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Clinical Outcomes After Suture Tape Augmentation of Quadriceps Tendon Autografts for Primary Anterior Cruciate Ligament Reconstruction

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Background: Quadriceps tendon (QT) autografts are increasingly being used for anterior cruciate ligament (ACL) reconstruction, although concerns for graft elongation and early graft failure persist. Suture tape augmentation was introduced to prevent excessive forces on remodeling graft tissue, but graft-specific data for QT autografts with suture tape augmentation remain limited.

Purpose: To evaluate short-term patient-reported outcome measures (PROMs), return-to-sport rates, postoperative complications, and graft rerupture rates in patients undergoing primary ACL reconstruction with QT autograft with and without suture tape augmentation.

Study Design: Cohort study; Level of evidence, 3.

Methods: A retrospective review was performed at a single institution evaluating patients younger than 40 years who underwent primary ACL reconstruction with all soft tissue QT autograft between 2017 and 2024. Patients were stratified into 2 cohorts with and without suture tape augmentation. Demographic data, surgical characteristics, PROMs, time to return to sport, postoperative activity level as categorized by level of athletic participation, postoperative complications, graft rerupture, and reoperation rates were recorded. Minimum follow-up was 2 years. Continuous variables were compared using Welch *t* test or Mann-Whitney *U* test, and categorical variables were analyzed using chi-square and Fisher exact tests.

Results: Of 225 patients initially identified, 80 (35%) were included in the final data analysis (42 controls, 38 augmented). Demographic, preoperative PROMs, and injury characteristics were similar between groups. At 2-year follow-up, no significant differences were found in PROMs, time to return to sport (41.2 vs 42.1 weeks; $P = .8$), or postoperative activity level. Graft rerupture occurred in 6 patients in the nonaugmented group (14%) and 0 patients in the augmented group (0%) ($P < .05$). Among patients with graft rerupture, median time to failure was 109.5 weeks (range, 35-204 weeks), and mean time to failure was 109.3 $\pm$ 59.0 weeks. No significant differences in reoperation rate were found between cohorts.

Conclusion: Suture tape augmentation of QT autografts for primary ACL reconstruction was associated with a significantly lower rate of early graft rerupture without differences in PROMs, return to sport, or reoperation rates compared with nonaugmented QT grafts.

Keywords: anterior cruciate ligament reconstruction; quadriceps tendon autograft; suture tape augmentation; graft failure; return to sport

Anterior cruciate ligament (ACL) injuries are among the most common orthopaedic conditions, with an estimated 200,000 to 400,000 cases occurring annually in the United States.[21] Approximately 90% of affected patients elect to undergo ACL reconstruction. Despite advances in surgical techniques and graft selection, more than half of patients

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do not return to their preinjury level of activity, and rerupture rates range from 10% to 17%.[3,4,22,28]

Quadriceps tendon (QT) autograft has gained traction as a reliable ACL graft choice due to its robust biomechanical profile and favorable donor site morbidity. Compared with hamstring tendon (HT) autografts, QT autografts offer a larger cross-sectional area, increased collagen density, greater ultimate load to failure, and less postoperative hamstring weakness.[18] Compared with bone–patellar tendon–bone autografts (BPTB), QT autografts demonstrate lower rates of anterior knee and kneeling pain while still providing similar biomechanical properties and versatility in graft diameter.[18]

The advent of suture tape augmentation of ACL grafts, including QT grafts, has been proposed to enhance graft stability and prevent excessive stresses, especially during the graft's most vulnerable early stages of healing and remodeling. ACL constructs augmented with suture tape demonstrate a 30% to 50% reduction in cyclic graft elongation, a 40% to 60% increase in construct stiffness, and up to a 40% reduction in peak graft strain under high-load conditions compared with nonaugmented grafts.[15] These improvements suggest greater protection against early graft stretching and mechanical overload, decreased failure rates, and earlier return to sport.[1,8,16] A large multicenter analysis by Daniel et al[8] demonstrated that suture tape augmentation across BPTB, QT, and HT autografts was associated with a significant decrease in the incidence of revision ACL reconstruction, reinforcing the potential protective effect of suture tape augmentation in a broad range of graft types.

