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Comparison of Clinical Outcomes, Revision Rates, and Sports Participation Between Hamstring and Quadriceps Tendon Autografts for Anterior Cruciate Ligament Reconstruction in Pediatric and Adolescent Patients: A Retrospective Cohort Study

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23 April 2026

No Difference in Clinical Outcomes, Revision Rates, and Sports Participation Between Hamstring and Quadriceps Tendon Autografts for ACL Reconstruction in Pediatric and Adolescent Patients: A Prospective Cohort Study

Abstract

Background

In recent years, anterior cruciate ligament (ACL) injuries in children and adolescents (age ≤ 18 years) have been increasing.

Purpose

The purpose of this study was to compare the outcomes of hamstring graft (HT) and quadriceps tendon (QT) autografts for ACL reconstruction in pediatric and adolescent patients (age ≤ 18 years) in terms of patient-reported functional outcomes (PROMs), knee stability, concomitant injuries, graft failure rates and sports participation after ACL reconstruction.

Methods

From 2010 to 2022, 2417 ACL reconstructions were performed. The inclusion criteria were primary ACL reconstruction using HT and QT autograft, age ≤ 18 years. The exclusion criteria were revision ACL reconstruction, utilization of graft tissue other than HT and QT autograft, concomitant posterior cruciate ligament (PCL) injuries, contralateral knee injuries and conditions that might interfere with the standard postoperative rehabilitation protocol. A minimally invasive technique was used for QT autograft harvesting. Patients were evaluated for pre-injury and 2-year follow-up for Lysholm knee score, Tegner activity level and VAS (visual analogue scale) for pain; knee stability (Lachman and pivot shift test); concomitant injuries, graft failure and sports participation. Lachman test and pivot shift test were recorded pre-operatively under anesthesia and post-operatively at a 2-year follow-up.

26 **Results**

27 The number of patients in the HT and QT groups was 77 and 80 respectively. The two groups
28 did not differ significantly in terms of age, gender and concomitant injuries. No significant
29 difference was found in the pre-injury PROMs (Lysholm, Tegner activity level and VAS for
30 pain) and knee stability between the two groups (p>0.05). Similarly, no significant difference
31 was observed at 2 years of follow-up between the two groups for PROMs and knee stability
32 (p>0.05). Lysholm knee score, Tegner activity level and VAS for pain score improved to pre-
33 injury level in both the groups and no significant difference was found between pre-injury
34 and 2-year follow-up for Lysholm, Tegner and VAS scores (p>0.05). At a 2-year follow-up
35 both the groups achieved pre-injury level sports participation (p>0.05). Graft failure occurred
36 in 11 (14%) and 8 (10%) patients of the HT and QT groups respectively. The rate of failure
37 did not differ significantly between groups (p>0.05).

38 **Conclusion**

39 Quadriceps tendon autograft for ACL reconstruction led to similar clinical outcomes, revision
40 rates, and sports participation compared to Hamstring in pediatric and adolescent patients.

41 **Level of evidence**

42 Level II

43 **What is known about the subject:** Conservative management of ACL injuries in the
44 pediatric and adolescent patient population may result in persistent instability and this can
45 predispose strongly to meniscal damage and cartilage degeneration. With the availability of
46 better instrumentation and a better understanding of ACL reconstruction with advances in
47 surgical techniques, ACL reconstructions have been performed in this age group with good
48 results, with the restoration of anterior knee stability and resumption of pre-injury activity.

49 **What this study adds to existing knowledge:** Arthroscopic ACL reconstruction by using
50 HT or QT autograft in pediatric and adolescent patients provides satisfactory patient-reported

51 functional outcomes and allows recovery of the pre-injury level of activity. Both HT and QT

52 autograft are acceptable graft options in this age group.

