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Original Research

Outcomes of bone-patellar tendon-bone autograft and quadriceps tendon autograft for ACL reconstruction in an all-female soccer player cohort with mean 4.8-year follow up

Zachary J. Herman [a], Neilen A. Benvegnu [a], Sahil Dadoo [a], Audrey Chang [b], Robert Scherer [b], Ehab M. Nazzal [a], Emre Anil Özbek [a,c], Janina Kaarre [a,d], Jonathan D. Hughes [a,*], Bryson P. Lesniak [a], Dharmesh Vyas [a]

[a] Department of Orthopaedic Surgery, UPMC Freddie Fu Sports Medicine Center, University of Pittsburgh Medical Center, Pittsburgh, PA 15203, USA
[b] University of Pittsburgh School of Medicine, Pittsburgh, PA 15213, USA
[c] Department of Orthopedics and Traumatology, Ankara University, Ankara 06100, Turkey
[d] Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy University of Gothenburg, Gothenburg 43130, Sweden

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ABSTRACT

Objective: The purpose is to compare functional outcomes, return to soccer rates, and revision rates in an all-female soccer player cohort undergoing quadriceps tendon (QT) autograft ACLR versus bone-patellar tendon-bone (BPTB) autograft ACLR.

Methods: Female soccer players who sustained an ACL rupture and underwent primary anatomic, single-bundle ACLR with BPTB autograft or QT autograft were included. Demographic and surgical characteristics were collected. Outcomes of interest included Tegner score, International Knee Documentation Committee (IKDC) score, Marx score, return to soccer rates, and failure rates.

Results: Data on 23 patients undergoing BPTB autograft ACLR and 14 undergoing QT autograft ACLR was available. Average age was 18.7 years, and average follow up was 4.8 years. Overall, 76 % (28/37) returned to soccer and 5.4 % (2/37) underwent revision ACLR. No major significant differences were found in demographic or surgical characteristics. No differences were found in postoperative IKDC scores, preoperative, postoperative, or change from pre-to postoperative Marx activity scores, or pre-and postoperative Tegner scores between the groups. QT autograft ACLR patients had significantly less change in Tegner scores pre-to postoperatively compared to the BTPB autograft ACLR group (0.6 ± 1.2 versus 2.1 ± 1.8; $p = 0.02$). Both groups had similar rates of return to soccer [78 % (18/23) BPTB autograft ACLR versus 71 % (10/14) QT autograft ACLR; $p = 0.64$] and rates of revision (8.7 % (2/23) BPTB autograft ACLR; 0 % (0/14) QT autograft ACLR.

Conclusion: Results of this study suggest that BPTB autograft ACLR and QT autograft ACLR produce comparable, successful functional and return to soccer outcomes in this all-female soccer player cohort study. Larger, prospective studies are needed to improve the strength of conclusions and provide more information on the optimal graft choice for female soccer players. Surgeons can use the results of this study to counsel female soccer players on expected outcomes after ACLR.

Level of Evidence: III.

* Corresponding author. 3200 South Water Street, Pittsburgh, PA 15203, USA. Tel.: 412-432-3600.
E-mail address: Hughesjd3@upmc.edu (J.D. Hughes).

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What are the new findings?

- Long term patient reported outcomes and return to soccer rates of female soccer players undergoing anterior cruciate ligament reconstruction with quadriceps tendon autograft and bone- patellar tendon- bone autograft are presented.
- In this cohort, fear of re-injury remains a common reason for failing to return to soccer after anterior cruciate ligament reconstruction.
- Surgeons can use the results of this study to counsel female soccer players on graft options and suspected outcomes after anterior cruciate ligament reconstruction with quadriceps tendon or bone- patellar tendon- bone autografts.

1. INTRODUCTION

Female athletes have been reported as two to eight times more likely to experience ACL injuries than male athletes [2,31], and in particular, female soccer players are nearly three times more likely than male soccer players to injure their ACL [24]. Furthermore, female soccer players are at a high risk of failure after ACL reconstruction (ACLR) upon returning to the field [1]. A 2021 study found these athletes had a two to five times higher risk of ipsilateral knee injury and knee surgery compared to healthy controls and female athletes who did not return to play following ACLR [13].

