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Graft type is not associated with revision ACL reconstruction in football players: a nationwide cohort analysis of subsequent ACL reconstructions

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ABSTRACT

Objective To determine whether autograft type (hamstring, patellar or quadriceps tendon) is associated with risk of revision anterior cruciate ligament reconstruction (ACLR) or contralateral ACLR in football players.

Methods Nationwide cohort included all primary ACLRs performed in registered football players in Sweden between 2014 and 2023, identified by linkage of the Swedish Knee Ligament Registry and the Swedish Football Association. Return to competition (RTC) was defined as participation in at least one official match. Outcomes were revision ACLR (index knee) and contralateral ACLR. Sex stratified, cause specific Cox models adjusted for age and pre-injury level of play (Elite, Non-elite, Youth) were used, with hamstring tendon as graft reference.

Results A total of 10 693 players were included, of whom 6238 (58%) RTC, mean age 22±7 years, mean follow up 5.2±2.9 years. Among RTC players, revision ACLR occurred in 232 women (10.8%) and in 349 (9.2%) men with no association between graft type and revision ACLR. Contralateral ACLR occurred in 263 women (12.2%) and 264 (6.9%) men. In women, quadriceps tendon was associated with a higher hazard of contralateral ACLR (HR 1.98, 95% CI 1.17 to 3.36). No graft-specific differences were seen in age-restricted sensitivity analyses or in the full cohort. Younger age and higher pre-injury level were consistently associated with greater subsequent ACLR risk.

Conclusions Graft choice was not independently associated with revision ACLR, including among young football players who RTC. An association between quadriceps tendon autograft and contralateral ACLR was observed among women. Across analyses, age and pre-injury level of play were the most consistent correlates of subsequent ACLR risk.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Younger age and return to high-level sport are consistently associated with a higher risk of subsequent anterior cruciate ligament (ACL) injury after ACL reconstruction (ACLR).

⇒ The influence of graft choice on reinjury risk remains debated, particularly in young athletes and football players.

WHAT THIS STUDY ADDS

⇒ In a nationwide cohort of more than 10 000 football players who underwent ACLR, graft choice (hamstring, patellar tendon or quadriceps tendon autograft) was not associated with the risk of revision ACLR among players who returned to competition, in either women or men.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ In football players who return to competition, these findings indicate no meaningful difference in subsequent ACLR risk between commonly used autografts. ACLR graft selection can be guided by patient characteristics, surgeon preference and other considerations beyond revision surgery risk.

INTRODUCTION

Anterior cruciate ligament (ACL) injury is common in football and carries substantial short- and long-term consequences, particularly for young players exposed to frequent cutting, pivoting and contact situations.[1] Despite advances in surgical technique and rehabilitation, the risk of a subsequent ACL injury (either graft rupture or contralateral ACL injury) remains high after ACL reconstruction (ACLR),[2] especially among players who return to competitive (RTC) football.[3 4]

Graft choice has traditionally been considered a potentially modifiable factor influencing outcomes after ACLR.[5 6] Hamstring tendon, patellar tendon and more recently quadriceps tendon autografts are all widely used in football players, but evidence comparing graft-specific risks of subsequent ACL injury remains inconsistent.[7 8] Many studies are limited by small sample sizes, heterogeneous sporting populations, short follow-up or inadequate adjustment for age, sex and level of play.[5 9–11] Importantly, few studies distinguish between all players who underwent ACLR and those who return to football, despite return to high-risk sport being a key determinant of subsequent ACL injury.[8] Separating the effects of graft choice from exposure-related factors therefore requires large, sport-specific cohorts with complete follow-up and accurate ascertainment of RTC, data that are rarely available.

Sweden provides a unique opportunity to address these limitations. By linking the Swedish Knee Ligament Registry (SKLR)[12] with the Swedish Football Association's (FA's) nationwide administrative system (FOGIS), it is possible to identify all primary ACLR in registered football players, capture actual RTC and follow players for subsequent ACLR across all levels of play. This linkage enables analyses both

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in the entire national ACLR cohort over a decade and in the clinically and biologically relevant subgroup of players who return to competitive football.

The primary aim of this nationwide cohort analysis was to compare the risk of index-knee revision ACLR between hamstring tendon, patellar tendon and quadriceps tendon autografts among football players who RTC after index ACLR. Secondary aims were to evaluate graft-specific risk of contralateral ACLR and to assess corresponding associations in the full ACLR cohort.

METHODS

Study design and data sources

This nationwide cohort analysis used prospectively collected registry data from the SKLR[12] linked with FOGIS competition system. The linkage enabled complete capture of surgical details and longitudinal football participation, including all official matches played at national team, senior, youth and cup levels. Data were extracted from both registries in April 2025.

The study was conducted in accordance with the Declaration of Helsinki.

Study population

All primary index ACLR, defined as the first ACLR for each individual, that were performed between 1 January 2014 and 31 December 2023 in registered football players were eligible. Players were identified through SKLR and linked to FOGIS using unique national personal identification numbers. All ages and all pre-injury levels of play recorded in FOGIS were eligible. Concomitant meniscal and cartilage injuries, as well as procedures such as meniscal repair, cartilage surgery or lateral extra-articular procedures (from 2018), were included as recorded in the registry.