53

54 **Introduction**

55 In recent years, anterior cruciate ligament (ACL) injuries in children and adolescents (age ≤
56 18 years) have been increasing [4,26,34,42]. The factors responsible for this increase are increased
57 participation in high-level competitive sports, year-round training and sports specialization [26].
58 Historically, ACL injuries in this population have been managed nonoperatively with
59 bracing, physical therapy, and activity modification [12]. However, poor outcomes in the form
60 of increased instability, irreparable meniscal tears, chondral injuries and inability to return to
61 previous activity levels have been reported with non-operative treatment [23,38]. The Knee
62 Anterior Cruciate Ligament, Nonsurgical versus Surgical Treatment [KANON] Study [8(p1)]
63 also showed a high rate of surgery in the patients who initially managed non-operatively. The
64 non-operative group did not achieve the same Tegner activity as compared to the operative
65 group and non-operative management is less likely to allow to get back to pre-injury sports
66 activity. Improvement in surgical techniques and good post-operative functional outcomes
67 reported in various recent studies [3,12,13]. Therefore, ACL reconstruction with autograft is the
68 treatment of choice for pediatric and adolescent ACL injuries.

69 Although over 90% of children and young athletes return to sports after ACL reconstruction
70 [7,21], a significantly higher incidence of graft failure is reported in adolescents and children
71 compared to adult patients [6,25,35]. Many factors are responsible for higher failure rates in the
72 pediatric and adolescent population, such as lower compliance with rehabilitation protocols,
73 higher activity levels, and higher anxiety levels [1,6].

74 Graft choice also affects functional outcomes and graft failure [2,37]. Allografts should not be
75 used in pediatric patients, since the use of allografts in pediatric ACL reconstruction has poor
76 clinical outcomes [20,41]. Traditionally, HT is the most commonly used graft [2,37]. But recently
77 STABILITY 1 trial [10] and other studies [19,43] may cast doubt on using this autograft (in
78 isolation) for at-risk athletes (ligamentous laxity, younger age, increased tibial slope, high-

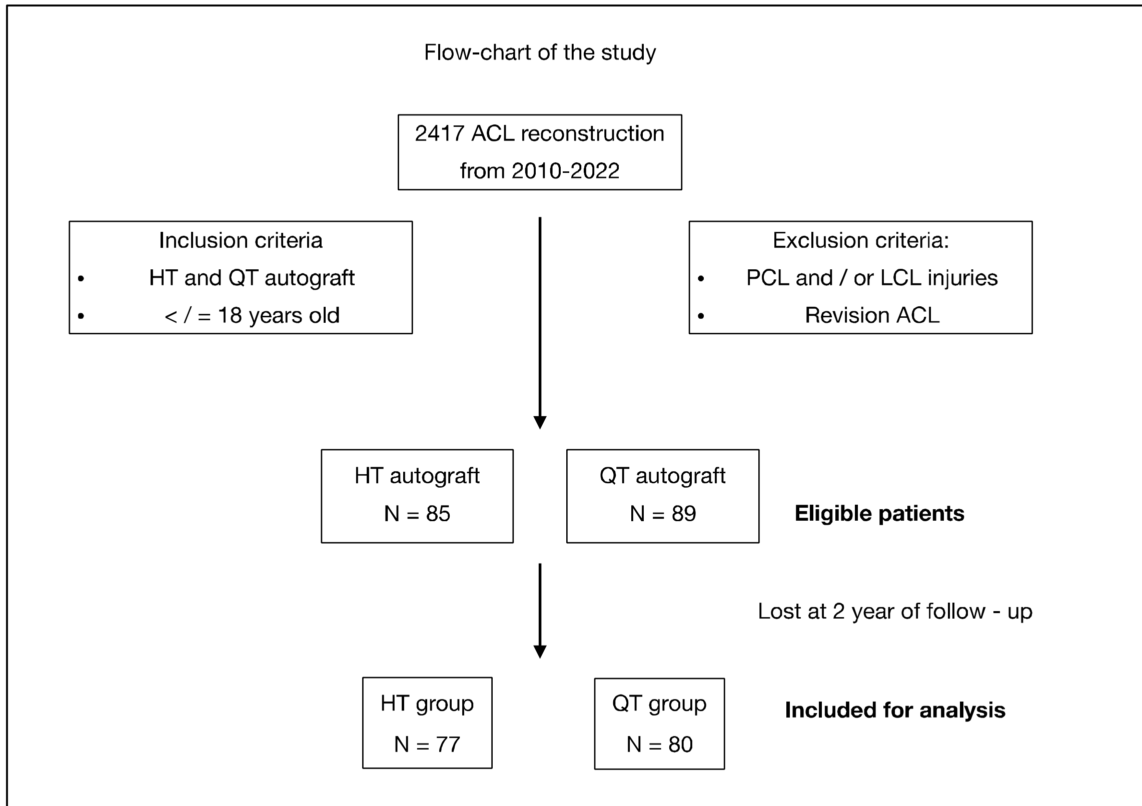
79 grade pivot shift, and early return to sport). Moreover, HT autograft may cause sensory
80 deficits due to the injury to the saphenous nerve, compromise medial stability of the knee,
81 and also cause weakness of knee flexion and internal rotation [16,17]. On the other hand, QT
82 autograft is gaining popularity for ACL reconstruction [12,27–31,37,40,44] because QT autograft is
83 associated with lower donor site morbidity [32], lower failure rate [37], greater mean cross-
84 sectional area and greater load to failure [24,33] compared to HT autograft. Therefore, QT
85 autograft for ACL reconstruction in adolescents and pediatric athletes seems a logical choice.
86 However, there is no consensus regarding the graft choice for ACL reconstruction in these
87 young patients.
88 There has been a paucity of literature comparing the functional outcomes of HT and QT
89 autograft in ACL reconstruction in patients aged ≤ 18 years. Therefore, the current study
90 aimed to compare the outcomes of HT and QT autografts for ACL reconstruction in pediatric
91 and adolescent patients in terms of PROMs, knee stability, concomitant injuries, graft failure
92 rates and sports participation after ACL reconstruction. Considering the different structural
93 properties of QT autograft, we hypothesize that QT autograft would result in better functional
94 outcomes with a good rate of return to sporting activity and low graft failure after ACL
95 reconstruction compared to HT autograft in this population.

