Anterior Cruciate Ligament Reconstruction in Young Female Athletes

Patellar Versus Hamstring Tendon Autografts

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Background: Female athletes are 2 to 8 times more prone to anterior cruciate ligament (ACL) rupture than males. Furthermore, reinjury to the ipsilateral or contralateral knee can occur in >20% of athletes. Female sex and younger age are known risk factors for graft failure. The optimal graft choice for young females remains unknown and poorly studied.

Purpose/Hypothesis: The authors aimed to compare clinical outcomes in young females who underwent ACL reconstruction (ACLR) with bone–patellar tendon–bone (BTB) and quadrupled hamstring (HS) autografts. It was hypothesized that no significant differences in outcomes exist between graft choices.

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

Methods: Female patients aged 15 to 25 years who underwent primary ACLR with BTB or HS autograft were included for review. Patients were subdivided into 2 age groups: 15 to 20 years and 21 to 25 years. The occurrence of chondral, meniscal, or ligamentous injury to either knee was recorded for comparison.

Results: A total of 256 females were included (BTB, n = 175; HS, n = 81). The majority of patients were between the ages of 15 and 20 years (BTB, 80%; HS, 77.8%). Overall, graft rupture occurred in 23 patients (9%) and contralateral ACL tear occurred in 18 (7%). Subgroup analysis showed that 75% of BTB and 100% of HS graft retears occurred in females aged 15 to 20 years. Within this age group, there was a significantly lower rate of graft ruptures in the BTB group (6.4%) as compared with the HS group (17.5%, $P = .02$). Allograft augmentation was used in 4 of the 11 HS grafts that retore. When allograft-augmented grafts were excluded, there was no significant difference in graft failure rate between graft choices. Fifteen patients in the BTB group (12%) as opposed to 1 in the HS group (2%) reported extreme difficulty or the inability to kneel on the front of the knee ($P = .04$).

Conclusion: In females aged 15 to 20 years undergoing ACLR, BTB autograft may lead to fewer graft ruptures than HS autograft. While this difference was not observed in females aged 21 to 25 years, a larger sample may be required to accept the null hypothesis in this age group. BTB autograft significantly increased the risk of kneeling pain as compared with HS regardless of age.

Keywords: ACL reconstruction; female; young; autografts

Female participation in high school sports has increased >11-fold over the past 5 decades with a resultant rise in the number of anterior cruciate ligament (ACL) injuries in female athletes.[28] The literature suggests that adolescent females are 2 to 8 times more likely to suffer a primary ACL tear than males who participate in the same sports.[1,4,14,15] Furthermore, female patients have been found to have a higher risk of rerupture after ACL reconstruction (ACLR) when compared with their male counterparts.[24] Younger patients have also been shown to be at increased risk of revision surgery after ACLR.[17,18,23]

Although ACLR has successfully restored knee stability in many athletes after ACL rupture, 35% to 45% are not able to return to their preinjury levels of sport.[3,40] Moreover, subsequent injury to either knee has been estimated to occur in >20% of younger athletes who return to sports after ACLR.[41] The optimal choice of graft tissue for ACLR remains a topic of ongoing debate. Autologous bone–patellar tendon–bone (BTB) and hamstring (HS) tendon are the 2 most commonly used grafts. Several high-quality studies have compared graft rupture rate in primary ACLR and found no significant difference between BTB and HS in the general population.[9,13,17,32,41] BTB reconstruction has been shown to provide better static stability to the knee, while HS constructs have demonstrated a lower risk of postoperative complications, pain, and osteoarthritis.[1,20,31,33,37,42]

Considering that young age and female sex are factors known to pose a risk to the survival of ACL grafts, it is

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surprising that there is a paucity of literature comparing graft failure rates after ACLR with BTB versus HS in young female athletes. The aim of the current study is to compare the rate of subsequent knee injury and subjective satisfaction in young female patients who underwent ACLR at our institution with BTB and HS autografts.