Exclusion criteria were:

- Use of grafts other than hamstring tendon, patellar tendon or quadriceps tendon autografts.
- Associated fractures, vascular or nerve injuries.
- Associated ligament injury, defined as:
-

Injury to the posterior cruciate ligament, lateral collateral ligament or posterolateral corner, as well as complete medial collateral ligament (MCL) ruptures (grade III) or surgically treated MCL injuries.

- After exclusions, the final analytic cohort comprised n=10 693 primary index ACLRs.

Surgical variables

Graft type was categorised as:

- Hamstring tendon autograft (reference).
- Patellar tendon autograft,
- Quadriceps tendon autograft

Hamstring tendon autografts included semitendinosus alone or semitendinosus combined with gracilis, in any configuration. Quadriceps tendon autografts were included with or without a bone block. Patellar tendon autografts (bone–patellar tendon–bone) were also eligible. Only the index ACLR was considered for each individual.

Football participation and level of play

Pre-injury level of play for those with available data was classified according to established definitions used in prior SKLR studies[13 14] and further categorised into Elite (Top and High), Non-elite adult (Middle, Low and Recreational) and Youth levels. Initial finer classifications were collapsed due to sparse events in some strata; this simplification did not materially affect model estimates.

RTC was defined as participation in ≥1 official football match after the index ACLR at any level. Verification of RTC was performed in FOGIS, the Swedish FA's nationwide competition administration system capturing official match rosters and results, enabling objective verification of RTC. Time to RTC and level at RTC were calculated among players who returned; denominators therefore vary across these descriptive analyses.

Outcomes

Two time-to-event outcomes were defined:

1. Index-knee revision ACLR, recorded in SKLR.
2. Contralateral ACLR, recorded in SKLR

Only surgically treated events were included, ensuring objective and complete outcome ascertainment.

Time scale and follow-up

Time at risk was defined as time from index ACLR. This time scale was chosen to avoid immortal time bias that would arise if follow-up were conditioned on postoperative milestones such as RTC. For analyses restricted to RTC players, surgery remained the time origin, and cohort restriction was applied rather than delayed entry. RTC was treated as a cohort restriction rather than a time-varying exposure to avoid post-baseline conditioning because subsequent surgery can occur before or without documented RTC.

For revision analyses, follow-up continued until revision ACLR, censoring at contralateral ACLR or end of follow-up, whichever occurred first. For contralateral ACLR analyses, follow-up continued until contralateral ACLR, censoring at revision ACLR or end of follow-up.

Equity, diversity and inclusion

This nationwide cohort included all eligible football players undergoing primary ACLR in Sweden without exclusions based on sex, age or region. Analyses were prespecified to be sex-stratified (women/men), and results are reported separately to support equitable interpretation.

Statistical analysis

All primary index ACLRs in football players performed in Sweden between 2014 and 2023 were analysed using registry data extracted in April 2025. The final analytical cohort comprised n=10 693. Baseline characteristics are presented as frequencies and percentages for categorical variables and means with SD for continuous variables.

Time-to-event analyses were conducted using Cox proportional hazards regression. Analyses were performed in:

1. The RTC cohort (primary analysis).
2. The full ACLR cohort (secondary analysis).

Separate sex-stratified models were fitted for women and men to allow baseline hazards to differ and to improve clinical interpretability.

Covariates in the final multivariable models included:

- Age at surgery (continuous; HR per 1-year increase).
- Graft type (hamstring tendon as reference, quadriceps tendon and patellar tendon autografts).
- Pre-injury level of play (Elite, Non-elite adult, Youth)

Potential effect-modification by age was evaluated by adding age×graft interaction terms to the pooled Cox model and

