0%) underwent excision of arthrofibrosis within the first year following their initial procedure. Though not statistically significant, all three patients necessitating a subsequent surgery secondary to arthrofibrosis were female. Additionally, seven patients (12%) underwent a meniscal procedure (6 partial meniscectomies; 1 all-inside repair). The mean time from the initial procedure to the second procedure was 16.4 months (95% CI, 6.4-26.4). A total of 6 patients (10%) underwent subsequent contralateral ACLR, whereas 0% experienced a graft failure. The mean time from initial surgery to contralateral ACLR was 18.3 months (95% CI, 9.1-27.5) with a range of 6 to 31 months. Of note, there were no postoperative infections or cases of chronic synovitis.

Regression Analysis

Cox regression analysis was performed, and it was found that younger patient age was associated with an increased risk of sustaining a contralateral ACL injury (HR – 2.51 [95% CI, 1.04-6.08], $p = 0.041$). We were unable to identify other factors associated with a subsequent contralateral tear or need for subsequent procedures on the ipsilateral knee.

Return to Sport

All patients in this study cohort played sports competitively in either high school or college (table 3). These were the sports the patients were playing which led to their injury. A total of 54 patients (90%) were able to return to sport at their same preoperative level. The six patients (10%) who were unable to return at their previous level related to sustaining their initial injury during their last year of eligibility. Those who did not return to the same level of competition or higher participated in basketball (n = 3/20), soccer (n = 2/8), and volleyball (n = 1/6). There was a total of 48 patients (80%) who participated in pivoting sports (basketball, football, soccer, volleyball, and lacrosse).

Subjective and Objective Patient Outcomes

All patients completed PROMs preoperatively and at final follow-up (table 4). All PROMs improved at final follow-up ($p < 0.001$). The MCID thresholds/patient threshold achievement are as follows for each PROM: VAS (–Δ1.1/65%), KOOS subscales (pain (Δ9.8/80%), symptoms (Δ10.6/77%), activities of daily living (Δ9.7/75%), sports/recreation (Δ15.6/92%) and quality of life (Δ13.6/87%)), IKDC (Δ10.4/95%), Tegner (Δ1.0/100%), Lysholm (Δ15.0/90%), and SANE (Δ14.0/93%). Of note, 16 patients (27%) who did not meet the MCID threshold for the VAS pain scale reported a preoperative VAS score of < 1.1. All patients demonstrated a negative pivot shift at final follow-up. Furthermore, 59 patients demonstrated a firm endpoint with their Lachman at final follow-up. Of note, one patient demonstrated a 1B Lachman at final follow-up following a subsequent sport-related injury; however, their pivot shift was negative, so no additional surgical intervention was pursued, and the patient was able to return to normal activity. Additionally, KT-1000 arthrometer measurements significantly improved postoperatively at 1-year clinical follow-up (6.5-mm [95% CI, 6.0-7.0] → 0.9-mm [95% CI, 0.5-1.3], $p < 0.001$).

DISCUSSION

The most important finding of this current study is that competitive high school and collegiate athletes following primary ASTQ with STA demonstrated satisfactory subjective and objective outcomes including a low ACLR revision rate with an overall mean follow-up > 3 years. Patients demonstrated satisfactory PROMs, acceptable anteroposterior knee laxity measurements, and no graft failures. Additionally, all eligible patients were able to fully RTS at their preinjury level of competition; those who were unable to do so sustained their injury during their final season of eligibility. These findings suggest that ASTQ with STA may lead to satisfactory outcomes in a highly active young patient population.