METHODS

Institutional review board approval was obtained before the inception of our study. Female patients aged 15 to 25 years who underwent primary ACLR at our institution between January 2012 and May 2015 with either BTB or HS autograft were included in our study. Patients were further divided into 2 age groups: 15 to 20 years and 21 to 25 years. Patients with a history of injury to either knee, those with multiligament knee injury, and patients with <2 years of follow-up were excluded from our analysis.

Thirteen fellowship-trained sports surgeons at a single institution were included in this study. Graft choice between BTB or HS autograft was at the discretion of the patient after a thorough discussion with the operating surgeon. ACL graft, HS graft diameter, femoral tunnel drilling technique, and fixation method were documented from a review of operative records.

A standard rehabilitation regimen was prescribed to all patients regardless of the ACL graft that they received. This included a hinged knee brace locked in extension for the first 3 weeks, which was subsequently unlocked to 0° to 90° through weeks 4 to 6. Physical therapy was initiated on postoperative day 10 and involved progressive range of motion and strengthening through the use of gentle stretching, isometrics, resistance, and stationary biking. After 3 months, patients began inline running with the use of a sports brace, and pivoting/agility drills were introduced 4.5 months postoperatively. Patients underwent a functional assessment at 6 months and started sport-specific training. Return to sports occurred anywhere from 6 to 8 months after surgery, and use of the sports brace was encouraged for 1 year.

After a minimum period of 2 years after ACLR, patients who were willing to participate were evaluated with a comprehensive physical examination and administration of the International Knee Documentation Committee (IKDC) evaluation form. Patients who were not available for complete clinical evaluation were contacted by phone and/or email to inquire about any subsequent injuries that were treated outside our institution or those in which medical evaluation was not sought.

TABLE 1
Patient Characteristics[a]

	BTB	HS	*P* Value
Women, n	175	81	
Age, y	18.5 ± 2.96 (15-25)	18.4 ± 2.77 (15-25)	.8
15-20	140 (80)	63 (77.8)	
21-25	35 (20)	18 (22.2)	
Follow-up, y	3.7 ± 0.62 (2.6-5.3)	3.7 ± 0.61 (2.7-5.4)	≥.99
Surgery within 3 mo of injury	155 (88.6)	72 (88.9)	.98

[a]Values are presented as n (%) or mean ± SD (range). BTB, bone–patellar tendon–bone; HS, hamstring.

Comparisons of frequency counts for categorical data were made with the chi-square test. In analyzing continuous data, the independent *t* test was used for comparisons. Statistical significance was set at $P < .05$.

RESULTS

Patient Characteristics

A total of 256 females were included in our review, with 175 in the BTB group and 81 in the HS group. There was no difference between the groups with regard to age or time to follow-up. In 96.5% of patients, ACL rupture was sustained during participation in athletic activity. The most commonly cited sports included soccer (33.6%), basketball (16.0%), lacrosse (12.9%), field hockey (5.5%), cheerleading (4.7%), and gymnastics (4.7%). Surgery was performed within 3 months of injury in 88.6% and 88.9% of patients in the BTB and HS groups, respectively. Eighty percent of the BTB group and 77.8% of the HS group were between the ages of 15 and 20 years (Table 1). In total, 68% of patients were available at final follow-up (mean, 3.7 years), including 71.4% of patients in the BTB group and 60.5% in the HS group.

Surgical Technique

Interference screw fixation was used in all BTB cases and 63% of HS cases. In the remainder of HS cases, femoral suspension and tibial screw (27.2%) and femoral pins and tibial screw (9.9%) were used. Biocomposite interference screws were used in all HS cases. In the BTB group, 70.8% of grafts were fixed on both sides with biocomposite interference screws; 16% were secured with metal interference screws

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on both sides; and the remainder had metal screw fixation on the femoral side and a bioabsorbable screw on the tibial side. Anteromedial tunnel drilling was utilized in 64% of BTB cases and 86.4% of HS cases. Transtibial tunnel drilling was employed in the remainder of cases. Fixation method, screw type, and drilling technique did not have a statistically significant effect on failure rates or complications in our study.