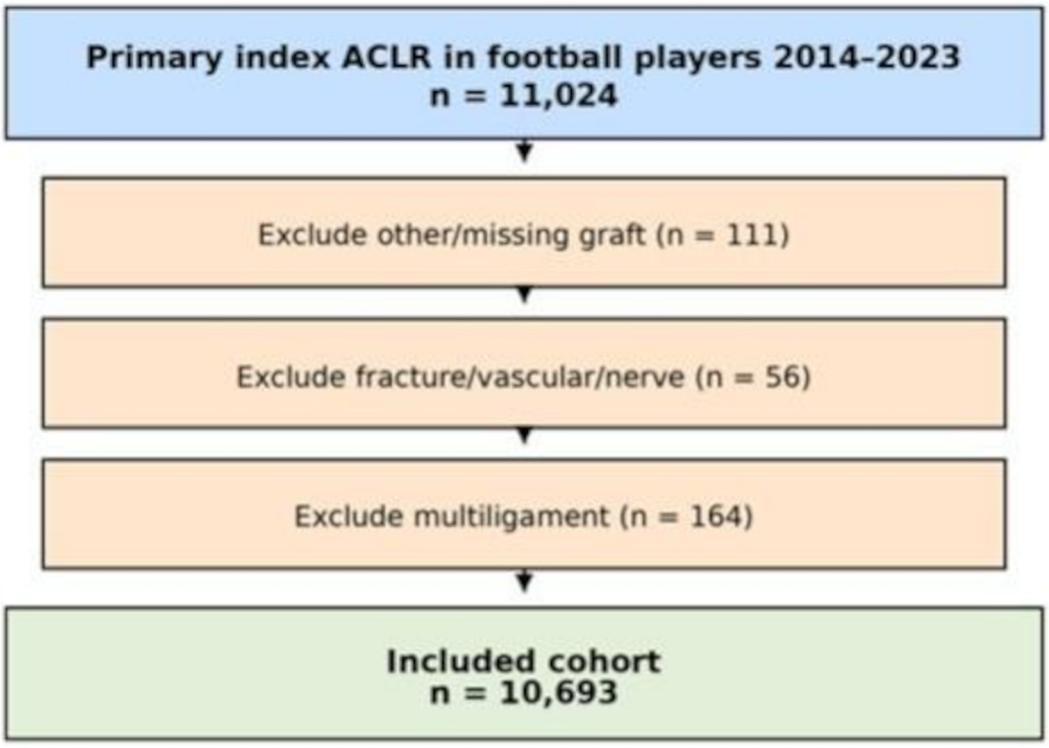


Figure 1 Flow chart of study population selection. Primary index ACLR in football players, 2014–2023. Exclusions: other/missing graft (n=111), fracture/vascular/nerve (n=56), multiligament (n=164). Final cohort n=10 693. ACLR, anterior cruciate ligament reconstruction.

testing them using Wald statistics. As the interaction terms were not statistically significant, the interaction was not retained in the final model. Cause-specific hazards with conventional right censoring were applied. Sensitivity analyses within the RTC cohort were prespecified for players aged <25 years and <20 years at index ACLR, reflecting clinically recognised high-risk age groups frequently examined separately in ACL epidemiology.[8 15 16] Candidate covariates included meniscal and cartilage lesions, but these were excluded from final models because they did not materially change graft estimates and were not the focus of the research question. Models were additionally adjusted for calendar year of surgery. Pre-injury level of play was unavailable for 296 (2.8%) players in the full cohort; among those who RTC, pre-injury level was missing for 236 (3.8%). This structural missingness reflects absence of documented competitive exposure rather than missing registry information; therefore, multivariable analyses including level of play were performed using an available-case approach, which resulted in slightly different analytical sample sizes for the models. Descriptive statistics are reported among those with available data, and multivariable analyses used an available-case approach within each sex-specific model. Proportional hazards assumptions were assessed using time-dependent covariates and residual-based diagnostics; no material violations were observed. Results are presented as HRs with 95% CIs. All tests are two-sided with $\alpha=0.05$. Analyses were performed using IBM SPSS Statistics (IBM, Armonk, New York, USA).

RESULTS

Study population and graft distribution

A total of 10 693 football players undergoing first time primary ACLR were included (figure 1). Baseline characteristics are shown in table 1. The cohort comprised 3767 women (35%) and 6926 men (65%), with a mean age at surgery of 22±7 years. A concomitant meniscal injury was recorded in 5137 players (48%) and cartilage lesions in 2094 (20%). The hamstring tendon group was either isolated semitendinosus 5927 (63%) or semitendinosus combined with gracilis 3550 (37%). The quadriceps group were either with a bone block 198 (44%) or without 78 (18%) and in 172 (38%) the use of bone block was not specified. Overall, 1443 players (13%) sustained a subsequent ACLR during follow-up, including 861 revision ACLRs (8%) and 639 contralateral ACLRs (6%); events were not mutually exclusive.

Return to competition

In total RTC occurred in 6238 players (58%). Among those who returned, RTC was achieved at the same or higher level in 3047 players (51%) and at a lower level in 2955 players (49%) (denominators restricted to players with available pre-injury level). Time to RTC was<9 months in 16%, 9–12 months in 23%, and>12 months in 60%, time to RTC was missing for 16 returners.

Temporal trends in graft choice

Hamstring tendon autograft predominated throughout the study period. Quadriceps tendon autograft was introduced later and increased in use toward 2023, while patellar tendon autograft remained a minority choice across all years (figure 2).

Index-knee revision ACLR among RTC players (primary analysis)

In sex-stratified Cox regression models among RTC players, increasing age was associated with a lower hazard of revision ACLR in both sexes (table 2). Among women (232 events among 2156 RTC players; 10.8%), the HR per 1-year increase in age

Table 1 Baseline characteristics of included football players undergoing primary ACLR in Sweden, 2014–2023: overall and by graft type