Despite these encouraging findings, the role of suture tape augmentation in QT autograft remains under consideration as a newer technique. Given the increasing adoption of QT autografts and relatively high rerupture rates in at-risk populations who undergo ACL reconstruction, understanding the clinical implications of suture tape augmentation in this setting is critical.

The purpose of this study was to evaluate short-term patient-reported outcome measures (PROMs), return-to-activity rates, and graft rerupture rates in patients undergoing ACL reconstruction with all soft tissue QT autograft with and without suture tape augmentation. We hypothesized that use of suture tape augmentation in QT autografts would be associated with lower early graft rerupture rates while demonstrating no significant differences in PROMs, return-to-play rates, or postoperative complication rates compared with nonaugmented reconstructions.

METHODS

Study Design

This was a cohort study performed at a single institution evaluating clinical outcomes of patients who underwent ACL reconstruction with all soft tissue QT autograft, with and without suture tape augmentation. Eligible procedures were performed between 2017 and 2024 by 3 fellowship-trained orthopaedic surgeons. After the study cohort was identified, patient data were collected retrospectively through review of the electronic medical record. Institutional review board (IRB) approval was obtained before data collection.

Patient Selection

Patients were identified through a query of electronic medical records. Inclusion criteria were (1) age <40 years at the time of surgery, (2) primary ACL reconstruction using all soft tissue QT autograft performed between 2017 and 2024, and (3) minimum follow-up of 2 years. Exclusion criteria were (1) multiligamentous knee injuries, (2) prior ipsilateral knee injury, and (3) alternative graft source (eg, BPTB, HT, allograft). Initial review yielded 225 patients, and 80 met all criteria and were included in the study.

Surgical Technique

Across all 3 orthopaedic surgeons, femoral tunnel preparation was done with either the anteromedial portal or outside-in technique, depending on surgeon preference. Suspensory fixation was used in all cases. In the suture augmentation group, suture tape was applied using the standard internal brace technique, fixed on both the femur and tibia, as a load-sharing construct alongside the graft to provide stability. Graft preparation, fixation method, and tensioning were similar across all surgeons.

This study entailed no standardized indications for suture augmentation. Suture tape augmentation was used from the beginning and throughout the entire study. The use of suture tape augmentation was determined entirely by surgeon preference rather than predefined clinical criteria. Consequently, some surgeons incorporated suture tape augmentation frequently, whereas others used it only sparingly, reflecting differences in personal practice patterns.

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Ethical approval for this study was obtained from Atrium Health Wake Forest Baptist Institutional Review Board (IRB00127243).