96 **Material and methods**

97 The study design has been reported in **Figure 1**. The study was conducted according to the

98 Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.

99 **Figure 1.** Flow-chart of the study



115 criteria were revision ACL reconstruction, utilization of graft tissue other than HT and QT

116 autograft, concomitant posterior cruciate ligament (PCL) injuries, contralateral knee injuries

117 and conditions that might interfere with the standard postoperative rehabilitation protocol.

118 Preoperatively, a magnetic resonance imaging (MRI) was performed to confirm ACL rupture

119 and to assess associated injuries. Concomitant cartilage, meniscus or ligament injuries were

120 documented based on the pre-operative clinical examination, MRI scan and intraoperative

121 diagnostic arthroscopy findings. Plain radiographs (anteroposterior and lateral view) were
122 obtained to exclude any bone injury and to evaluate the status of physis. From the analysis of
123 medical records, 90 and 95 patients underwent ACL reconstruction with HT and QT autograft
124 respectively. At 2 years of follow-up, patients were contacted by phone to perform a new
125 clinical assessment. Eight patients (9.4%) in the HT group and nine patients (10.1%) have
126 been lost at 2 years of follow-up. Therefore, HT and QT groups consisted of respectively 77
127 and 80 patients. The majority of the patients were operated on within 1 week of ACL injury
128 and during this period patients were unable to do any sports activities. Moreover, during the
129 acute phase of injury due to swelling and pain; functional outcomes may not be reliable.
130 Therefore, the patient-reported pre-injury scores were recorded and used as a baseline rather
131 than a pre-operative score. Patients were specifically asked to fill out the questionnaire
132 considering their pre-injury state during the first week after surgery for the baseline
133 functional scores. Similarly, patients were evaluated at 2-year follow-up for Lysholm knee
134 score, Tegner activity level and VAS (visual analogue scale) for pain; concomitant injuries,
135 graft failure and sports participation. Sports participation was evaluated by a direct question.
136 For the stability testing Lachman test and pivot shift test were recorded pre-operatively under
137 anesthesia and post-operatively at follow-up visits at our clinic. As regards to pivot shift test,
138 the International Knee Documentation Committee (IKDC) classification defined the pivot
139 shift test as follows: grade 0 (normal), grade 1 (glide), grade 2 (clunk), or grade 3 (locked
140 subluxation) [14].
141 Graft failure was defined in case of reported subsequent surgery, clinical examination and/or
142 MRI with graft rupture. Patients with graft failure were also excluded from the analysis of
143 PROM scores.
144 *Surgical technique*