Due to the high risk of failure after ACLR in the female soccer player population, there remains a debate on the optimal graft choice in these patients. A 2020 retrospective study compared outcomes of hamstring autograft and bone-patellar tendon-bone (BPTB) autograft ACLR in female soccer players and found comparable patient reported outcomes between the groups with similar rates of return to soccer [5]. Yet, hamstring autograft may be decreasing in popularity in the female athlete, as other studies have shown higher risk of failure in this population [25,30]. Furthermore, given results supporting the quadriceps tendon (QT) autograft's decreased donor site morbidity [21] as well as its proven success in functional knee recovery and limiting failure, it is becoming a more common choice in adolescent athletes [3,4,32]. As such, its results should be further examined in the female soccer player population.

Currently, limited data exists comparing outcomes of female soccer players after ACLR with QT autograft to other graft options. As such, the purpose of this study was to compare functional and return to soccer outcomes as well as operative knee reinjury and revision ACLR rates between BPTB autograft and QT autograft ACLR in an all-female soccer player cohort. We hypothesized that both graft types would result in similar functional outcomes, return to soccer rates, and revision rates in female soccer players.

2. METHODS

2.1. Data collection

This combined retrospective study was approved by the Institutional Review Board at the University of Pittsburgh, IRB#: STUDY22050138 and IRB#: STUDY19030196. All female soccer players who sustained an ACL rupture underwent primary anatomic, single-bundle ACLR with BPTB autograft or QT autograft between 2015 and 2021 by one of seven sports medicine fellowship trained orthopaedic surgeons were included for analysis. Exclusion criteria included males, patients <14 years old, revision ACLR, double-bundle ACLR, multi-ligament knee reconstruction, all-epiphyseal techniques, and follow-up length less than 2 years.

All female soccer players underwent primary, anatomic, transphyseal, single-bundle ACLR with ipsilateral QT autograft or BPTB autograft. Diagnostic arthroscopy was performed to confirm ACL tear and evaluate for meniscal or chondral pathology, which were treated appropriately. For patients receiving QT autograft ACLR, QT autograft was harvested lateral to the vastus medialis oblique muscle. Graft thickness, diameter, and harvest of patellar bone block were determined based on surgeon discretion. For patients receiving BPTB autograft ACLR, the patellar tendon graft was harvested from the medial third of the ipsilateral patellar tendon with tibial and patellar bone block lengths based on surgeon preference. A bone block of 15–20mm in length was taken from the patella and care was taken to not disrupt the underlying articular surface of the patella during bone block harvest. The native ACL femoral and tibial footprints were identified. The femoral tunnel was drilled through the anteromedial portal at the femoral footprint of the ACL insertion. The tibial tunnel was drilled with an outside-in technique using a tibial guide. Grafts were passed and fixated appropriately on the femoral and tibial sides using interference screws or continuous or adjustable loop suspensory fixation, with a posterior drawer force applied. Patients were made weight bearing as tolerated immediately after surgery unless a concomitant meniscus repair was performed. In this case, patients were instructed to remain toe touch weight bearing for 6 weeks. A standardized postoperative physical therapy protocol was initiated a week after surgery to include pain and swelling modalities, quadriceps strengthening, range of motion, and a stepwise physical therapy protocol with return to sport after passing a battery of return to sports testing with athletic trainers and physical therapists.

Demographic data including patient age, body mass index (BMI), level of soccer competition [defined as high school/recreational or collegiate (no professionals included in study)], laterality of injury, time to surgery from injury, and completion of physical rehabilitation with a licensed physical therapist prior to surgery were collected. Surgical characteristics including regional nerve block administration, procedure time, and concomitant meniscal procedure were recorded. All patients included for analysis were prospectively contacted for completion of a questionnaire assessing postoperative International Knee Documentation Committee (IKDC) [14,15] score, pre- and postoperative Marx activity scale scores [20], and pre-and postoperative Tegner scores [29], return to soccer information (including reason for failure to return), future ipsilateral knee injury (subjectively defined by patients completing the questionnaire), and ipsilateral revision ACLR. The primary outcome of interest was Tegner score. Secondary outcomes of interest included IKDC, Marx score, RTS rates, and failure rates. All questionnaires were completed using an institutional REDCap database (REDCap, Vanderbilt University) and stored alongside retrospective data collection. Follow-up length was determined using date of questionnaire completion.

