Adolescents Have Twice the Revision Rate of Young Adults After ACL Reconstruction With Hamstring Tendon Autograft

A Study From the Swedish National Knee Ligament Registry

Baldur Thorolfsson,*†‡§ MD, Eleonor Svantesson,‡§ MD, Thorkell Snaebjornsson,†‡§ MD, PhD, Mikael Sansone,†‡§ MD, PhD, Jon Karlsson,†‡§ MD, PhD, Kristian Samuelsson,†‡§ MD, PhD, and Eric Hamrin Senorski,§‖¶ PT, PhD

Investigation performed at Sahlgrenska University Hospital, Gothenburg, Sweeden / Gothenburg Sports Trauma Research Center, Gothenburg, Sweden

Background: Previous studies have identified young age as a risk factor for anterior cruciate ligament (ACL) revision. However, few studies have looked separately at pediatric patients and adolescents with regard to outcomes after ACL reconstruction.

Purpose: To determine whether patient age at ACL reconstruction affects the risk of undergoing revision surgery in young patients.

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

Methods: This study was based on data from the Swedish National Knee Ligament Registry. Patients aged 5 to 35 years who underwent a primary ACL reconstruction with a hamstring tendon autograft between January 1, 2005, and December 31, 2015, were included. The cohort was stratified into different age groups of pediatric patients, adolescents, and young adults to estimate patients with open, recently closed, and closed epiphyses, respectively. The primary endpoint was ACL revision. A multivariable Cox regression model was used to assess the ACL revision rate. The results were expressed as hazard ratios (HRs) and 95% CIs.

Results: A total of 36,274 ACL reconstructions were registered during the study period. Of these, 2848 patients were included in the study: 47 pediatric patients (mean age, 13.6 years; range, 9-15 years), 522 adolescents (mean age, 17.4; range, 14-19 years), and 2279 young adults (mean age, 27.0; range, 20-35 years). A total of 31 patients (1.1%) underwent ACL revision within 2 years (0 pediatric patients, 9 adolescents [1.7%], and 22 young adults [1.0%]) and a total of 53 patients (2.6%) underwent ACL revision within 5 years (2 pediatric patients [6.9%], 15 adolescents [3.9%], and 36 young adults [2.2%]). The adolescent age group had a 1.91 times higher rate of ACL revision compared with the young adults (HR = 1.91 [95% CI, 1.13-3.21]; $P = .015$). There were no differences in revision rates between the pediatric age group and the young adults (HR = 2.93 [95% CI, 0.88-9.79]; $P = .081$).

Conclusion: Adolescents had almost twice the rate of revision ACL reconstruction compared with young adults.

Keywords: adolescent; anterior cruciate ligament; ACL; epiphyses; pediatric; registry; revision

A rupture of the anterior cruciate ligament (ACL) is a common injury among young, active individuals.[1,17,28] The incidence of ACL injuries in the pediatric and adolescent population has increased in recent years, due in part to the increase in youth competitive athletic activity with year-round training and competition.[14,20,24,28,39] An ACL rupture is a serious knee injury that may lead to an inability for young individuals to return to sports at their previous recreational or competitive level, despite receiving the best possible treatment.[11,23,38]

A rupture of the ACL can lead to functional knee instability, with episodes of giving way when walking or during other everyday activities. The injured knee, with increased laxity, is believed to be at risk of suffering secondary injuries to the menisci and cartilage, which, as the years pass, leads to the development of posttraumatic osteoarthritis (OA) of the knee in almost 50% of patients.[1,14,36] In Scandinavia, approximately 50% of patients who sustain an ACL injury undergo surgical reconstruction.[10,17,36] The goal of ACL reconstruction is to restore knee laxity, re-create the anatomy and kinematics of the injured knee to regain biologic function, and

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prevent secondary injuries to the cartilage and eventually OA. For each individual, the return to sports or previous activity level is commonly an important goal.