		Total (n=10 693)		Hamstring (n=9477)		Quadriceps (n=448)		Patellar (n=768)	
		n	%	n	%	n	%	n	%
Sex	Women	3767	35	3329	35	140	31	298	39
	Men	6926	65	6148	65	308	69	470	61
Age at surgery, mean±SD (years)		22±7		22±7		22±6		22±5	
Age intervals	7–15 years	1194	11	1104	12	52	12	38	5
	16–20 years	3842	36	3332	35	182	41	328	43
	21–25 years	2745	26	2417	26	103	23	225	29
	26–30 years	1677	16	1494	16	63	14	120	16
	31–35 years	752	7	676	7	33	7	43	6
	36–40 years	306	3	283	3	13	3	10	1
	>40 years	177	2	171	2	2	0	4	1
Follow up, mean±SD (years)		5.2±2.9		5.3±2.9		3.8±2.3		4.3±2.5	
Subsequent ACLR		1443	13	1282	14	54	12	107	14
Revision ACLR		861	8	775	8	30	7	56	7
Contralateral ACLR		639	6	556	6	28	6	55	7
Pre-injury level Elite	Top	203	2	121	1	10	2	72	10
	High	1698	16	1502	16	69	16	127	17
Non-elite	Middle	2402	23	2148	23	72	17	182	24
	Low	3159	30	2849	31	119	27	191	25
	Recreational	464	4	420	5	12	3	32	4
	Youth	2471	24	2166	24	153	35	152	20
Missing pre-injury level		296	3	271	3	13	3	12	2
Meniscal injury		5137	48	4533	48	250	56	354	46
Cartilage lesions		2094	20	1894	20	94	21	106	14
Lateral extra-articular procedures		169	2	92	1	31	7	46	6
Returned to competition†		6238	58	5509	58	229	51	500	65
RTC level†	Same or higher	3047	51	2712	51	121	55	214	43
	Lower	2955	49	2575	49	99	45	281	57
RTC time†	<9 months	1010	16	912	17	26	11	72	14
	9–12 months	1450	23	1282	23	53	23	115	23
	>12 months	3762	60	3299	60	150	66	313	63

Values are n and % unless otherwise stated. Age at surgery and follow-up are presented as mean±SD. RTC defined as participation in ≥1 official competition match after index ACLR as recorded in the Swedish Football Association's nationwide administrative system. Pre-injury level of play was missing for some players; level-specific percentages are calculated among those with available pre-injury level, and totals may therefore not equal 100%. See Methods for details. †Percentages calculated among players who RTC.
ACLR, anterior cruciate ligament reconstruction; RTC, return to competition.

was 0.932 (95% CI 0.899 to 0.967, p<0.001). Among men (349 events among 3814 RTC players; 9.2%), the corresponding HR was 0.892 (95% CI 0.867 to 0.918, p<0.001).

No statistically significant differences in revision hazard were observed between hamstring tendon, quadriceps tendon and patellar tendon autografts. Relative to hamstring tendon autograft (reference), quadriceps tendon autograft had HR 1.293 (95% CI 0.662 to 2.525, p=0.452) in women and HR 0.790 (95% CI 0.407 to 1.535, p=0.487) in men; for patellar tendon autograft had HR 0.911 (95% CI 0.547 to 1.515, p=0.718) in women and HR 1.044 (95% CI 0.703 to 1.551, p=0.830), in men.

Pre-injury level of play was associated with a higher hazard of revision ACLR. Compared with Elite players, Non-elite adult and Youth players had lower hazards of revision ACLR in both sexes: women—Non-elite HR 0.670 (95% CI 0.494 to 0.908, p=0.010) and Youth HR 0.660 (95% CI 0.461 to 0.945, p=0.023); men—Non-elite HR 0.734 (95% CI 0.550 to 0.979, p=0.035) and Youth HR 0.585 (95% CI 0.410 to 0.834, p=0.003).

The graft×age interaction was not statistically significant, and inclusion of the interaction term did not materially alter effect estimates. Sensitivity analyses restricted to players younger than 25 years and players younger than 20 years at the time of surgery within the RTC cohort showed no material change in the association between graft choice and revision ACLR. Estimates were directionally consistent with the primary analysis, and no graft demonstrated a statistically significant difference in revision ACLR hazard in either age group. Adjustment for calendar year did not materially change the estimates for graft choice in either women or men (data not shown).

Contralateral ACLR among RTC players

Increasing age was associated with a lower hazard of contralateral ACLR in both sexes: among women (263 events among 2159 RTC players; 12.2%), HR 0.950 (95% CI 0.919 to 0.982, p=0.002); among men (264 events among 3818 RTC players; 6.9%), HR 0.921 (95% CI 0.894 to 0.950, p<0.001)(table 3).

Relative to hamstring tendon autograft, quadriceps tendon autograft was associated with a higher hazard of contralateral ACLR in women (HR 1.983, 95% CI 1.172 to 3.355, p=0.011) but not in men (HR 1.465, 95% CI 0.798 to 2.686, p=0.218). Patellar tendon autograft was not associated with contralateral ACLR in either sex. Pre-injury level of play was not significantly associated with contralateral ACLR.