2.2. Power analysis

An a priori power analysis was conducted utilizing data from a previous manuscript investigating differences in outcomes between female soccer players undergoing BPTB and hamstring ACLR [5]. It was found that 17 and 25 individuals were required for the quad tendon and BPTB groups, respectively, to observe a difference of 1.8 points in Tegner scores with a power of 0.8 (alpha = 0.05, beta = 0.2).

2.3. Statistical analysis

All data was analyzed using Microsoft Excel (V16.6) and SPSS V28 (IBM). Descriptive statistics were reported for all demographic variables, surgical characteristics, and post-operative outcomes and displayed as

means with standard deviations (SD) or numbers (n) with proportions (%). Continuous data was compared between BPTB autograft ACLR and QT autograft ACLR groups with independent t-test or Mann–Whitney U test for parametric and non-parametric data, respectively. Categorical data was compared between BPTB autograft ACLR and QT autograft ACLR groups with chi-squared tests. Statistical significance was set at $p < 0.05$.

3. RESULTS

A total of 123 consecutive female soccer players met inclusion for the study, 53 undergoing QT autograft ACLR and 70 undergoing BPTB ACLR. Nine (9) patients were excluded from the BPTB autograft ACLR group as they underwent revision ACLR with BPTB autograft (hamstring autograft for primary ACLR). After survey distribution under protocol derived by the Institutional Review Board and completion by participants, data on 37 total female soccer players were available: 23 patients undergoing BPTB autograft ACLR and 14 undergoing QT autograft ACLR (Table 1). Average age was 18.7 years, and average follow up was 4.8 years. Overall, 76 % (28/37) returned to soccer and 5.4 % (2/37) underwent revision ACLR.

No significant differences were found between age at surgery, BMI, laterality of injured knee, level of competition, or completion of rehabilitation prior to surgery (Table 2). Mean time from injury to surgery was longer in the QT autograft ACLR group (3.7 ± 6.0 months versus 1.0 ± 0.7; $p = 0.03$). One patient in the QT autograft ACLR group had a time from injury to surgery of over 24 months, likely contributing to the wide standard deviation in the QT autograft ACLR group and this statistical finding. In terms of surgical characteristics, no significant differences were found between the groups with respect to regional nerve block usage, procedure time, and or percentage of female athletes undergoing concomitant meniscal repair. Lastly, mean follow up was comparable between the groups, as the BPTB autograft group had average follow up of 5.1 years, and the QT autograft group had average follow up of 4.5 years ($p = 0.36$).

No significant differences were found in postoperative IKDC scores, preoperative, postoperative, or change from pre-to postoperative Marx activity scores, or pre-and postoperative Tegner scores between the groups (Table 3). QT autograft ACLR patients had significantly less change in Tegner scores pre-to postoperatively compared to the BTPB autograft ACLR group (0.6 ± 1.2 versus 2.1 ± 1.8; $p = 0.02$). Both groups had similar rates of return to soccer [78 % (18/23) BPTB autograft ACLR versus 71 % (10/14) QT autograft ACLR, $p = 0.064$], subsequent ipsilateral knee injury [30 % (7/23) BPTB autograft ACLR versus 21 % (3/14) QT autograft ACLR, $p = 0.64$], and revision ACLR [9 % (2/23) BPTB autograft ACLR versus 0 % (0/14) QT autograft ACLR, $p = 0.26$]. Based on the information available in health records and survery answers, all patients that had a graft re-rupture in both cohorts underwert revision. Therefore, the rate of revision ALR represents the rate of graft re-rupture (different from a subjective re-injury in the postoperative period).

Lastly, female soccer players who did not return to soccer after ACLR were asked to choose as many answers that applied from a list of reasons as to why they did not return (Table 4). Twenty-one percent (22 %; 5/23) of patients undergoing BPTB autograft ACLR while 29 % (4/14) patients undergoing QT autograft ACLR did not return to soccer. Out of the reasons listed, 60 % (3/5) of those undergoing BPTB autograft ACLR and 50 % (2/4) of those undergoing QT autograft ACLR selected that "fear of re-injury or lack of confidence in the knee" kept them from returning. Forty percent (40 %; 2/5) patients undergoing BPTB autograft ACLR selected "ipsilateral re-injury or complication" as a reason for preventing them from returning to soccer. Other reasons for not returning to soccer

Table 1
Demographic characteristics of study population.