HS grafts were augmented with allograft tissue in 18 cases (22.2%), owing to inadequate size of the autograft (mean ± SD, 6.98 ± 0.41 mm; range, 6.0-7.5 mm). The choice of allograft was semitendinosus tendon in 10 cases, tibialis anterior tendon in 5 cases, and gracilis tendon in the remaining 3 patients. After augmentation, the mean diameter of hybrid grafts was 9.54 ± 0.52 mm (range, 9.0-10 mm). Of the 63 HS cases with autograft alone, the mean diameter was 8.22 ± 0.76 mm (range, 7.0-10.5 mm). As a general guideline, HS grafts <8 mm in diameter were deemed inadequate in size and were augmented with allograft tissue by most surgeons included in our study. However, 8 patients with a graft diameter <8 mm (7.5 mm, n = 5; 7.0 mm, n = 3) did not receive allograft augmentation. Interestingly, no complications were observed in this group at final follow-up.

Return to Sports

In total, 67.2% of patients returned to their preinjury levels of athletic activity. No significant differences were identified when this rate was compared between the BTB (67.5%) and HS (66.7%) groups or the younger (67.5%) and older (66.0%) groups. In the BTB group, 67.9% of patients aged 15 to 20 years returned to their preinjury levels of sport activity as compared with 65.7% of patients aged 21 to 25 years. Within the HS group, identical rates were observed in both age groups (66.7%).

Graft Failure

Graft rupture occurred in 12 of 175 (6.9%) BTB cases and 11 of 81 (13.6%) HS cases ($P = .09$). Allograft augmentation was used in 4 of the 11 HS grafts that ruptured ($P = .26$). Contralateral ACL tear occurred in 7.4% of BTB cases and 6.2% of HS cases ($P = .72$) (Table 2). Subgroup analysis showed that 75% of BTB and 100% of HS graft tears occurred in females aged 15 to 20 years. Within this group, there was a significant decrease in graft tears in the BTB group (6.4%) as compared with the HS group (17.5%, $P = .02$) (Table 3). After HS reconstructions that were augmented with allograft were eliminated (Table 4), the difference in rerupture rate between BTB (6.4%) and HS (15.6%) in the 15- to 20-year age group was not statistically significant ($P = .06$). In the 21- to 25-year age group, graft rupture occurred in 8.6% of patients who underwent BTB reconstruction, as opposed to none in the HS group. However, this difference did not reach statistical significance ($P = .21$).

Among the 11 graft ruptures in the HS group, 8 were sustained during the same sport activity as the primary injury; 1 occurred in a different sport at the same level of competition; and 2 were the result of a fall or jump unrelated to sports. Similarly, 9 of the 12 graft failures in the BTB group were sustained in the same sport; 2 occurred in a different sport at the same level; and 1 was unrelated to participation in sports. The rate of return to previous level of athletic activity did not differ significantly between groups based on age or ACL graft.

TABLE 2
Reinjuries[a]

	BTB (n = 175)	HS (n = 81)	*P* Value
Graft rupture	12 (6.9)	11 (13.6)	.09
Femoral tunnel drilling technique			.75
Anteromedial	7 of 112 (6.25)	10 of 70 (14.29)	
Transtibial	5 of 63 (7.94)	1 of 11 (9.09)	
Contralateral ACL rupture	13 (7.4)	5 (6.2)	.72
Meniscal tear	2 (1.1)	3 (3.7)	.17
Collateral ligament injury	2 (1.1)	1 (1.2)	.95
Patellofemoral chondromalacia	3 (1.7)	0	.24
Arthrofibrosis	6 (3.4)	4 (4.9)	.57
Patellar tendinitis	2 (1.1)	0	.34

[a]Values are presented as n (%). ACL, anterior cruciate ligament; BTB, bone–patellar tendon–bone; HS, hamstring.