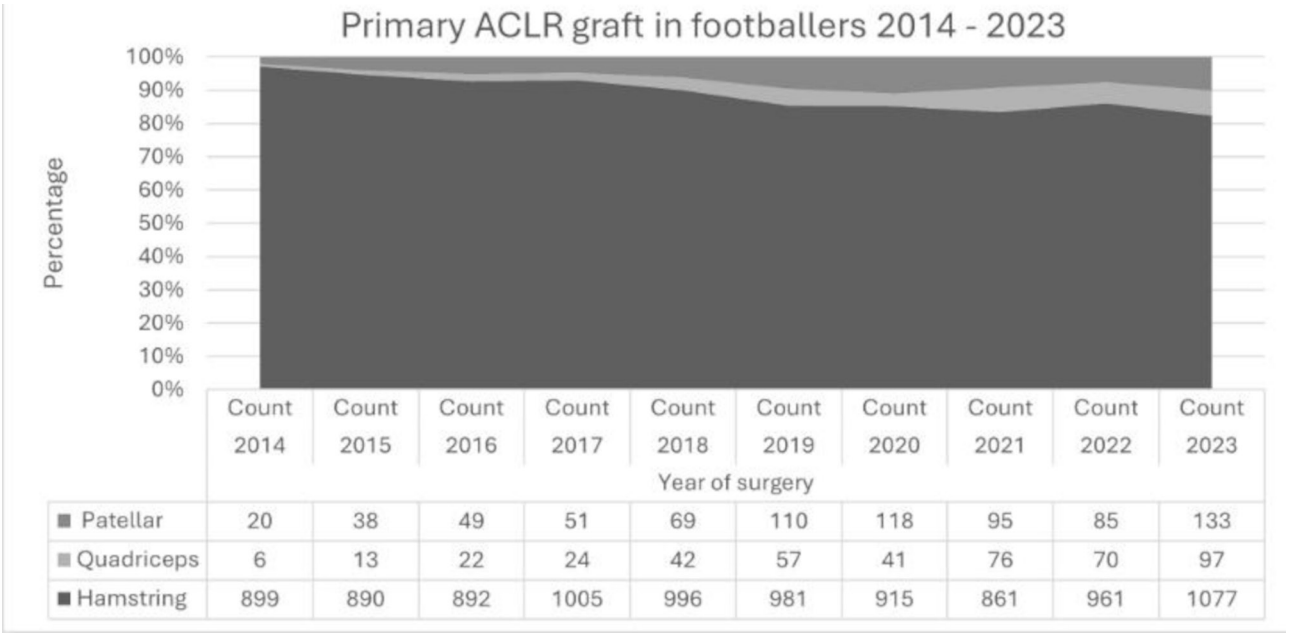


Figure 2 Temporal trends in graft choice among football players undergoing ACLR in Sweden, 2014–2023. Values are number of index ACLR performed per calendar year. Quadriceps tendon grafts were introduced later in the period and therefore have shorter median follow-up. ACLR, anterior cruciate ligament reconstruction.

Index-knee revision ACLR in the full cohort

In analyses of the full ACLR cohort, including players who did not RTC, younger age remained associated with a higher hazard of revision ACLR in both sexes: women (329 events among 3683 players; 8.9%) HR 0.926 (95% CI 0.899 to 0.953, p<0.001) and men (508 events among 6708 players; 7.6%) HR 0.892 (95% CI 0.872 to 0.912, p<0.001)(table 4).

Graft type was not statistically significantly associated with revision ACLR hazard in either sex. Compared with Elite players, Non-elite adult and Youth players had lower revision hazards in both women and men. Full estimates (HR, 95% CI, p value) are provided in table 4.

Figure 3 provides a summary of the key results.

DISCUSSION

In this nationwide cohort of more than 10 000 football players undergoing index ACLR, graft choice was not associated with the risk of index-knee revision ACLR. Across women and men, and consistently in analyses restricted to players who RTC, neither quadriceps tendon nor patellar tendon autografts conferred a lower risk of index-knee revision ACLR compared with hamstring tendon autografts. These findings were robust across multiple analytic approaches, including sex-stratified models and sensitivity analyses restricted to younger age groups. For contralateral ACLR, a higher risk was observed among women who RTC and received a quadriceps tendon autograft, whereas no such association was identified in men. This sex-specific result indicates that graft-related differences may be present in certain subgroups, but the overall pattern across both revision and contralateral ACLR outcomes does not support a consistent graft-specific effect. Rather than graft choice, age at surgery and pre-injury playing level were the variables consistently associated with subsequent ACLR. This finding aligns with previous registry-based and cohort-based studies demonstrating substantially higher rates of second ACL injury among younger athletes and those returning to high-level sports.[8 17–22] Together,

Table 2 Multivariable Cox regression for index-knee revision ACLR among players who returned to football (sex-stratified)