145 All surgeries were performed under general anesthesia by two fellowship-trained knee
146 surgeons. Trans-physeal anatomic ACL reconstruction or all-epiphyseal technique was used
147 according to age and Tanner stage. Diagnostic arthroscopy was performed to evaluate
148 concomitant injuries. The remnant of torn ACL was removed and concomitant injuries were
149 addressed individually. Anatomic placement of the tibial and femoral tunnel was made
150 through an anteromedial portal, graft diameter and tunnel diameter were equal in size. A
151 bioabsorbable interference screw (the same size as the tibial tunnel) or tibial button were used
152 for distal fixation of the graft while a fixed cortical suspensory fixation button was used for
153 graft fixation at the femoral cortex.
154 The selection of the graft was not randomized. Graft selection was based on a shared
155 decision-making approach after consultation with the surgeon, reviewing the risks, benefits,
156 and alternatives as well as post-operative rehabilitation implications of both options. A
157 minimally invasive technique was used for QT autograft harvesting as described by Fink et al
158 [9]. For HT autograft quadrupled semitendinosus alone was used primarily, but if the thickness
159 of the graft < 6.5 mm or the length of the graft < 6.5 cm then it was augmented with gracilis
160 tendon. A round trans-physeal tunnel was made in the tibia and femur.
161 *Rehabilitation*
162 A similar rehabilitation protocol was used in both groups. The immediate focus was to
163 control pain and achieve full extension of the knee. After surgery, patients were admitted for
164 2 days and during this time pain management and mobilization training was administered.
165 Thereafter, all patients followed outpatient physiotherapy for at least 3 months. Partial
166 weight-bearing and knee flexion up to 90^0 was allowed with a knee brace for an initial 2
167 weeks. After two weeks weight and range of motion were gradually increased as tolerated by
168 the patients.

The study was performed at Gelenkpunkt – Sports and Joint Surgery, FIFA Medical Centre of Excellence and approved by the ethics committee of the Medical University of Innsbruck (AN2015-0050).

Statistical analysis

A priori power analysis was performed to determine the appropriate sample size for the study. Considering an α level with $p = 0.05$, a power of 80%, and an effect size of 0.5 it was estimated that 51 subjects would be needed to detect a statistically significant difference in Lysholm knee score. The sample size calculation was performed with the use of the G-Power software (G-Power version 3.1, Düsseldorf, Germany).

Data were collected using an Excel sheet (Microsoft, Redmond, WA, USA). Categorical variables were expressed in numbers and percentages (%). Continuous variables were expressed by average and standard deviation (SD) or interquartile range (IRQ) according to their distribution. The normal distribution of variables was verified through the Shapiro–Wilk test. Variables were not normally distributed; therefore, nonparametric tests were used for the comparison of variables. Specifically, the Mann-Whitney test was used for unpaired samples, whereas Kruskal Wallis tests with Bonferroni correction were used for analyzing variables over time. The exact Fisher test was used to determine differences in nominal data between groups. Clinical relevance and significance were evaluated through the minimal clinically important difference (MCID). The MCID of Lysholm and Tegner were set respectively to 16.3 and 1.4 MCID has been calculated by 0.5*SD of differences between post- and pre-operative values [11].

A p-value less than 0.05 was indicative of statistically significant differences. The statistical analysis was performed with XLSTAT (Addinsoft SARL) software packages.