TABLE 3
Reinjuries by Age Group[a]

Age: Injury	BTB	HS	*P* Value
15-20 y	140	63	
Graft rupture	9 (6.4)	11 (17.5)	**.02**
Contralateral ACL rupture	12 (8.6)	5 (7.9)	.89
21-25 y	35	18	
Graft rupture	3 (8.6)	0	.21
Contralateral ACL rupture	1 (2.9)	0	.47

[a]Values are presented as n (%). Bold indicates $P < .05$ ACL, anterior cruciate ligament; BTB, bone–patellar tendon–bone; HS, hamstring.

Meniscal Injuries

Seventy-four patients in the BTB group (42.3%) had a concomitant meniscal injury, 42 (56.8%) of which were amenable to meniscal repair at the time of primary ACLR. The remaining 32 meniscal tears were treated with partial meniscectomy. In the HS group, 44 patients (54.3%) had a concomitant meniscal injury. Of these, 29 (65.9%) were repaired, while the remaining 15 underwent partial meniscectomy. Meniscal repair failure, defined as a surgical procedure addressing the meniscus repaired at the index surgery, was identified in 16.7% and 27.6% of cases in the BTB and HS groups, respectively ($P = .38$). After elimination of patients whose failed meniscal repair was found during revision ACL surgery after graft rupture, a significant decrease in isolated meniscal repair failures was observed in the BTB group (2.4%) as compared with the HS group (20.7%) ($P = .041$). In the younger age group (15-20 years), BTB was associated with a lower incidence of total (14.3% vs 35%, $P = .036$) and isolated (3.2% vs

TABLE 4
Hamstring Graft Diameters

	Total (n = 81)	Failed (n = 11)	Did Not Fail (n = 70)	*P* Value
Autograft (n = 63)	8.22 ± 0.76 (7-10.5)	8.44 ± 0.62 (8-9.5)	8.17 ± 0.79 (7-10.5)	.38
Hybrid (n = 18)	9.54 ± 0.52 (9-10)	9.42 ± 0.49 (9-10)	9.58 ± 0.54 (9-10.5)	.5

[a]Values are presented as mean ± SD, mm, unless otherwise specified.

TABLE 5
Failed Meniscal Repair[a]

	BTB	HS	*P* Value
Total			
Meniscal repairs at initial surgery	42	29	.053
Isolated meniscal repair failures	1 (2.4)	6 (20.7)	**.041**
All meniscal repair failures[b]	7 (16.7)	8 (27.6)	.38
Age, 15-20 y (n = 203)			
Meniscal repairs at initial surgery	31	20	.16
Isolated meniscal repair failures	1 (3.2)	6 (30)	**.011**
All meniscal repair failures[b]	3 (14.3)	7 (35)	**.036**
Age, 21-25 y (n = 53)			
Meniscal repairs at initial surgery	11	9	.23
Isolated meniscal repair failures	0	0	≥.99
All meniscal repair failures[b]	4 (36.4)	1 (11.1)	.19

[a]Values are presented as n (%). Bold indicates $P < .05$. BTB, bone–patellar tendon–bone; HS, hamstring.
[b]Including failures that occurred with concomitant anterior cruciate ligament graft rupture.

30%, $P = .011$) meniscal repair failure as compared with the HS group. Of note, 5 of the 7 failures in the younger HS group were allograft-augmented reconstructions (Table 5).