Children and adolescents often impose high demands on their knees and a strong desire to return to pivoting sports. Together with the risk of developing secondary injuries to the menisci and cartilage and more positive results from ACL reconstruction in pediatric patients in recent years,[5,6,41] this has led to an increasing trend toward early surgical reconstruction in this age group.[5,6,13-15,31,41] In Scandinavia, an ACL reconstruction using a hamstring autograft is the most common means of managing this injury in pediatric and adolescent patients.[17,36]

A second injury to the reconstructed ACL after completing rehabilitation and returning to sport is a devastating outcome for the patient. Most previous studies have shown that the incidence of revision ACL surgery in the general population is somewhere between 3% and 18% within the first 5 years after the index operation.[9,29,35,42] Previous studies have identified young age as a risk factor for ACL revision,[9,21,26,33] as well as a return to a high level of activity and sports.[20,40]

The aim of this study was to evaluate the risk of ACL revision in pediatric and adolescent patients to determine whether patient age at the time of ACL reconstruction is associated with an increased risk of ACL revision. The hypothesis was that patients who sustain an ACL rupture in childhood and adolescence run a higher risk of ACL revision at 2 and 5 years after index treatment, compared with skeletally mature young adults.

METHODS

The patient data in the present study were extracted from the Swedish National Knee Ligament Register (SNKLR). The SNKLR is a nationwide database that uses a web-based protocol for data registration. The protocol consists of 2 parts: 1 patient-reported section and 1 surgeon-reported section. The patients register general information about their lifestyle and complete the Knee injury and Osteoarthritis Outcome Score (KOOS). The surgeon registers all surgical procedures performed on the injured knee, including meniscal surgery and treatment of chondral lesions. The graft type and size, fixation techniques, patient activity when the ACL injury occurred, time from injury to reconstruction, and other concomitant injuries are also reported by the surgeon along with information about whether the operation was a primary reconstruction or a revision. Unfortunately, radiographs are not kept in the database, and there is no feature that enables registration of open or closed physes. Recent database validation revealed that the quality of the data was good, with accuracy of more than 95% when patient- and surgeon-reported data were compared with data from patient journals.[36] Since 2018, the registry has been used by more than 90% of all the orthopaedic departments in Sweden and it is financed by Swedish authorities.[36]

TABLE 1
Definition of Age Groups in the Study

Group	Male	Female
Pediatric	5-15 years[a]	5-13 years[a]
Adolescents	16-19 years	14-19 years
Young adults	20-35 years	20-35 years

[a]To generalize the cohort, the age of skeletal maturity was set at 14 years in girls and 16 years in boys.

The study protocol was approved by a regional ethical review board. According to Swedish law, no written consent is necessary for national registries, and participation is voluntary for both patients and surgeons. The extracted data are confidential, and patient age and sex can be identified by the authorized personnel from the patient's Social Security number.

Patients

Eligible for inclusion were patients aged 5 to 35 years registered in the SNKLR for primary ACL reconstruction between January 1, 2005, and December 31, 2015. Patients were excluded if they underwent surgery with a graft other than a hamstring tendon autograft, or if they had a concomitant fracture, vascular injury, nerve injury, injury to the posterior cruciate ligament (PCL), injury to the medial collateral ligament (MCL), or injury to the lateral collateral ligament (LCL) requiring reconstruction.

The cohort was stratified into age groups of male patients aged 5 to 15, 16 to 19, and 20 to 35 years and female patients aged 5 to 13, 14 to 19, and 20 to 35 years, as listed in Table 1. The different age grouping of male and female patients was conducted to create 1 group of skeletally immature individuals with open physes, a second group of individuals who underwent ACL reconstruction around the time of physeal closure, and a third reference group of skeletally mature young adults. Physiological closure of the physes takes place

*Address correspondence to Baldur Thorolfsson, MD, Department of Orthopedics, Sahlgrenska University Hospital, SE-43180 Mölndal, Sweden (email: baldur.thorolfsson@vgregion.se)
†Department of Orthopedics, Sahlgrenska University Hospital, Gothenburg, Sweden.
‡Department of Orthopedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.
§Gothenburg Sports Trauma Research Center, Gothenburg, Sweden.
‖Department of Health and Rehabilitation, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.
¶Sportrehab Sports Medicine Clinic, Gothenburg, Sweden.
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Ethical approval for this study was obtained from the regional ethical review board in Stockholm, Sweden (registration number: 2011/337-31/3).