192 **Results**

193 Demographic details and characteristics of the study population are summarized in **Table 1.**

194 **Table 1.** Patient's characteristics and associated injuries. ‡: Mann-Whitney test, § exact

195 Fisher test if not specified.

		QT (N= 80)	HT (N=77)	p-value§
Age				
	mean (SD), [range]	15.4.7 (2.5) [7.0-18]	14.9 (2.6) [7 – 18]	0.28‡
	Median (IQR, 1 – 3 qt)	16.1 [3.6, 13.8 – 17.4]	15.2 [3.3, 13.6 – 16.9]	
Gender, male/female N. (%)		28 (35%) / 52 (65%)	49 (63.6%) / 28 (36.4%)	0.87
Isolated ACL Reconstruction N (%)		43 (54%)	51 (66%)	0.14
Concomitant Injuries		37 (46%)	26 (34%)	
Meniscal injuries		34 (43%)	22 (29%)	0.10
	Medial	16 (20%)	11 (14%)	0.40
	Lateral	18 (23%)	15 (20%)	0.70
	Meniscal Repair	32 (40%)	23 (30%)	1.0
	Meniscectomy	5 (6%)	3 (4%)	
Cartilage Lesions, N (%)		1 (1%)	2 (3%)	0.62
MCL injuries (treated with repair)		2 (3%)	2 (3%)	1.00

196

197 The number of patients in the HT and QT groups was 77 and 80 respectively. The two groups
198 did not differ significantly in terms of age, gender and concomitant injuries. No significant
199 difference was found in the pre-injury PROMs (Lysholm, Tegner activity level and VAS for
200 pain) and knee stability between the two groups (p>0.05). Similarly, no significant difference
201 was observed at 2 years of follow-up between the two groups for PROMs and knee stability
202 (p>0.05) (**Table 2**).

203 **Table 2**. Patients reported outcomes measures for QT and HT graft. Data are expressed as
204 median and Interquartile range. ‡: Mann-Whitney test; §: Kruskal-wallis test.

	Baseline		2 years FU		
Lysholm knee score	HT graft (n = 77)	QT graft (n = 80)	HT graft (n =77)	QT graft (n = 80)	P value§
Mean (SD) [range]	93.2 (17.8) [0-100]	92.8 (15.4) [18-100]	92.5 (14.3) [0-100]	88.9 (19.9) [0-100]	0.06
Median (IQR, 1 -3 qt)	100 (5, 95 – 100)	100 (5.2, 94.8 -100)	99 (10.7, 89.3 – 100)	95 (14, 86 - 100)	0.06
P value‡	0.788		0.101		
Tegner Activity level score					
Mean (SD) [range]	7.0 (1.9) [1-10]	7.0 (1.6) [2-10]	6.9 (2.1) [1-10]	6.7 (1.8) [0-10]	923
Median (IQR, 1 -3 qt)	7 (2, 6-8)	7 (2, 6-8)	7 (2, 6-8)	7 (2, 6-8)	0.346
P value‡	0.588		0.336		
VAS					
Mean (SD)	0.7 (1.7) [0-	1.2 (2.1) [0-8]	0.6 (1.1) [0-5]	0.7 (1.2) [0-	0.624

	[range]	8]			6]	
	Median (IQR, 1 -3 qt)	0 (1, 0-1)	0 (1, 0-1)	0 (1, 0-1)	0 (1, 0-1)	0.451
P value‡		0.069		0.463		

205

206 Lysholm knee score, Tegner activity level and VAS for pain score improved to pre-injury

207 level in both the groups and no significant difference was found between pre-injury and 2-

208 year follow-up for Lysholm, Tegner and VAS scores (p>0.05). At a 2-year follow-up both the

209 groups achieved pre-injury level sports participation (p>0.05) (**Table 3**).

210

211 **Table 3.** Comparison of sports participation of study subjects preoperatively, and 2-year

212 follow up. FU: Follow-up; HT: hamstring tendon; QT: quadriceps tendon. §: exact Fisher test.