STA for ACLR has become more refined in recent years as a means to reduce the incidence of graft failure. Despite biomechanical studies documenting the benefit of STA,[12,13,32-34] there are only a few relatively small studies describing clinical outcomes with a minimum of 2-year follow-up.[14,17-21]

In a matched-pairs study examining patients who underwent primary non-augmented ASTQ and hamstring tendon ACLR, Runer et al found that 22% of the quadriceps tendon graft patients with a Tegner activity level ≥ 7 sustained a subsequent graft rupture.[5] Interestingly, a majority of the subsequent graft failures in the QT group did not occur within the first two years following procedure (2.2%), but rather the majority sustained their graft failure up to 4 years postoperatively (11%), with another 4.6% decrease in graft survivability at 5 years and a further 2.1% decrease at final follow-up. Though our final follow-up was not as long as the study described by Runer et al., it is worth mentioning that our mean patient age was 12 years younger than their QT cohort. As some groups are at higher risk of sustaining ACL graft rupture, efforts have been taken to decrease this risk including the addition of extra-articular and intra-articular augmentation(s).

In a recent systematic review and meta-analysis examining 420 with 143 of them receiving quadriceps tendon autograft ACLR, Meena et al. found the failure rate to be 9.8%.[35] This was with a mean final follow-up of 39 months and a mean patient age of 28.9-years-old. Similar to the study performed by Runer et al.,[5] their systematic review and meta-analysis demonstrated a mean patient that was significantly older than that of this current study. It did, however, detail a similar mean follow-up to this current study which slightly exceeded three years.

In a small series observing 16 consecutive older patients with a mean age of 24-years old (range, 16-45)—12 of which received ASTQ ACLR with independent STA and demineralized bone matrix/bone marrow aspirate concentrate in the bone sockets—Lavender et al[21] demonstrated that these patients were consistently able to return to their preinjury activity levels at 1-year follow-up. In a cohort study matching 40 patients with STA (20 ASQT, 20 HT autografts) to 40 non-augmented patients, von Essen et al[19] were unable to demonstrate any differences seen between cohorts. There were 2 total graft retears with one patient in the HT with STA group and one patient in the non-augmented ASTQ group. Though promising, the actual effect of STA in combination with ASTQ ACLR is not well-understood.

Although we did not have a comparison group, reporting a 0% graft failure rate in a patient population with a mean age of < 17-years-old is encouraging. The graft failure for the quadriceps tendon autograft has been reported as high as 18%.[5] Additionally, 90% of all eligible patients returned to their sport at full-capacity which further suggests that STA may safely and effectively protect the graft.

There was a total of three patients (5.0%) who required reoperation for arthrofibrosis, all of which were females. In a large case-control study examining 2424 patients who underwent ACLR over a 10-year period, Huleatt et al[36] demonstrated that patients ≤ 18-years-old (8% arthrolysis rate), females (5.7% arthrolysis rate), and use of quadriceps tendon autografts (8.3% arthrolysis rate) all increased the risk of necessitating arthrolysis following ACLR which were consistent with the findings of this current study. In a prospective clinical trial of 721 patients who underwent primary ASTQ ACLR, Haley et al found that anterior arthrofibrosis was found in 7.2% of patients prior to postoperative month six.[37] They reported a greater incidence in females, male patients with a femoral tunnel diameter < 9.25-mm, and in those who underwent concomitant meniscal repair. Our study results suggest that STA may not increase the risk of postoperative arthrofibrosis; however, we are unable to definitively conclude this due to lack of a comparison group. Regarding the risk of overconstraining the joint with STA for ACLR, previously published clinical studies have emphasized the importance of tape fixation in full hyperextension which leads to some degree of tape laxity in flexion following normal ACL biomechanics.[13,24,38]

It was noted that six patients (10%) sustained a contralateral ACL injury which led to ACLR. In a prospective analysis of 2488 primary ACLRs from the MOON cohort, Kaeding et al[39] found that increased activity levels and younger patient age were found to be risk factors for subsequent contralateral ACLR which were consistent with our findings. In a cohort study observing professional alpine skiers who underwent primary quadriceps and hamstring tendon ACLR, Csapo et al found that subsequent contralateral ACL tears occurred in 30% of patients.[40] These findings suggest that ASTQ ACLR with STA leads to a contralateral ACL injury rate comparable to what has already been described in the current literature, as these appear to be more related to the age and activity levels of the patient.[39,40]

The patients in this study population demonstrated satisfactory subjective outcomes. With the exception of the VAS pain scale, ≥ 75% of the patients met the MCID thresholds for all of their PROMs. Notably, despite only 65% of patients meeting the MCID threshold for VAS (-Δ1.1), there were a total of 16 patients (27%) who reported a VAS of < 1.1 preoperatively thus not making them eligible to achieve this threshold. Additionally, all patients met the MCID threshold for Tegner, and ≥ 90% of patients met the MCID thresholds for the KOOS sports & recreation subscale, IKDC, Lysholm, and SANE.