Variable	Total cohort (n = 37)
Age (years), mean (SD)	18.7 (4.0)
BMI, mean (SD)	22.0 (2.7)
Laterality (right), n (%)	15 (40.5)
Follow-up length (years), mean (SD)	4.8 (1.3)
Return to soccer (yes), n (%)	28 (75.7)
Return to soccer at higher level[a], n (%)	9 (32.1)
Return to soccer at same level[a], n (%)	13 (46.4)
Return to soccer at lower level[a], n (%)	6 (21.4)
Revision ACLR	2 (5.4)

SD = standard deviation, n = number of patients, BMI = body mass index.
[a] Indicates percentage of patients among those who returned to soccer.

Table 2
Comparison of demographic and surgical characteristics between BPTB autograft ACLR versus QT autograft ACLR.

Variable	BPTB (n = 23)	QT (n = 14)	p-value[b]
Age (years), mean (SD)	18.1 (2.6)	19.7 (5.4)	0.96
BMI, mean (SD)	21.7 (2.1)	22.3 (3.4)	1.00
Laterality (right), n (%)	9 (39.1)	6 (42.9)	0.82
Level of competition[a] (college), n (%)	10 (43.5)	2 (14.3)	0.07
Completed prehab (yes), n (%)	7 (30.4)	7 (50.0)	0.23
Time to surgery (months), mean (SD)	1.1 (0.7)	3.7 (6.0)	***0.03***
Regional Nerve Block (yes), n (%)	17 (73.9)	9 (64.3)	0.40
Concomitant meniscal repair (yes), n (%)	12 (52.2)	8 (57.1)	0.77
Procedure time (minutes), mean (SD)	111.5 (29.1)	119.0 (26.9)	0.70
Follow-up length (years), mean (SD)	5.1 (1.4)	4.5 (1.0)	0.36

BMI = body mass index, SD = standard deviation, n = number of patients, BPTB = bone-patellar tendon-bone, QT = quadriceps tendon, ACLR = ACL reconstruction.
[a] Level of competition: College versus high school/recreational.
[b] Statistical significance at $p < 0.05$ (bold).

Table 3
Comparison of patient-reported outcomes between BPTB autograft ACLR versus QT autograft ACLR.

Variable	BPTB (n = 23)	QT (n = 14)	p-value[a]
Post-operative IKDC, mean (SD)	85.8 (11.20)	91.6 (9.7)	0.10
Pre-operative Marx, mean (SD)	14.7 (3.1)	14.6 (1.8)	0.51
Post-operative Marx, mean (SD)	11.0 (5.3)	11.8 (4.6)	0.75
Change in pre- to post-op Marx, mean (SD)	3.7 (4.3)	2.9 (3.8)	0.70
Pre-operative Tegner, mean (SD)	9.4 (1.1)	8.9 (1.0)	0.12
Post-operative Tegner, mean (SD)	7.3 (2.3)	8.2 (1.6)	0.23
Change in pre- to post-op Tegner, mean (SD)	2.1 (1.8)	0.6 (1.2)	***0.02***
Return to soccer (yes), n (%)	18 (78.3)	10 (71.4)	0.64
Subsequent ipsilateral knee injury (yes), n (%)	7 (30.4)	3 (21.4)	0.64
Subsequent revision ACLR (yes), n (%)	2 (8.7)	0 (0)	0.26

IKDC = International Knee Documentation Committee, BPTB = bone-patellar tendon-bone, QT = quadriceps tendon, ACLR = ACL reconstruction, SD = standard deviation, n = number of patients.
[a] Statistical significance at $p < 0.05$ (bold).

Table 4
Descriptive comparison of reasons for failing to return to soccer BPTB autograft ACLR versus QT autograft ACLR.