213

Sports Participation	Baseline		2 - FU		
	HT graft (n = 77)	QT graft (n = 80)	HT graft (n =77)	QT graft (n = 80)	P value
No Sport	1 (1.3%)	2 (2.3%)	2 (2.6%)	2 (2.5%)	0.593 §
Occasionally	3 (3.9%)	5 (6.3%)	5 (6.5%)	7(8.8%)	
2 to 3 times a week	26 (33.8%)	25 (31.3%)	31 (40.3%)	36 (45%)	0.220
> 5 times a week	47 (61%)	48 (60%)	39 (50.6%)	35 (43.8%	

			)	
Intra group P value	0.904§		0.856§	

214

215 Graft failure occurred in 11 (14%) and 8 (10%) patients of the HT and QT groups

216 respectively. The rate of failure did not differ significantly between groups (p>0.05). No

217 differences have been observed in terms of Lachman test and pivot shift tests between groups

218 at baseline and follow-up **(Table 4).**

219 **Table 4.** Clinical examination of the patients before and after ACL reconstruction**.**

220

	Pre-operative	Follow-up

221

	HT (N = 77)	QT (N = 80)	HT (N = 77)	QT (N = 80)
Lachman test				
Negative	0 (0%)	0 (0%)	75 (97.4%)	78 (97.5%)
Positive	77 (100%)	80 (100%)	2 (2.6%)	2 (2.5%)
P value	1.0		1.0	
Pivot shift test				
0	0 (0%)	0 (0%)	75 (97.4%)	78 (97.5%)
1+	8 (10.4%)	6 (7.5%)	2 (2.6%)	2 (2.5%)
2+	23 (29.9%)	28 (35%)	0 (0%)	0 (0%)
3+	46 (59.7%)	46 (57.5%)	0 (0%)	0 (0%)
P value	0.692		1.00	

222 **Discussion**

223 The most important finding of the current study was that both HT and QT autografts offer
224 similar patient-reported functional outcomes, knee stability, sports participation and graft
225 failure after ACL reconstruction in pediatric and adolescent patients at 2-year follow-up. All
226 of the patients returned to their pre-injury levels of activity and engagement in sports.

227

228 The literature is sparse concerning studies examining functional outcomes of ACL
229 reconstruction using QT in the adolescent age cohort. One study [22] analyzed 15 adolescent
230 patients who had undergone an ACL reconstruction with QT autograft and at 4 years of mean
231 follow-up, the mean Lysholm score was 94. In the current study, the mean Lysholm score for
232 the QT graft group was found to be 92.8, and 88.9, pre-injury, and 24 months follow up
233 respectively and for the hamstring tendon graft group the values were 93.2, and 92.5 pre-
234 injury, and 24 months follow up respectively. These are similar to PROMs published by a
235 recent study [37], in which patients had mean Lysholm scores of 96 and 94 for quadriceps and

236 hamstring tendon groups respectively. Another study [40] conducted in 2021 amongst
237 adolescent patients which studied PROMs at 6 and 9 months postoperatively, found that there
238 was no clinically important difference in Lysholm scores at 6 and 9 months follow-up
239 between the two graft groups. In a similar study measuring the PROMs the median Pedi-
240 IKDC score was 94 and the median Lysholm score was 99.5 [12].
241 The Tegner score in the current study was 7.0 and 6.7 for pre-injury, and 24-month follow-up
242 for the QT group whereas 7.0, and 6.9 respectively preoperatively, and 24 months follow-up
243 for the HT group. The mean Tegner score was found to be 6.6 for the QT group and 7.1 for
244 the HT group at 2 years of follow-up in a recent study amongst adolescents [37], which is
245 comparable to the current study. Another study [40] found that there was a clinically important
246 difference of 1.3 in Tegner scores at 6 and 9 months follow-up. A minimum change of 1 in
247 Tegner score is required for clinical importance which is not seen in the current study. This
248 could be due to the fact that they have evaluated the scores in the period where the patient is
249 undergoing rigorous physiotherapy and returning to sports, and the change is assessed over a
250 very short span of 3 months. In the current study, all patients reported their follow-up Tegner
251 scores which were comparable to the pre-injury level.
252 The VAS for pain score was 1.2, and 0.7 pre-injury, up and 24 months follow-up up
253 respectively in the QT group and 0.7, and 0.6 pre-injury, and 24 months follow up
254 respectively in the HT group. These findings are comparable to those of Pennock et al [37] who
255 reported mean VAS scores of 0.6 and 0.9 for QT and HT groups respectively at 2 years of
256 follow-up. The similarity in the findings between the two studies is attributable to the fact
257 that appropriately timed surgical intervention in patients with ACL injuries with adequate
258 rehabilitation programs leads to pain-free knee and preinjury VAS scores at subsequent
259 follow-ups.