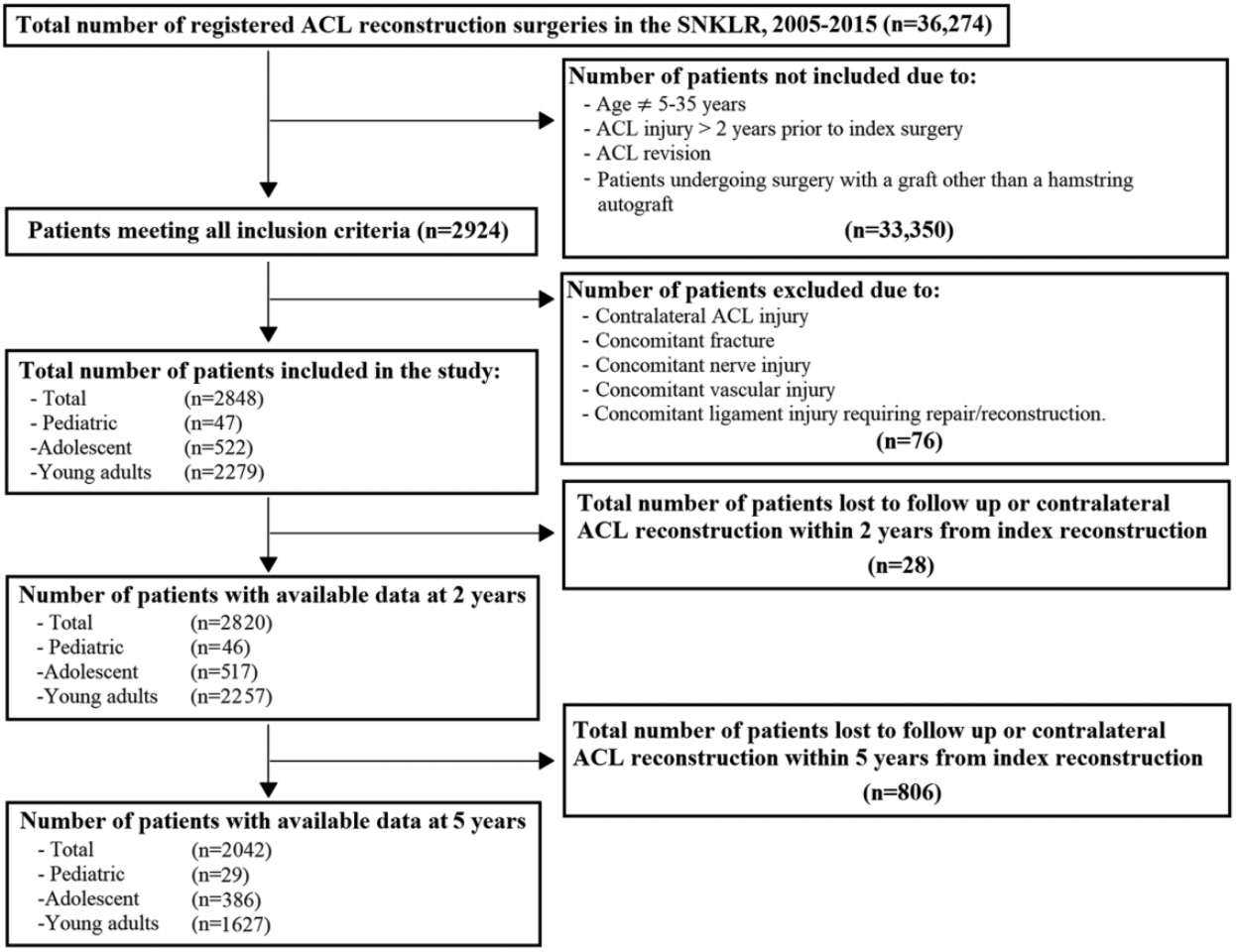

Figure 1. Flowchart of inclusion and exclusion criteria. ACL, anterior cruciate ligament; SNKLR, Swedish National Knee Ligament Register.

in adolescence, varying individually, but roughly around the age of 14 in girls and 16 in boys.[7,20,25] Radiographs are needed to thoroughly determine skeletal age and maturity on an individual basis, but as they are unfortunately not kept in the SNKLR, the age of skeletal maturity was set at 14 years in girls and 16 years in boys, which is generally considered a fair estimation.[7,14,20]

Variables and Outcome

The following data were extracted from the SNKLR: patient age at index surgery, patient sex, surgical data including fixations, concomitant injuries registered at index surgery, graft type, and activity when the injury occurred. Follow-up began at index surgery and finished at ACL revision surgery or on December 31, 2017, whichever occurred first. Patients who underwent surgery more than 2 years after the occurrence of ACL injury were excluded. The primary study endpoint was ACL revision surgery, defined as the replacement of the previously reconstructed ACL. A flow chart of the inclusion and exclusion criteria is presented in Figure 1.