It was decided to include patients that underwent concomitant MCL repair with STA. Historically, it has been found that patients with a concomitant MCL injury that was treated nonoperatively at the time of ACLR were at increased risk of subsequent graft reinjury as well as a decreased likelihood of returning to sport at the same level.[41,42] For these reasons, the MCL was repaired at the time of surgery to restore valgus stability as well as proper knee kinematics. There is currently a paucity of literature demonstrating inferior results for those who underwent ACLR with MCL reconstruction compared to isolated ACLR—even more so when the ACL graft was augmented intra-articularly.

Historically, there has been a negative connotation surrounding intra-articular stabilizing techniques such as the Kennedy Ligament-Augmentation Device (Kennedy-LAD) due to its high rate of postoperative complications being a synthetic device made of polypropylene. [43,44,45]. Another synthetic device used for ACLR made of polyethylene terephthalate-Ligament Augmentation and Reconstruction System (LARS)—also has resulted in significant intra-articular complications.[46,47] However, present-day augmentation techniques utilizing polyester suture tape not only differ in the material used but has also been shown translationally through canine studies to be safe within the joint.[48,49]

With any additional stabilization whether it be intra-articular or extra-articular there is always a concern for overconstraining the joint. At this time, the published literature has not shown that suture tape augmentation for ACLR leads to deficits in range of motion or osteoarthritis development.. However, given the newness and novelty of the method being described in this current study, it is unclear whether or not that the addition of suture tape to an ACL graft will lead to any untoward long-term effects different then what is typically seen with non-augmented ACLR. Furthermore, there is a paucity of literature describing any unusual drawbacks of independent STA. However, based on the normal shortening of the ACL from extension to flexion, it is theoretically possible that if the suture tape is fixed with the knee in a flexed position, then the normal physiological lengthening of the ACL during knee extension/hyperextension may be compromised leading to loss of motion and joint overconstraint.[50]

Limitations

This study was not without limitations. Due to this being a retrospective observational study, it lacked a comparison group. Additionally, since all of these cases were performed by an experienced surgeon in a private practice setting, these findings may not be generalizable to other practice settings, or to other physicians who may or may not be familiar with the technique used. Additionally, postoperative MRIs were not obtained in these patients, so we were unable to radiologically assess the joint at final follow-up. Interestingly, the majority of the patients in our cohort consisted of basketball players, particularly female which may have subjected our data to an unrecognized selection bias. Another limitation is the heterogeneity of the concomitant procedures at the time of ACLR. Along with the relatively small sample size, this current study may not have had the power to adequately assess further differences among patients.[51] Furthermore, since long term radiological follow-up was not obtained, it is not known whether or not the addition of suture tape had any adverse consequences on joint health. Another limitation is that preinjury PROMs were not obtained. Lastly, all patients completed adult PROMs which may have resulted in bias against the younger adolescent patients.

CONCLUSION

ASQT ACLR with STA in a young athletic patient population may result in a low graft failure rate while maintaining satisfactory patient outcomes at short-term follow-up, including a return to preinjury level of 90%.

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FIGURE LEGENDS

Figure 1. Intraoperative photo of a full-thickness quadriceps tendon autograft (asterisk) immediately following graft harvesting.

Figure 2. Intraoperative photo of the final all-soft tissue quadriceps tendon autograft (asterisk) construct. The suture tape (black arrow) is looped through the femoral button (white arrow) and to remain independent from the graft. Black arrowhead, shortening strands. White arrowhead, shuttle sutures.