	Women			Men		
	n events (%)	HR (95% CI)	P value	n events (%)	HR (95% CI)	P value
Age		0.932 (0.899 to 0.967)	<0.001		0.892 (0.867 to 0.918)	<0.001
Hamstring (ref)	207 (10.9)	Reference		313 (9.3)	Reference	
Quadriceps	9 (11.4)	1.293 (0.662 to 2.525)	0.452	9 (6.5)	0.790 (0.407 to 1.535)	0.487
Patellar	16 (8.6)	0.911 (0.547 to 1.515)	0.718	27 (8.9)	1.044 (0.703 to 1.551)	0.830
Elite (ref)	112 (12.9)	Reference		62 (11.4)	Reference	
Non-elite	66 (8.5)	0.670 (0.494 to 0.908)	0.010	193 (7.7)	0.734 (0.550 to 0.979)	0.035
Youth	54 (10.5)	0.660 (0.461 to 0.945)	0.023	94 (12.3)	0.585 (0.410 to 0.834)	0.003

Models are Cox proportional hazards regressions stratified by sex and adjusted for age (continuous; HR per 1-year increase) and pre-injury level of play (Elite, Non-elite adult, Youth). Reference (ref) category for graft=hamstring tendon autograft. Follow-up from date of index ACLR to revision ACLR; censoring at contralateral ACLR or end of follow-up, whichever occurred first. Pre-injury level of play was missing for some players; handling of missing data is described in Methods, and counts/percentages in the table reflect the data available within each stratum. Data extracted April 2025; surgeries included 2014–2023. Number of events (n) and percentage refer to ACLR revisions within the stratum. Women n=2156; ACLR revisions n=232 (10.8%). Men (RTC) n=3814; ACLR revisions n=349 (9.2%).
ACLR, anterior cruciate ligament reconstruction; RTC, return to competition.

Table 3 Multivariable Cox regression for contralateral ACLR among players who returned to football (sex-stratified)

	Women			Men		
	n events (%)	HR (95% CI)	P value	n events (%)	HR (95% CI)	P value
Age		0.95 (0.919 to 0.982)	0.002		0.921 (0.894 to 0.950)	<0.001
Hamstring (ref)	224 (11.8)	Reference		229 (6.8)	Reference	
Quadriceps	15 (19)	1.983 (1.172 to 3.355)	0.011	11 (7.9)	1.465 (0.798 to 2.686)	0.218
Patellar	24 (12.9)	1.307 (0.857 to 1.993)	0.214	24 (7.9)	1.362 (0.892 to 2.081)	0.153
Elite	102 (11.7)	Reference		41 (7.6)	Reference	
Non-elite	77 (9.9)	0.867 (0.644 to 1.166)	0.344	155 (6.2)	0.879 (0.621 to 1.245)	0.468
Youth	84 (16.4)	1.235 (0.893 to 1.706)	0.202	68 (8.9)	0.789 (0.516 to 1.207)	0.275

Cause-specific Cox proportional hazards models stratified by sex and adjusted for age (continuous; HR per 1-year increase) and pre-injury level of play (Elite, Non-elite adult, Youth); reference (ref) graft=hamstring tendon autograft. Follow-up from date of index ACLR to contralateral ACLR; censoring at revision ACLR or end of follow-up. Pre-injury level of play was missing for some players; handling of missing data is described in Methods, and counts/percentages in the table reflect the data available within each stratum. Surgeries included 2014–2023; data extracted April 2025. Number of events (n) and percentages in the 'n events (%)' column refer to contralateral ACLR within the stratum. Women n=2159; contralateral ACLRs n=263 (12.2%). Men n=3818; contralateral ACLRs n=264 (6.9%).
ACLR, anterior cruciate ligament reconstruction.

these data suggest that subsequent ACLR risk in football players is primarily driven by factors related to re-exposure to football and competitive demands rather than by graft selection.

The lack of an association between graft type and revision ACLR contrasts with earlier reports suggesting lower revision rates with patellar tendon autografts,[23] particularly in young athletes[24 25] but is in line with other studies.[6 26] However, much of this evidence derives from mixed-sport populations, earlier surgical eras or studies without objective confirmation of return to high-risk sport and inconsistent failure definitions.[16] Sensitivity analyses restricted to younger age groups yielded results consistent with the primary analyses, with no statistically significant association between graft type and revision ACLR. In football-specific cohorts, where knee pivoting exposure following RTC is both high and relatively homogeneous, differences attributable to graft choice may be attenuated. Our findings extend this literature by demonstrating that, among football players who RTC, graft choice does not appear to be associated with differences in the risk of index-knee revision ACLR.

Women who RTC and received a quadriceps tendon autograft were observed to have a higher hazard of contralateral ACLR than those receiving a hamstring tendon autograft, whereas no such association was identified in men. This secondary, sex-stratified finding was based on 15 contralateral events among women with quadriceps tendon autograft and should therefore be interpreted with caution, as reflected by the wide 95% CI. This sex-specific result indicates that graft-related differences may arise in subgroups, although the underlying reasons for this pattern are not clear based on the available data.

The consistent associations observed for younger age and higher pre-injury playing level are compatible with, an exposure-based interpretation of subsequent ACLR risk.[8 27] Exposure was not directly quantified (eg, minutes or training load); this interpretation is therefore based on football-specific proxies available in the data—age, pre-injury level of play and verified RTC. Younger players, particularly those competing at higher levels, are likely to accumulate substantially greater match and training exposure over time, often during a period characterised by ongoing neuromuscular development.[28] From this perspective, the elevated rates of subsequent ACLR observed in young football players may reflect the intensity, frequency and cumulative load of football participation rather than differences in graft biology or mechanical properties.