Clinical Evaluation

Among patients who were available at final follow-up and did not sustain a subsequent graft rupture, 62.3% with a BTB graft and 78.9% with an HS graft underwent comprehensive clinical evaluation at least 2 years postoperatively. The mean time to clinical follow-up was 2.4 years (range, 2.1-4.9) in the BTB group and 2.5 years (range, 2.0-4.2) in the HS group. One patient in the BTB group was found to have a 1A Lachman but a negative pivot shift 2.1 years postoperatively (Table 6). In the HS group, 1 patient with a 7.5-mm nonaugmented HS graft had a 1A Lachman and a pivot-shift glide 2.7 years after the index procedure. Nine patients in the BTB group (12.6%) and 4 patients in the HS group (13.3%) were unable to achieve full extension ($P = .92$).

Patient-Reported Outcomes

We found no significant difference between groups when comparing patient-reported outcome measures, with mean IKDC scores of 86.7 and 86.9 in the BTB and HS groups, respectively (Table 7). However, we did observe a significantly increased incidence of kneeling pain in the BTB group as compared with the HS group. According to IKDC item 9c, 15 patients in the BTB group versus 1 in the HS group experienced extreme difficulty or were unable to kneel on the front of their knee ($P = .041$). A significantly larger proportion of patients in the HS group (65.3%) experienced no difficulty at all when kneeling on the front of the knee as compared with the BTB group (39.2%, $P = .002$).

DISCUSSION

The results of our study indicate that ACLR with BTB leads to fewer graft ruptures when compared with HS after ACLR in female patients aged 15 to 20 years. However, this difference was not observed in women aged 21 to 25 years. This is consistent with the results of a recent multicenter study that found younger age to be a predictor of subsequent ACL surgery after primary ACLR.[17] This trend was also detected in a study by Persson et al[29] in which a 2.3-fold increased risk of revision surgery after ACLR was noted with HS as compared with BTB reconstruction and the largest difference existed in the youngest subgroup of patients (15-19 years). Several studies have linked lower age to a greater risk of graft failure in ACLR with HS autograft.[17,18,23,25] These studies also implicated smaller HS graft diameter as a predictor of graft failure after ACLR, and females are known to have smaller HS tendon graft diameters than males.[7,38] While no difference in graft failure rate has been identified in high-quality studies comparing BTB and HS autograft in the general population,[9,13,17,32,41] separate analyses in young female athletes are warranted owing to unique factors that place them at increased risk of reinjury.[5,7,11,22,38] To our knowledge, the only comparison of ACLR outcomes with BTB versus HS specific to young female patients found an increased risk of graft failure in HS reconstructions.[34] This finding with the results of our study may indicate that BTB autograft is the superior choice for ACLR in female patients <21 years of age.

In the current study, we identified no significant differences in reinjury rates among patients aged ≥21 years. It must be noted, however, that these findings carry a risk of type II error, owing to the smaller proportion of patients within this age group. Magnussen et al[23] found that, similar to the results of our study, only 0.7% of patients aged ≥21 years required revision surgery after ACLR with HS autograft, as opposed to 14.3% in patients aged <21 years ($P < .0001$). Thus, HS autograft may be a suitable choice in women

TABLE 6
Objective Outcomes[a]

	Lachman		Pivot Shift		Loss of Extension		Loss of Flexion	
Graft	Result	n (%)	Result	n (%)	Result	n (%)	Result	n (%)
BTB (n = 71)	1A	2 (2.8)	—	—	0°-5°	9 (12.6)	—	—
HS (n = 30)	1A	1 (3.3)	1+	1 (3.3)	0°-5°	2 (6.6)	5°-10°	1 (3.3)
					6°-10°	2 (6.6)		

[a]BTB, bone–patellar tendon–bone; HS, hamstring.

TABLE 7
Subjective Outcomes[a]

	BTB (n = 125)	HS (n = 49)	*P* Value
IKDC score	86.7 ± 10.57	86.9 ± 10.06	.91
Kneeling pain[b]			
Unable to do	7 (5.6)	0	**.041**
Extremely difficult	8 (6.4)	1 (2)	
Moderately difficult	20 (16)	5 (10.2)	.33
Minimally difficult	41 (32.8)	11 (22.4)	.18
Not difficult at all	49 (39.2)	32 (65.3)	**.002**

[a]Values are presented as mean ± SD or n (%). Bold indicates $P < .05$. BTB, bone–patellar tendon–bone; HS, hamstring; IKDC, International Knee Documentation Committee.