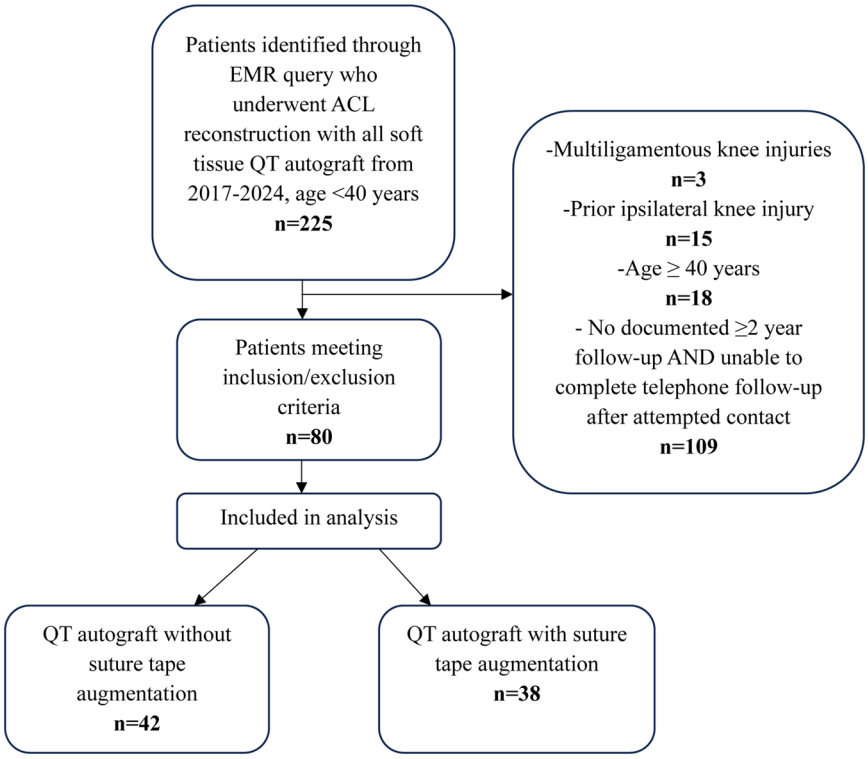


Figure 1. Flow chart highlighting patient selection for final analysis. ACL, anterior cruciate ligament; EMR, electronic medical record; QT, quadriceps tendon.

Study Groups

Patients were categorized into 2 cohorts. The control group consisted of patients who underwent ACL reconstruction with QT autograft without suture tape augmentation. The experimental group included patients who underwent ACL reconstruction with QT autograft augmented with suture tape.

Data Collection

Data were collected from electronic medical records using a standardized data collection form. Variables collected included patient demographic characteristics, such as age at surgery, sex, race/ethnicity, body mass index (BMI), comorbidities (eg, diabetes mellitus, nicotine use, psychiatric history, connective tissue disorders), family history of ACL injury, Beighton score, and mechanism of injury (contact vs noncontact).

Surgical details encompassed graft type, graft diameter, suture tape augmentation status, concomitant pathology (eg, meniscal repair, meniscectomy), intraoperative pivot-shift grade, and fixation method. Concomitant procedures included meniscal repair and meniscectomy (chondroplasty, abrasion arthroplasty, and synovectomy were not considered concomitant procedures). Preinjury and postinjury activity levels (sedentary, recreational, high school, collegiate, or professional athlete) were documented along with preoperative range of motion, time from injury to surgery, and rehabilitation protocol adherence.

For patients missing PROMs at ≥2-year follow-up, PROMs were obtained through scripted telephone surveys following IRB-approved protocols. Each patient was contacted on 2 separate occasions. Patients who could not be reached after 2 attempts and lacked ≥2-year follow-up data in the medical record were excluded from the final analysis. A total of 80 patients were included in the statistical analysis. A flow chart highlighting patient selection for final analysis is demonstrated in Figure 1.

Graft rerupture was assessed through review of the electronic medical record and was defined as a documented postoperative ACL graft tear based on clinical evaluation, imaging findings when available, and/or subsequent revision ACL reconstruction. Although a minimum of 2 years of follow-up was required for inclusion, outcome data were recorded through the most recent available clinical follow-up within the study period. Therefore, graft reruptures occurring beyond 2 years were captured when patients returned for subsequent clinical evaluation, underwent postoperative imaging, or had revision ACL reconstruction documented in the medical record.

Statistical Analysis

Statistical analysis was conducted using Microsoft Excel. Descriptive statistics were calculated. Continuous

TABLE 1
Patient Characteristics[a]

Characteristic	Control Group	Suture Tape Augmentation Group	*P*
No. of patients	42	38	
Age at surgery, y	20.2 ± 8.4	23.3 ± 7.9	.01[b]
Sex			.6
Male	23 (55)	23 (61)	
Female	19 (45)	15 (40)	
Race/ethnicity			.3
White/Caucasian	28 (67)	20 (53)	
African American	10 (24)	10 (26)	
Hispanic	3 (7)	3 (8)	
Other/not reported	1 (2)	5 (13)	
Body mass index, kg/m^2	27.5 ± 8.7	27.3 ± 7.0	.6
Family history of anterior cruciate ligament injury	0 (0)	1 (3)	.5
Mechanism of injury			.3
Noncontact	33 (79)	33 (87)	
Contact	9 (21)	5 (13)	

[a]Values are reported as a mean ± SD or number (percentage).
[b]Statistically significant defined by $P < .05$.