These findings support complementing graft-centred decision-making with a practical risk–exposure framework particularly in young football players. While graft choice remains important for surgical reasons, the present findings suggest that meaningful reductions in subsequent ACLR may be more likely to be achieved through strategies that address modifiable aspects of re-exposure to football after RTC, for example, progressive load management, structured injury-prevention programmes[29–31] and carefully calibrated return-to-play decisions,[32] rather than through preferential selection of one autograft over another.

Table 4 Multivariable Cox regression for index-knee revision ACLR in full cohort (all ACLR players, sex-stratified)

	Women			Men		
	n events (%)	HR (95% CI)	P value	n events (%)	HR (95% CI)	P value
Age		0.926 (0.899 to 0.953)	<0.001		0.892 (0.872 to 0.912)	<0.001
Hamstring (ref)	296 (9.1)	Reference		458 (7.7)	Reference	
Quadriceps	13 (9.4)	1.339 (0.768 to 2.337)	0.304	16 (5.4)	0.815 (0.494 to 1.343)	0.421
Patellar	20 (6.7)	0.869 (0.552 to 1.368)	0.543	34 (7.4)	1.047 (0.738 to 1.486)	0.796
Elite	134 (11)	Reference		73 (10.8)	Reference	
Non-Elite	105 (6.9)	0.660 (0.511 to 0.852)	0.001	287 (6.4)	0.707 (0.545 to 0.916)	0.009
Youth	90 (9.6)	0.650 (0.484 to 0.872)	0.004	148 (9.7)	0.526 (0.390 to 0.710)	<0.001

Cause-specific Cox proportional hazards models stratified by sex and adjusted for age (continuous; HR per 1-year increase) and pre-injury level of play (Elite, Non-elite adult, Youth); reference (ref) graft=hamstring tendon autograft. Follow-up from date of index ACLR to revision ACLR; censoring at contralateral ACLR or end of follow-up. Pre-injury level of play was missing for some players; handling of missing data is described in Methods, and counts/percentages in the table reflect the data available within each stratum. Surgeries included 2014–2023; data extracted April 2025. Number of events (n) and percentages in the 'n events (%)' column refer to ACLR revisions within the stratum. Women n=3683; revision events n=329 (8.9%). Men n=6708; revision events n=508 (7.6%).