Figure 3. Close-up intraoperative photo of the proximal adjustable loop device showing the suture tape (asterisk) looped through the femoral button (black arrow) and runs distally. The femoral shortening strands (black arrowhead) must be together on one side of the looped suture tape (white arrow). White arrowhead, shuttle sutures.

Figure 4. Close-up intraoperative photo of the distal adjustable loop device shows the distal suture tape ends (black arrow) and the tibial shortening strands (white arrow) shuttled through the tibial button (asterisk). C, clamp.

Figure 5. Arthroscopic view from the anterolateral portal of a left knee at 90° of knee flexion demonstrating the final all-soft tissue quadriceps tendon autograft (A) with suture tape augmentation (S). P, probe. L, lateral femoral condyle.

Figure 6. Fixation points for primary repair of the superficial medial collateral ligament with suture tape augmentation. A) Lateral fluoroscopic image demonstrating a pin (asterisk) drilled into the isometric point of the femur. B) Anchor placement (white arrow) at the isometric point of the femur. C) Anchor placement at the superficial medial collateral ligament attachment site for final ligament fixation with suture tape (T). M, superficial medial collateral ligament. S, infrapatellar branch of the saphenous nerve. P, probe. Black arrow, Pes tendons.

Figure 7. Flow chart detailing patient inclusion and exclusion. ASTQ, all-soft tissue quadriceps tendon autograft. ACLR, anterior cruciate ligament reconstruction. STA, suture tape augmentation. ALLR, anterolateral ligament reconstruction.

TABLES

Table 1. Patient Characteristics.

Characteristic	N = 60
Age, years (range)	16.8 (13-23)
Sex	
Females	41 (68)
Males	19 (32)
Body mass index (95% CI)	24.1 (22.8-25.4)
Laterality	
Left	34 (57)
Right	26 (43)
Final follow-up, months (95% CI)	37.1 (33.1-41.1)
ASTQ width, millimeters (95% CI)	10.4 (10.2-10.5)
LM procedures	27 (45)
MM procedures	23 (38)
MCL repair	10 (17)
Chondral procedure	3 (5.0)

Data presented as mean (95% confidence intervals) or (range), or number (percentage).
Abbreviations: ASTQ, all-soft tissue quadriceps tendon autograft. LM, lateral meniscus. MM, medial meniscus. MCL, medial collateral ligament.

Table 2. Complications and Subsequent surgical interventions.

Intervention	N = 60
Total interventions	12 (20)
Elapsed time, months	16.4 (6.4-26.4)
APM	6 (10)
Arthrolysis	3 (5.0)
Meniscus repair	1 (2.9)
Plica synovectomy	1 (1.7)
Incision & drainage	1 (1.7)
Contralateral ACLR	6 (10)
Time to contralateral ACLR, months	18.3 (9.1-27.5)
Graft failure	(0)

Data presented as mean (95% confidence intervals) or number (percentage).
Abbreviations: APM, arthroscopic partial meniscectomy. ACLR, anterior cruciate ligament reconstruction. m, months

Table 3. Patient sport participation by level of competition.

Sport	Entire population (n = 60)	High school (n = 43)	College (n = 17)
Basketball	20 (33)	17 (40)	3 (18)
Football	11 (18)	11 (21)	1 (5)
Soccer	8 (13)	3 (7.0)	5 (29)
Volleyball	6 (10)	3 (7.0)	3 (18)
Other*	15 (23)	11 (21)	5 (28)
Pivoting sport?†	48 (80)	35 (81)	13 (77)
Returned to sport	54 (90)	40 (95)	14 (82)
RTS time, months	7.5 (7.0-8.0)	7.2 (6.7-7.7)	8.4 (7.2-9.7)

Data presented as mean (95% confidence intervals) or number (percentage).
*Other sports included gymnastics/tumbling, lacrosse, softball, track and field, and wrestling.
†Basketball, football, soccer, volleyball, and lacrosse.
Abbreviations: RTS, return to sport.

Table 4. Patient-reported outcome measures at a minimum of 2 years and 1-year KT-1000 arthrometer measurements.