Statistical Analysis

Statistical analysis was performed using the SAS statistical analysis system (SAS/STAT; Version 14.2; IBM). Data were reported as counts and proportions for categorical variables and as means with standard deviations or medians with ranges for continuous variables. A multivariable Cox regression model was used to assess the ACL revision rate, adjusted for concomitant meniscal injury, cartilage injury, tibial fixation technique, and femoral fixation technique. Adjusted factors were determined by differences in baseline and intraoperative data. The results from the Cox regression model were expressed as hazard ratios (HRs) and 95% CIs. Young adults (age, 20-35 years) were used as the reference variable. The significance level for all statistical analyses was set at 5%.

RESULTS

A total of 36,274 ACL reconstructions were registered in the SNKLR from 2005 to 2015. Of these, 2848 patients met the inclusion criteria and were included in the study:

TABLE 2
Demographic Data of Study Groups[a]

	All (N = 2848)	Pediatric (n = 47)	Adolescent (n = 522)	Young Adult (n = 2279)
Sex				
Male	1699 (59.7)	34 (72.3)	208 (39.8)	1457 (63.9)
Female	1149 (40.3)	13 (27.7)	314 (60.2)	822 (36.1)
Age at index surgery, y	25.0 ± 5.7	13.6 ± 1.6	17.4 ± 1.4	27.0 ± 4.5
	25 (9-35)	14 (9-15)	18 (14-19)	26 (20-35)
Activity at ACL injury				
Pivoting sport	1759 (61.8)	23 (48.9)	355 (68.0)	1381 (60.6)
Nonpivoting sport	64 (2.2)	1 (2.1)	12 (2.3)	51 (2.2)
Martial arts	75 (2.6)	1 (2.1)	8 (1.5)	66 (2.9)
Winter sport	382 (13.4)	8 (17.0)	62 (11.9)	312 (13.7)
Other	560 (19.7)	14 (29.8)	85 (16.3)	461 (20.2)
Missing	8 (0.3)	0	0	8 (0.4)
Groups of femoral fixations				
Cortical suspensory fixation	1234 (43.3)	32 (68.1)	209 (40.0)	993 (43.6)
Adjustable cortical suspensory fixation	416 (14.6)	11 (23.4)	73 (14.0)	332 (14.6)
Screw fixation	340 (11.9)	1 (2.1)	72 (13.8)	267 (11.7)
Intratunnel transfixation	828 (29.1)	3 (6.4)	165 (31.6)	660 (29.0)
Other	17 (0.6)	0	3 (0.6)	14 (0.6)
Femoral fixation missing	13 (0.5)	0	0	13 (0.6)
Groups of tibial fixations				
Cortical suspensory fixation	22 (0.8)	0	3 (0.6)	19 (0.8)
Adjustable cortical suspensory fixation	147 (5.2)	4 (8.5)	32 (6.1)	111 (4.9)
Screw fixation	1981 (69.6)	36 (76.6)	360 (69.0)	1585 (69.5)
Bioabsorbable screw	544 (19.1)	4 (8.5)	101 (19.3)	439 (19.3)
Intratunnel transfixation	82 (2.9)	0	17 (3.3)	65 (2.9)
Other	52 (1.8)	3 (6.4)	8 (1.5)	41 (1.8)
Tibial fixation missing	20 (0.7)	0	1 (0.2)	19 (0.8)
Concomitant injuries				
Medial meniscus	1063 (37.3)	13 (27.7)	185 (35.4)	865 (38.0)
Lateral meniscus	690 (24.2)	14 (29.8)	143 (27.4)	533 (23.4)
Cartilage injury	956 (33.6)	5 (10.6)	126 (24.1)	825 (36.2)
MCL	18 (0.6)	0	1 (0.2)	17 (0.7)
LCL	6 (0.2)	0	1 (0.2)	5 (0.2)

[a]Data are presented as n (%) except for age, which is presented as mean ± SD and median (range). ACL, anterior cruciate ligament; LCL, lateral collateral ligament; MCL, medial collateral ligament.