Reason for failure to return to soccer	BPTB (n = 5)	QT (n = 4)
Not cleared to play, n (%)	0 (0)	0 (0)
Fearful of re-injury or lack of confidence in knee, n (%)	3 (60)	2 (50)
Interests have changed, n (%)	1 (20)	2 (50)
Ipsilateral re-injury or complication, n (%)	2 (40)	0 (0)
Contralateral injury or complication, n (%)	0 (0)	0 (0)
Season not started or sport not available, n (%)	1 (20)	0 (0)
Other, n (%)	2 (40)	2 (50)

n = number of patients, BPTB = bone-patellar tendon-bone, QT = quadriceps tendon.

for athletes in both groups included "interests have changed," "the season has not started yet or the sport is no longer available," and "other." Full results are listed in Table 4.

4. DISCUSSION

The main findings of this study were that both BPTB autograft ACLR and QT autograft ACLR result in similar, successful patient reported outcomes in a unique study population of all female soccer players with high return to soccer rates of 78.1 % after BPTB autograft ACLR and 71.4 % after QT autograft ACLR and low failure rates of 9 % after BPTB autograft ACLR and 0 % after QT autograft ACLR.

Functional knee outcomes in this study are comparable with the literature. A 2020 retrospective study with average follow up of 3.4 years comparing all-female soccer player cohorts undergoing BPTB autograft ACLR versus hamstring autograft ACLR found mean postoperative Tegner scores of 6.0 in the 41 athletes undergoing BPTB autograft ACLR [5]. While these results were statistically superior to the hamstring autograft ACLR cohort (mean postoperative Tegner 4.2) [5], postoperative Tegner scores for the BPTB autograft ACLR group in the 2020 study are comparable to the mean postoperative Tegner scores for both cohorts in this study (7.3 BPTB autograft ACLR; 8.2 QT autograft ACLR). Interestingly, in this study, mean change from pre-to postoperative Tegner scores were significantly lower in the QT autograft group (0.6) compared to the BPTB autograft group (2.1), suggesting that patients undergoing QT autograft ACLR may have retained a higher level of activity at follow up than those undergoing BPTB autograft ACLR. Furthermore, postoperative IKDC scores were similar between cohorts, with mean scores of 85.8 and 91.6 for the BPTB autograft ACLR and QT autograft ACLR groups respectively, and both cohorts' mean IKDC values reached the patient acceptable symptom state (PASS) of 75.9 defined by a 2016 study [23]. Overall, the results of patient reported outcomes in this study support the literature on a wider scale of patient populations, as data has shown the effectiveness of both BPTB and QT autografts in functional knee recovery after ACLR in athletes [9,10,22].

Return to soccer rate in the entire study population was 76 % (28/37), and when broken down by graft type, both cohorts had similar rates of return [78 % (18/23) BPTB autograft ACLR versus 71 % (10/14)] QT autograft ACLR. These results are higher than rates reported in the literature, as two case series of female soccer players from 2015 and a 2020 study comparing BPTB autograft ACLR versus hamstring autograft ACLR in female soccer players showed return to soccer rates between 46% and 66 % at similar follow up timepoints [5,11,26]. Recent data has focused on reasoning for failing to return to sport after ACLR. Fear or lack of psychological readiness is commonly cited as a reason for failed or delayed return to sport [5,6,33], and some studies show that females may be slower to develop psychological readiness to return to sport than males [17,19]. In this study, despite small sample sizes and small percentage of patients failing to return to soccer, "fear of reinjury and lack of confidence in operative knee" was a commonly chosen reason for lack of return. As such, a focus of the postoperative rehabilitation should continue to include interventions designed to increase confidence and psychological readiness such as visualization of success, routine assessment of self-efficacy and fear of reinjury, strict adherence to physical therapy programs, goal-setting, and positive self-talk [7,18,28].