TABLE 2
Intraoperative Details[a]

Variable	Control Group	Suture Tape Augmentation Group
Graft diameter, mm	9.6 ± 0.5	9.8 ± 0.5
Concomitant pathology	36 (86)	25 (66)
Concomitant procedure	34 (81)	25 (66)
Time from injury to surgery, wk	11.8 ± 9.8	11 ± 8.0

[a]Values are reported as a mean ± SD or number (percentage).

variables were assessed for normality using the Shapiro-Wilk test in combination with visual inspections of histograms. Based on distributional characteristics of the data, continuous variables were compared between the groups with and without augmentation using the Welch *t* test for normally distributed data and Mann-Whitney *U* test for nonnormally distributed data. For categorical variables, Fisher exact tests were used to calculate *P* values if counts were ≤5, and chi-square tests were used for larger samples. *P* values <.05 were considered statistically significant.

RESULTS

A total of 80 patients were included in the final data analysis, including 42 in the control group and 38 in the suture tape augmentation group. The overall mean age at surgery was 21.7 ± 8.3 years (range, 11-39 years), and the mean BMI was 27.4 ± 7.9 (range, 17.4-55). No significant differences were found between groups with respect to sex, race, mechanism of injury (contact vs noncontact), or time from injury to surgery (11.8 vs 11.0 weeks; $P > .05$). However, a significant difference in age was found between the control and suture augmentation groups (20.2 ± 8.4 vs 23.3 ± 7.9, respectively; $P < .05$). Baseline demographic characteristics, surgical characteristics, and intraoperative findings of both cohorts are summarized in Tables 1 and 2.

Patients in the suture tape augmentation group had a significantly lower rate of graft rerupture compared with controls (0% vs 14%; $P < .05$). Among the 6 patients who sustained graft rerupture, the mean time to failure was 109.3 ± 59.0 weeks, with a median of 109.5 weeks and a range of 35 to 204 weeks. Characteristics of the 6 patients who sustained a retear are summarized in Table 3. The majority of graft reruptures in the control group occurred at >1 year postoperative, and half of the reruptures occurred at >2 years postoperative. Reoperation rates were also higher in the control group (24% vs 21%), although this difference was not statistically significant ($P = .8$). These outcomes are summarized in Table 4.

At a minimum 2-year follow-up, no significant differences were found in visual analog scale (VAS) score, Single Assessment Numeric Evaluation (SANE) score, Knee injury and Osteoarthritis Outcome Score (KOOS), or Marx Activity score between groups ($P > .05$). Both cohorts demonstrated significant improvement from preoperative

TABLE 3
Characteristics of Patients With Graft Rerupture[a]

Age, y	Sex	BMI	Graft Diameter, mm	Sport/Activity Level	Concomitant Injuries	Time to Rerupture After Surgery, wk
18	Male	20.4	10	Baseball (HS)	Vertical lateral meniscal tear	35
13	Female	18.4	10	Soccer (HS)	Lateral femoral condyle cartilage lesion	133
16	Male	27.6	10	Football, track, and basketball (HS)	Complex posterior lateral meniscus tear with popliteal fascicular involvement	95
17	Male	23	10	Football (HS)	None	204
16	Male	20.1	10	Basketball (HS)	Medial and lateral meniscal tears	124
13	Female	23.4	9	Basketball and softball (HS)	Bucket-handle meniscal tear	65

[a]BMI, body mass index; HS, high school.

TABLE 4
Complications and Reoperations[a]

Outcome	Control Group	Suture Augmentation Group	*P*
Graft rerupture	6 (14)	0 (0)	**<.05**[b]
Reoperation (any cause)	10 (24)	8 (21)	.795
Infection (superficial or deep)	0 (0)	2 (5)[b]	
Secondary meniscal tear	0 (0)	2 (5)	
Stiffness	1 (2)	2 (5)	

[a]Values are reported as number (percentage). Statistical comparisons were performed between groups, with significance defined as $P < .05$. Boldface indicates statistical significance.
[b]The 2 infections reported in the suture augmentation group were both superficial.