Outcome Measure*	Preoperative (n = 60)	Postoperative (n = 60)	MCID (n = 60)
Visual Analog Scale	2.7 (2.2-3.2)	0.8 (0.4-1.1)	39 (65)†
KOOS			
Pain	67.0 (62.8-67.0)	90.7 (88.0-93.4)	48 (80)
Symptoms/Stiffness	56.7 (52.4-60.9)	82.0 (78.1-85.9)	46 (77)
Activities of daily living	73.3 (68.7-77.9)	96.7 (95.1-98.3)	45 (75)
Sports & recreation	26.6 (18.9-34.2)	85.5 (80.5-90.5)	55 (92)
Quality of life	32.1 (27.1-32.1)	78.0 (73.3-82.6)	52 (87)
IKDC, subjective	41.7 (36.5-46.9)	88.6 (85.6-91.7)	57 (95)
Tegner activity scale	4.8 (3.8-5.7)	7.0 (6.4-7.6)	60 (100)
Lysholm	52.1 (45.2-59.0)	90.6 (87.7-93.5)	54 (90)
SANE	36.7 (30.3-43.1)	89.2 (85.8-92.6)	56 (93)
KT-1000			NA
30-lb pull, millimeter	5.3 (4.9-5.7)	0.4 (0.1-0.8)	
Manual maximum	6.5 (6.0-7.0)	0.9 (0.5-1.3)	
Lachman *,‡			NA
Grade 1			
A	(0)	59 (98)	
B	(0)	1 (1.7)	
Grade 2			
A	(0)	(0)	
B	9 (15)	(0)	
Grade 3			
A	(0)	(0)	
B	51 (85)	(0)	
Pivot Shift *,‡			NA
Unable‖	1 (1.7)	(0)	
None	(0)	60 (100)	
Grade 1	(0)	(0)	
Grade 2	52 (87)	(0)	
Grade 3	7 (12)	(0)	

Data presented as mean (95% confidence intervals) or number (percentage).
*All outcome measures significantly improved postoperatively ($p < 0.001$).
† Did not meet MCID due to reporting a preoperative score of < 1.1 (n = 16).
‡ Evaluated intraoperatively and at final follow-up.
‖ Unable to assess pivot shift due to locked bucket-handle tear.
Abbreviations: MCID, minimal clinically important difference. KOOS, Knee Injury and Osteoarthritis Outcome Score. IKDC, International Knee Documentation Committee.

Figure 1.

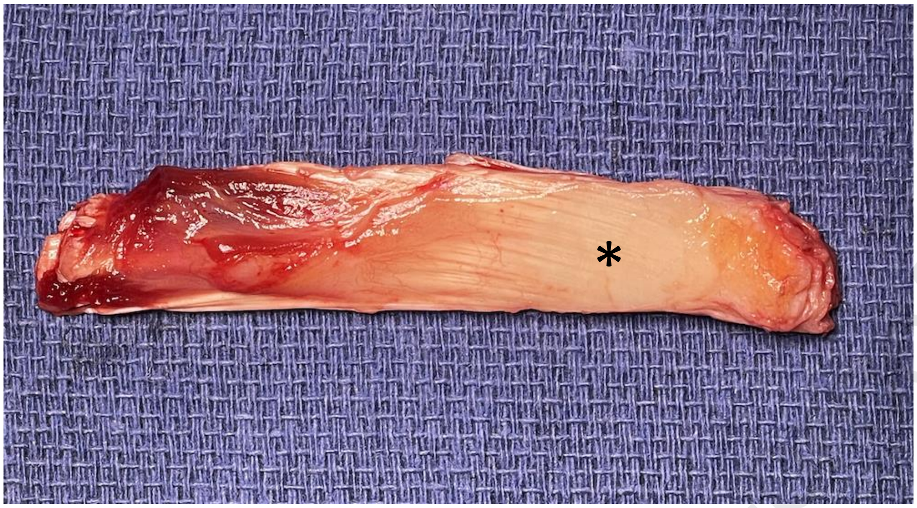


Figure 2.