260 Graft failure is the most commonly encountered complication in pediatric and adolescent
261 patients who have undergone ACL reconstruction surgery. There is a wide variability in the
262 values of graft failure reported in the literature but it typically ranges from 6.7% to 21% in
263 the adolescent population [15,18,39,45]. In a recent study, the incidence of graft failure within the
264 36-month follow-up period was 1.2% for QT in the adolescent population [12]. Pennock et al [37]
265 reported a graft failure rate of 21% with HT and 4% with QT in this patient population and
266 expressed their doubts if this high graft failure rate was due to HT graft usage or the
267 physiology of the adolescent hamstring tendon tissue and bone. Some authors have implied
268 that HT have an inconsistent and smaller size in the pediatric population leading to an
269 increased incidence of graft rupture [5,36]. In the current study graft failure rate was 14% for the
270 HT group and 10% for the QT group at 2 years of follow-up and no significant difference
271 was noted in the graft failure rate between the two groups. This implies that both graft
272 choices are comparable and reliable options.
273
274 In a recent study on the adolescent population, authors observed that at 36 months after
275 surgery, 87.9% of individuals had returned to play [12]. In their meta-analysis, Kay et al [21] also
276 found over 90 % of return to sports after ACL reconstruction. Similarly, Pennock et al [37]
277 reported a high return to sports. Another systematic review has shown that ACL
278 reconstruction with QT autograft in the pediatric population preserves the possibility of
279 restoring a pre-injury level of knee stability and delivers good postoperative function and
280 rates of RTS, delivering comparable results relative to HT autograft. Findings of the current
281 study in accordance with previous literature where pre-injury level sports participation was
282 achieved by all patients in their desired sports following ACL reconstruction. Rigorous
283 physical therapy might be the reason for the high functional outcome measures and return-to-
284 sports rate in this study.

285

286 This study has some limitations. First, this study focused on patient-reported subjective
287 outcome measures and there were no objective scores as well as postoperative quadriceps and
288 hamstring strength testing. Second, small size leads to limited and underpowered statistical
289 analysis (Type II errors) and limits the generalizability of the results. Third, the follow-up
290 was short, which may lead to an underrepresentation of future complications like graft
291 rupture and future arthritis in the long term. Fourth, the selection of the graft was not
292 randomized but chosen according to the surgeon’s and patient's preferences after a detailed
293 explanation of the strengths and weaknesses of each graft. Fifth, baseline scores were taken
294 during the first postoperative week which may result in recall bias. Considering these
295 limitations, there is a need for a high-quality, global, multi-center, RCT with a large sample
296 size and longer-term follow-up to validate these findings. One of the ongoing clinical trials is
297 Soft-tissue Quadriceps Autograft ACL reconstruction in the Skeletally-immature vs.
298 Hamstrings (SQuASH) trial, which is focused on rate of reoperation, patient-reported knee
299 function, rate of return to sport, range of motion and knee stability.

300

301 Despite the limitations, the findings of the current study are important for surgeons managing
302 ACL injuries in the pediatric and adolescent populations. The results of the current study will
303 assist the surgeons and patient families in decision-making in graft selection for the
304 management of ACL injuries in young athletes.

305

306 **Conclusion**

307 ACL reconstruction using QT or HT autograft in adolescent patients has good patient-
308 reported functional outcomes, high rates of return to sports, and low graft failure rates. Based

309 on the results, both autografts are the reliable choice for ACL reconstruction in adolescent

310 patients.

311

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