TABLE 5
Patient Outcomes and Functional Scores[a]

	Control Group			Suture Augmentation Group			
Outcome Measure	Preoperative	2-Year Postoperative	*P*	Preoperative	2-Year Postoperative	*P*	*P*[b]
VAS pain	2.8	0.7	<.05	3.0	1.2	.05	.3
SANE	37.9	91.6	<.05	56.3	84.8	<.05	.1
KOOS-Pain	63.1	93.7	<.05	68.8	92.5	<.05	.7
KOOS-Symptoms	58.4	88.2	<.05	62.9	85.6	<.05	.5
KOOS-ADL	68.2	96.5	<.05	74.9	96.8	<.05	.9
KOOS-Sport/Rec	18.1	90.5	<.05	28.0	88.4	<.05	.7
KOOS-QOL	29.25	82.9	<.05	36.3	79.3	<.05	.5
Marx Activity Score	10.9	9.0	.3	11.8	13.1	.7	.1
Time to return to sport, wk	—	41.2	—	—	42.1	—	.8

[a]Values are reported as mean. Statistical significance was defined as $P < .05$. ADL, activities of daily living; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, quality of life; SANE, Single Assessment Numeric Evaluation; VAS, visual analog scale.
[b]*P* value represents between-group comparisons between control and suture tape augmentation groups at 2-year follow-up.

baseline to 2 years postoperatively, but no statistically significant differences were found between groups at any time point. These outcome measures are summarized in Table 5.

The mean time to return to unrestricted physical or sporting activity was similar between groups (41.2 weeks in controls vs 42.1 weeks in the augmented group; $P = .8$). Postoperative activity levels did not differ significantly, with the majority of patients returning to recreational athletics (45%) or high school competitive sports (35%). Fewer patients resumed collegiate (4%) or professional play (1%).

Postoperative complications occurred in 1 of 42 patients (2%) in the control group and in 6 of 38 patients (16%) in the suture tape augmentation group. In the control cohort, complications consisted of stiffness requiring intervention in 1 patient (2%). In the suture tape augmentation cohort,

complications included superficial infection in 2 patients (5%), secondary meniscal tear in 2 patients (5%), and postoperative stiffness in 2 patients (5%). No significant differences were observed between groups in rates of infection, secondary meniscal injury, or stiffness.

DISCUSSION

The literature on suture tape augmentation for ACL reconstruction remains heterogeneous.[5-8,10,15,24,25,28,29] In this study, suture tape augmentation was associated with a significantly lower graft rerupture rate compared with nonaugmented controls (0% vs 14%; $P < .05$). Similarly, other studies have reported a potential association between suture tape augmentation and reduced early graft failure. In a retrospective analysis by Daniel et al[6] of patients who underwent QT autograft with suture tape augmentation, none experienced graft rerupture at 2-year follow-up. This has also been reflected when applied to other soft tissue grafts like HT autografts, as demonstrated in a retrospective study by Daniel and Smith,[7] with 4-year graft survival significantly higher in the suture augmentation versus control group (97.2% vs 82.4%, respectively; $P = .031$). In a systematic review and meta-analysis by Jiang et al,[13] suture tape augmentation demonstrated reduced rerupture risk and improved return-to-sport rates across multiple graft types.

Conversely, other studies have reported no difference in graft failure rates or increased laxity with suture tape augmentation. In a systematic review and meta-analysis by Tang et al,[25] suture tape augmentation was significantly associated with increased knee anterior to posterior laxity scores compared with nonaugmented groups, and there was no difference in return-to-sport rate. Tamburini et al[24] found no difference in graft failure rate or time to graft failure in adolescents who underwent ACL reconstruction with QT autograft with or without suture tape augmentation.

The use of QT autograft has demonstrated good patient outcomes and low retear rates, supporting its increased use.[3,17] Previous studies have also reported comparable graft failure rates among QT, BPTB, and HT autografts (QT 2.7%-3.4%; BPTB 2.2%-3.1%; HT 4.8%-5.5%).[20] A 2024 randomized controlled trial by Ebert et al[9] reported no differences in graft rupture rate, laxity, or PROMs between QT and HT autografts at 2-year follow-up. However, potential downsides with the use of QT autografts include graft elongation, postoperative quadriceps weakness, and loss of knee extension. Patients who have undergone ACL reconstruction with QT autograft have demonstrated up to an 11% loss in >5° of knee extension compared with the contralateral knee.[12]