Female soccer players are at higher risk of failure after ACLR compared to non-soccer female athletes undergoing ACLR [1]. A 2016 cohort study reviewed medical records of female athletes undergoing ACLR, dividing patients into 2 groups: female soccer athletes and matched female athletes that did not participate in soccer [1]. Over an average follow up time of 68.8 months, the authors found that soccer players had higher rates of ACLR failure compared to non-soccer athletes (11 % vs 1 %) [1]. Furthermore, in a comparative study of BPTB autograft ACLR versus hamstring autograft ACLR in an all-female soccer player population, overall failure rate was reported as 11.3 % (8/71), with 9.8 % (4/41) failure rate for the BPTB autograft ACLR group and 13.3 % (4/30) for the hamstring autograft ACLR group [5]. While approximately 27 % (10/37) of female soccer players in this study reported a subsequent injury to ipsilateral knee, a smaller percentage experienced a retear requiring revision ACLR [5.4 % (2/37) overall; 8.7 % (2/23) BPTB autograft ACLR; 0 % (0/14) QT autograft ACLR]. Despite the long duration of follow up, these low revision rates may be due to the small sample size of the study, relying on a survey to assess the status after ACLR and placing the study at risk for sampling bias. It is also possible that, as mean Tegner and Marx scores have decreased pre-to postoperatively, some of the athletes no longer participate in sport, resulting in decreased strenuous activity and less stress on their ACL graft.

The literature has shown that female soccer players that have undergone ACLR have almost a five-fold higher incidence of developing new knee-related injuries (ipsilateral ACL retear, contralateral ACL injury, other non-ACL related injury) than healthy-knee female soccer players [12]. It is worth questioning why these athletes continue to fail and reinjure, especially at higher rates than other athletic populations [12]. As the optimal graft type for the female soccer player continues to be studied, focus on other factors such as multicomponent exercise-based prevention programs, coronal and sagittal malalignment, rotatory instability, and postoperative neuromuscular training as well as quadriceps, hamstring, and core muscle development should continue in this population in attempt to provide these athletes with successful return to the field and the lowest possible chance of reinjury [8,16,27].

In spite of its uniqueness in presenting outcomes of QT autograft ACLR in an all-female soccer player population, this study is hypothesis-generating, and it is difficult to formulate strong conclusions with the available sample size. Further, several limitations to this study exist and include its retrospective nature and low sample size, which is underpowered and increases the likelihood of type II error. Despite the advantage of QT autograft ACLR having been shown to decrease donor site morbidity compared to other graft options, this was not investigated and compared to donor site morbidity in patients undergoing BPTB autograft ACLR, largely because this data was not available for retrospective collection. Additionally, this study also relied on survey responses to address current knee function as well as rates of return to soccer and ACLR revision, introducing the possibility for sampling bias. Larger, randomized studies are needed to draw firmer conclusions on graft types with the most successful outcomes following ACLR in female soccer players.

5. CONCLUSIONS

Results of this study suggest that BPTB autograft ACLR and QT autograft ACLR produce comparable, successful functional and return to soccer outcomes in this all-female soccer player cohort study. Larger, prospective studies are needed to improve the strength of conclusions and provide more information on the optimal graft choice for female soccer players. Surgeons can use the results of this study to counsel female soccer players on expected outcomes after ACLR.

Author contributions

All listed authors have contributed substantially to this work: literature search, and primary manuscript preparation were performed by ZJH, NB, SD, AC, RS, EMN, EAÖ, and JK. JDH, BPL, and DV assisted with study design, interpretation of the results, as well as editing and finalizing the manuscript. All authors have read and approved the final manuscript to be submitted and published.

IRB approval

University of Pittsburgh Institutional Review Board, IRB #: STUDY22050138 and IRB #: STUDY19030196.

Declaration of competing interest

The authors declare the following financial interests/personal relationships that may be considered as potential competing interests: Jonathan D. Hughes reports a relationship with Smith and Nephew Inc that includes: travel reimbursement. Jonathan D. Hughes reports a relationship with Stryker that includes: travel reimbursement. Jonathan D. Hughes reports a relationship with Arthrex Inc that includes: travel reimbursement. Dharmesh Vyas reports a relationship with Smith and Nephew Inc that includes: speaking and lecture fees. Dharmesh Vyas reports a relationship with Stryker that includes: speaking and lecture fees. Dharmesh Vyas reports a relationship with Arthrex Inc that includes: speaking and lecture fees. Dharmesh Vyas reports a relationship with Arthrex Inc that includes: consulting or advisory. Jonathan D. Hughes reports a relationship with Knee Surgery, Sports Traumatology, Arthroscopy (KSSTA) that includes: board membership.

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