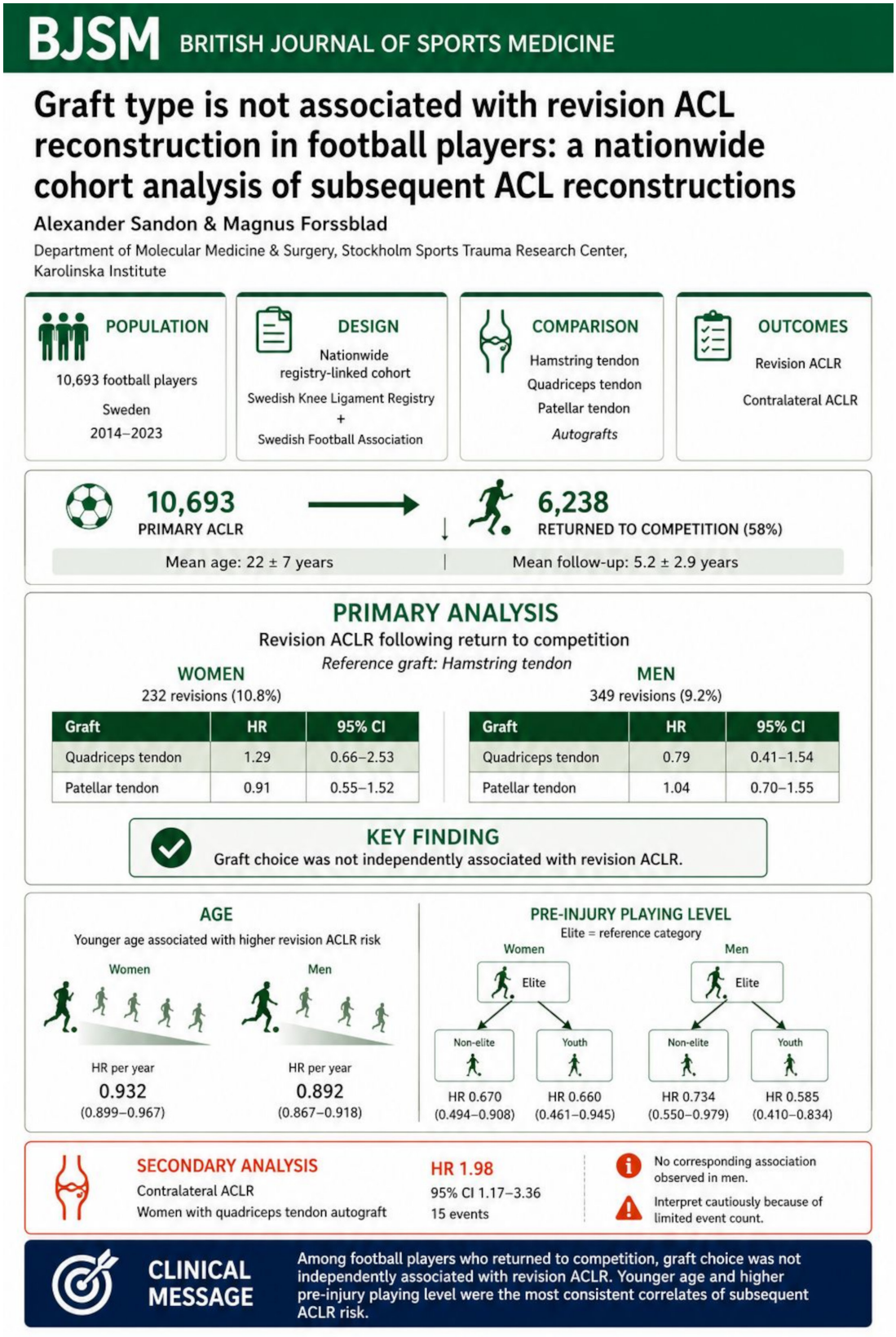


Figure 3 Central figure summarising the association between graft type and subsequent ACLR in football players. Nationwide registry-linked cohort of 10 693 football players undergoing primary ACLR in Sweden between 2014 and 2023. Among the 6238 players who returned to competition, graft type (hamstring tendon, quadriceps tendon or patellar tendon autograft) was not independently associated with the risk of revision ACLR in either women or men. Younger age and higher pre-injury playing level were the factors most consistently associated with revision ACLR risk. In secondary analyses, women receiving a quadriceps tendon autograft had a higher risk of contralateral ACLR, although this finding was based on a limited number of events and should be interpreted cautiously. ACL, anterior cruciate ligament; ACLR, ACL reconstruction.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the observational registry-based design precludes causal inference, and graft selection was not randomised. Although the analyses were adjusted for key clinical and some football-related covariates and stratified by sex, residual confounding related to surgeon preference, surgical technique, rehabilitation protocols or unmeasured patient characteristics cannot be excluded. Subsequent revision ACLR and contralateral ACLR were used as outcome measures and therefore capture only surgically treated events. Non-operatively managed graft failures or contralateral injuries are not included, which may lead to underestimation of the true incidence of subsequent ACL injury. However, revision ACLR remains a clinically relevant and robust endpoint. Third, RTC was defined as participation in at least one official match. While this definition is objective and registry-verified, it does not capture training exposure, informal play or detailed measures of cumulative workload. Furthermore, returning to a single official match does not necessarily reflect the amount of football exposure accrued after ACLR, as some players may participate in only a few matches whereas others return to sustained football participation over several seasons. As a result, exposure could not be directly quantified, and age, level of play and RTC was used as a proxy for risk exposure. Differences in football exposure after RTC may therefore have influenced the risk of subsequent ACLR. This may partially explain the association observed between age, playing level and injury risk. Fourth, pre-injury level of play was missing for a subset of players, leading to smaller sample sizes in multivariable models that included this covariate. Complete-case analyses were used, which may introduce selection bias if missingness was not random. However, sensitivity analyses and consistency across models suggest that this limitation is unlikely to materially affect the main conclusions. Fifth, some subgroup analyses—particularly those involving quadriceps tendon grafts in women—were based on relatively small numbers of events. For example, among women who RTC, only 15 contralateral ACLR events occurred in recipients of quadriceps tendon autografts; this reduces the precision of the corresponding HR, as reflected by the wide 95% CI, and should be considered when interpreting this sex-specific association. These subgroup findings did not change the overall interpretation that graft choice showed no consistent association with subsequent ACLR across primary, sex-stratified and age-restricted analyses. Finally, although this is a nationwide cohort with comprehensive linkage between surgical and competition registries, the findings reflect the structure of Swedish football and healthcare systems. Caution is therefore warranted when extrapolating results to other sporting contexts, age groups or healthcare settings with different injury management practices.

CONCLUSION

Graft choice was not independently associated with revision ACLR, including among young football players who RTC. An association between quadriceps tendon autograft and contralateral ACLR was observed among women. Across analyses, age and pre-injury level of play were the most consistent correlates of subsequent ACLR risk.

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Patient consent for publication Not applicable.

Ethics approval This study used data from the Swedish Knee Ligament Registry linked with the Swedish Football Association database. The study was approved by the Swedish Ethical Review Authority (Dnr 2024-06108-01). Under Swedish law, written patient consent is not required for registry-based research using anonymised data. All individuals consented to inclusion in the national registry at the time of surgery, and no identifiable patient information is reported in this manuscript.

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Data availability statement Data may be obtained from a third party and are not publicly available. The data used in this study originate from SKLR and the Swedish Football Association's system. Swedish registry regulations prohibit public sharing of individual-level data. Access can be requested directly from the data owners in accordance with Swedish legal and ethical requirements.

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