All 6 failures occurred in the control group, predominantly in young competitive athletes with concomitant injuries despite successful completion of a return-to-sport progression with favorable strength and performance parameters. These findings potentially indicate the beneficial use of suture tape augmentation in high-risk populations—female sex, high-demand cutting and pivoting sports, generalized hyperlaxity, young age (ie, <25 years), and meniscal or other ligamentous pathology.[19,27] Synthetic augmentation may be considered alongside lateral extra-articular procedures, such as the iliotibial band tenodesis or anterolateral ligament reconstruction, in further reducing risk in those with an elevated risk of graft rupture. As demonstrated by the multicenter, prospective, randomized controlled STABILITY 1 trial, the addition of iliotibial band tenodesis to ACL reconstruction with HT autografts in high-risk populations had significantly lower graft rerupture rates and persistent rotatory laxity at 2 years when compared with ACL reconstruction alone.[11] Half of the graft reruptures in the control group occurred at >2 years postoperative. Although no graft reruptures were reported in the suture augmentation group, it is important to note the possibility of fatigue failure with suture tape augmentation at longer follow-up. Although suture tape augmentation provides time-zero construct stiffness, a theoretical potential exists for abrasive wear over time with repetitive loading.[2,13,15]

Furthermore, the use of suture tape augmentation did not demonstrate a significant difference in reoperation rate compared with the control group, suggesting a favorable safety profile. Previous use of intra-articular synthetic implants was associated with particulate wear, synovitis, and florid foreign body reaction, whereas other authors have expressed concerns about stress shielding and/or overconstraint of the joint leading to chondrosis.[2,26] Although our study did not analyze the presence of synovitis, persistent effusion, or foreign body reaction, prior magnetic resonance imaging studies demonstrated no adverse intra-articular reactions and reported significantly improved PROMs at 2-year follow-up.[23] Furthermore, these data support the load-sharing nature of synthetic augmentation alongside ACL reconstruction, serving as a "safety belt" to prevent the extremes of knee translation.[14,15,21]

Despite the difference in graft survivorship, no significant differences were found in PROMs (VAS, SANE, KOOS, Marx), time to return to sport, or postoperative activity level. Both cohorts demonstrated improvement compared with preoperative baselines, with the majority of patients returning to recreational or high school competitive sports, suggesting that the primary benefit of suture tape augmentation lies in graft protection rather than improving subjective patient outcomes.

This study has several limitations. The retrospective design introduces potential selection bias, and although cohorts were well-matched demographically, unmeasured confounding variables may exist, such as differences in anatomy or laxity. The study had a 35% follow-up at 2 years, which could also introduce selection bias, because patients with poorer outcomes may be less likely to complete follow-up at 2 years. This could also cause the sample size to be underpowered to assess rare complications. Follow-up duration beyond the minimum 2-year requirement was not standardized across patients or formally compared between cohorts. Additionally, no standardized in-person physical examination or imaging assessment of

graft integrity was performed at or beyond 2 years. Graft rerupture was assessed through available clinical documentation, imaging when obtained, and/or revision ACL reconstruction records. The indications for the use of suture tape augmentation were not standardized and were based solely on surgeon preference, which also serves as a significant confounding factor. In addition, patients in the augmentation group were significantly older than those in the control group (23.3 vs 20.2 years; $P < .05$). This baseline difference may have contributed to the higher rerupture rate observed in the control cohort group. This potential confounding variable should be considered when interpreting the difference in graft failure between cohorts. Finally, although PROMs were collected comprehensively, they may not fully capture the subtle differences in dynamic knee stability, sport-specific function, or as a substitute for physical assessment of graft integrity.

CONCLUSION

Suture tape augmentation of all soft tissue QT autografts for primary ACL reconstruction was associated with a significant reduction in early graft retear compared with non-augmented controls, without an increase in reoperation rates. PROMs and return-to-play rates were similar between the 2 groups. Larger multicenter studies with longer follow-up are warranted to further define the value of suture tape augmentation of QT autograft in primary ACL reconstruction.

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