47 pediatric patients (mean age, 13.6 ± 1.6 years), 522 adolescents (mean age, 17.4 ± 1.4 years), and 2279 young adults (mean age, 27.0 ± 4.5 years). For all age groups, pivoting sports such as soccer, basketball, floorball, and team handball were the most common cause of ACL injury. Associated injuries to the medial meniscus, joint cartilage, MCL, and LCL increased for older age groups. However, there were fewer associated injuries to the lateral meniscus in the older age groups. The demographic characteristics of the study groups are presented in Table 2.

A total of 31 patients (1.1%) had undergone revision surgery at 2 years from the index operation, and 53 patients (2.6%) had undergone revision surgery at 5 years from the index operation (Table 3).

TABLE 3
Crude ACL Revision Rates[a]

	Total (N = 2848)	Pediatric (n = 47)	Adolescent (n = 522)	Young Adult (n = 2279)
Revision within 2 years	31 (1.1)	0	9 (1.7)	22 (1.0)
Missing[b]	28 (1.0)	1 (2.1)	5 (1.0)	22 (1.0)
Revision within 5 years	53 (2.6)	2 (6.9)	15 (3.9)	36 (2.2)
Missing[b]	806 (28.3)	18 (38.3)	136 (26.1)	652 (28.6)

[a]Data are reported as n (%). ACL, anterior cruciate ligament.
[b]Missing data because of patients lost to follow-up or contralateral ACL reconstruction within 2 and 5 years, respectively, from the index reconstruction.

The adolescent age group had a 1.91-times increase in the rate of ACL revision compared with the young adults (HR = 1.91 [95% CI, 1.13-3.21]; $P = .015$) (Table 4). The pediatric age group had a 3.45-times unadjusted increase in the rate of ACL revision compared with the young adults ($P = .038$). However, when adjusted for concomitant meniscal injury, cartilage injury, tibial fixation technique, and femoral fixation technique, there were no differences in the ACL revision rates between pediatric patients and

young adults (HR = 2.93 [95% CI, 0.88-9.79]; $P = .081$) (Figure 2).

DISCUSSION

The main finding in this large, population-based registry study was that adolescents had a revision rate that was almost twice as high compared with young adults. However, the findings did not show a statistically significantly higher revision rate among pediatric patients when compared with young adults. In general, the revision rates were low for all age groups. The overall 2-year revision rate was 1.1%: 0% in pediatric patients, 1.7% in adolescents, and 1.0% in young adults. The overall 5-year revision rate was 2.6%: 6.9% in pediatric patients, 3.9% in adolescents, and 2.2% in young adults.

The steep increase in revision rate between 2 and 5 years could have many different explanations. One is that, at the 2-year follow-up, many of the patients had been exposed to much less sporting activity and load compared with patients at the 5-year follow-up.

The 5-year revision rate in the present study is comparable with the results of previous studies.[9,12,16,21,32,34] Desai et al[9] reported an overall revision rate of 3.1% in a large cohort study from the same registry, which also included older patients. In that study, patients aged 13 to 15 years had a risk of revision that was 5.3 times higher compared with their reference group of adults aged 36 to 49 years. This higher revision rate can probably be explained by the older age of the reference group, the longer follow-up, and the lower activity level of the reference group.

TABLE 4
Hazard Ratio for ACL Revision, Adjusted for Concomitant Meniscal Injury, Cartilage Injury, Tibial Fixation Technique, and Femoral Fixation Technique[a]

Groups Compared	Unadjusted HR (95% CI)	*P* Value	Adjusted HR (95% CI) [b]	Adjusted *P* Value [b]
Pediatric vs adult	3.45 (1.07-11.08)	**.038**	2.93 (0.88-9.79)	.081
Adolescent vs adult	1.93 (1.15-3.23)	**.012**	1.91 (1.13-3.21)	**.015**

[a]Bold *P* values indicate statistically significant difference between groups ($P < .05$). ACL, anterior cruciate ligament; HR, hazard ratio.
[b]Adjusted for concomitant meniscal injury, cartilage injury, tibial fixation technique, and femoral fixation technique.