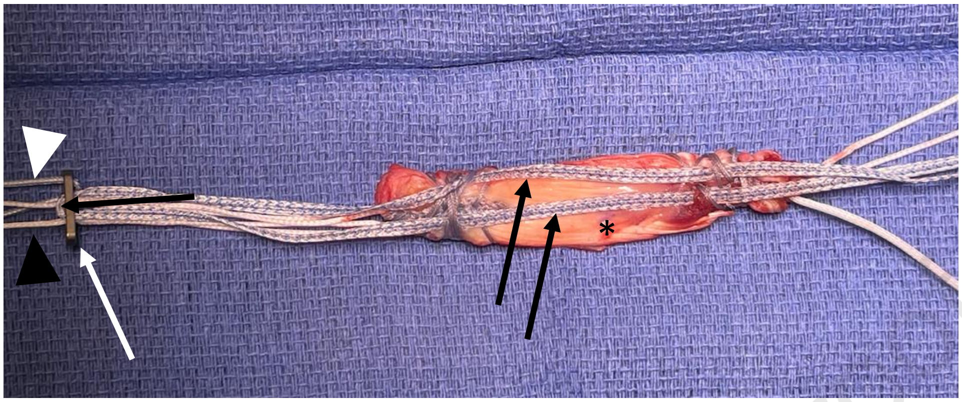


Figure 3.

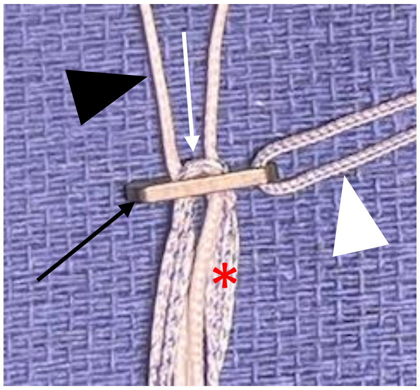
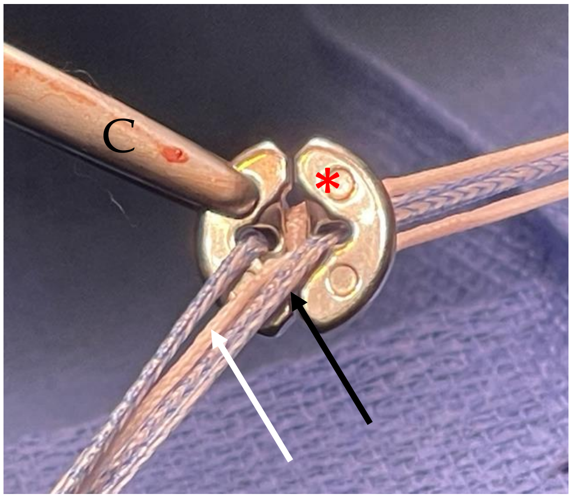


Figure 4.



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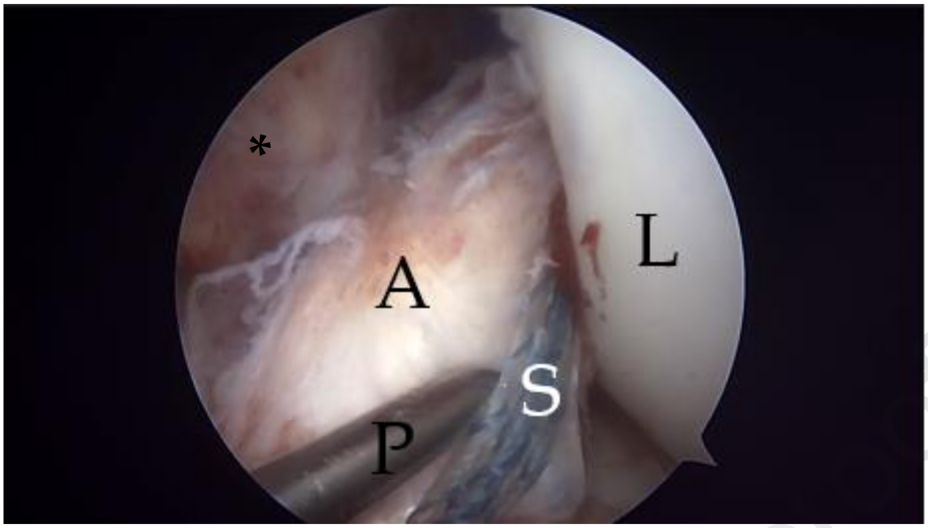