[b]Responses from item 9c of the IKDC subjective evaluation form.

aged 21 to 25 years, but further investigation regarding optimal graft choice is warranted in this age group.

After exclusion of HS reconstructions that were augmented with allograft, the difference in failure rate between BTB and HS in the younger age group was rendered not statistically significant. Although our study was not powered to detect a difference between these groups, this finding is consistent with the results of recently published literature. Burrus et al[8] found that allograft-autograft hybrid HS ACL grafts fail at a higher rate than HS autograft alone. Moreover, HS grafts >8 mm have been found to decrease failure rates, particularly in patients aged <20 years.[10] Going forward, younger patients with HS grafts that are of small diameter should probably not undergo augmentation, and perhaps an alternative graft source should be sought. In our series, no graft ruptures were identified among the nonaugmented HS grafts that were 7 or 7.5 mm in diameter.

We identified a significant increase in meniscal repair failures in the HS group versus the BTB group. Among the 7 meniscal repair failures in HS patients aged <21 years, 5 occurred in patients with a hybrid allograft-autograft reconstruction. Shakked et al[34] found significantly increased side-to-side knee laxity in young female patients who underwent ACLR with HS versus BTB. Furthermore, allograft-augmented HS grafts have been shown to result in increased knee laxity when compared with autograft HS alone.[43] The ACL is the primary restraint to anteroposterior and rotational knee laxity, and the medial and lateral menisci serve as secondary knee stabilizers in these respective directions.[6,12,21,26,27,35,36,39] Intuitively, a graft that provides less stability than the native ACL may subject the menisci to increased strain and thus create a suboptimal environment for a repair to heal adequately. This notion is supported by a biomechanical investigation that found ACL insufficiency to increase strain placed on the medial meniscus in knees resisting an anterior tibial load.[2] A previous comparison of hybrid versus autograft HS found an increased risk of meniscal repair failure with hybrid ACLR.[8] Because younger age and female sex have been linked to a smaller HS graft diameter,[25,38] these results should be considered when choosing an ACL graft for young female patients with repairable meniscal tears.

In addition to preservation of the reconstructed ACL, patient satisfaction and residual pain must be taken into account when selecting the most appropriate graft tissue, particularly in patients who do not wish to return to high-risk sports. We found a significant increase in kneeling pain after ACLR with BTB as compared with HS, which is consistent with the results of numerous studies.[16,19,30,31,37] Studies that evaluated the long-term outcomes of ACLR found HS reconstruction to be advantageous over BTB with regard to harvest site morbidity and postoperative radiographic osteoarthritis.[30,31] Accordingly, BTB graft harvest should be avoided in patients who frequently work, exercise, or pray on their knees.

The current study exhibits several strengths. We utilized a consecutive series of patients to help minimize selection bias. Fellowship-trained sports medicine orthopaedic surgeons operated on all patients in our study. Our results provide data on a high-risk patient population that is growing steeply over time and yet is underrepresented in the current literature.

Our study, however, is not without limitations. We performed a retrospective review, and as such, it carries inherent shortcomings. The selection of patients for BTB and HS autografts was not randomized and may have been subject to selection bias. Because it is not a single-surgeon study, differing surgical techniques may have contributed to our results. In addition, several of the HS autografts were performed with allograft supplementation, which may have contributed to a higher failure rate. Finally, a low follow-up rate and differential losses to follow-up could have introduced bias to our results.

CONCLUSION

The results of our study indicate that ACLR with BTB autograft leads to a lower rate of graft rupture when compared with HS autograft in females between 15 and 20 years of age. This trend, however, was not observed in females aged 21 to 25 years. Further large-scale studies investigating the optimal graft choice in this age group are warranted.

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