Figure 6

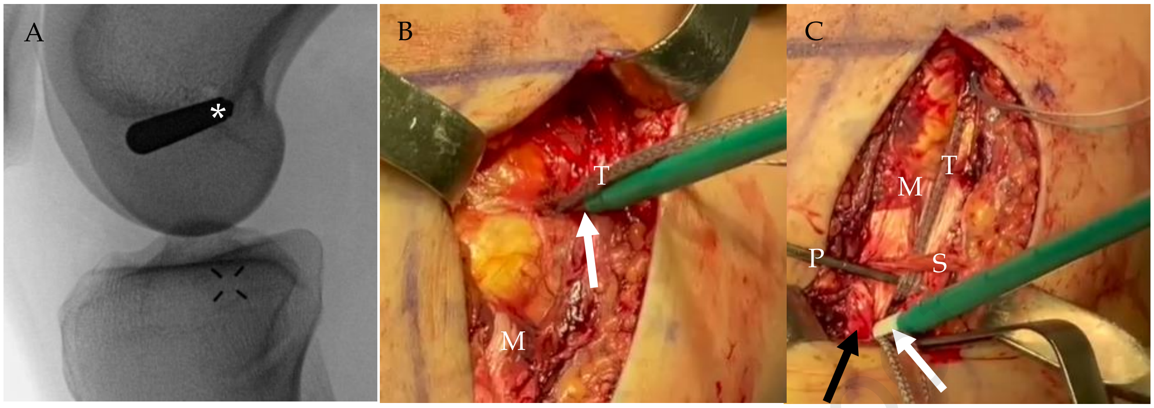
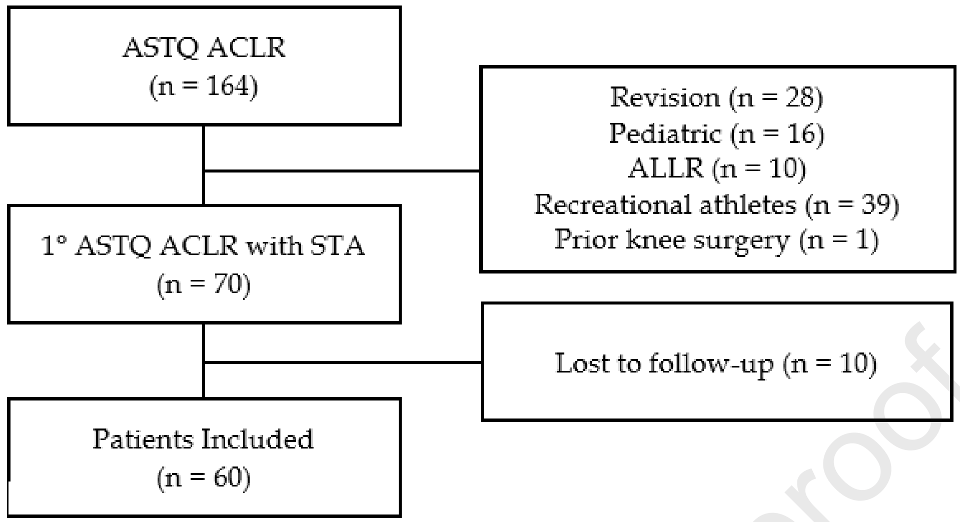


Figure 1


ASTQ ACLR
(n = 164)
Revision (n = 28)
Pediatric (n = 16)
ALLR (n = 10)
Recreational athletes (n = 39)
Prior knee surgery (n = 1)
1° ASTQ ACLR with STA
(n = 70)
Lost to follow-up (n = 10)
Patients Included
(n = 60)