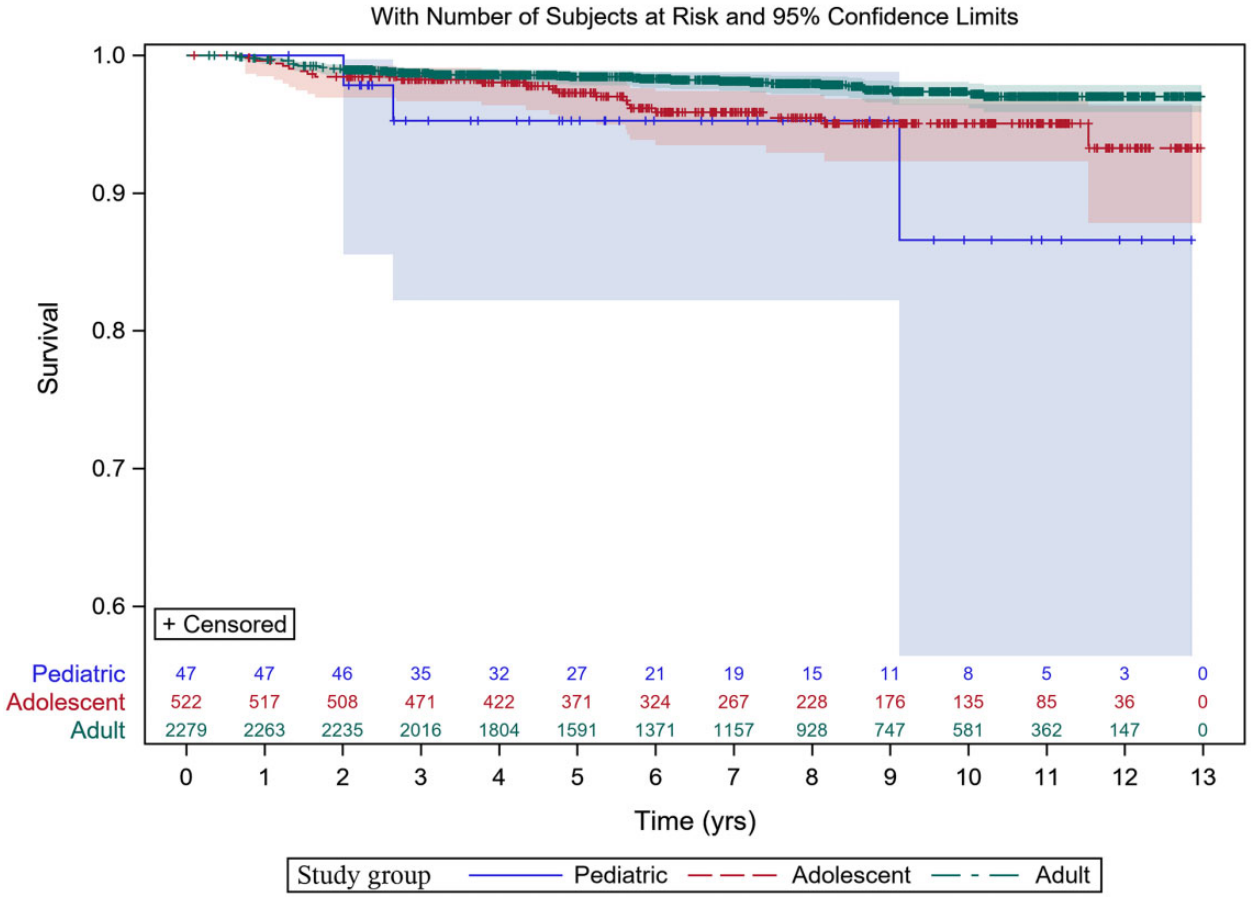

Figure 2. Graft survival analysis after anterior cruciate ligament reconstruction.

The present study showed the highest 5-year revision rate among pediatric patients. Several previous studies have shown similar results in skeletally immature patients, with an increase in the risk of failure of 1.5 to 3 times compared with adults.[2,4,6,16] In a large registry study from Denmark from 2005 to 2011, Fauno et al[16] reported that the risk of revision was more than 3 times higher among patients aged 13 to 15 years and 2.5 times higher among patients aged 15 to 20 years when compared with adults aged over 20 years. However, Cordasco et al[5] recently reported a lower revision rate in skeletally immature patients operated with an all-epiphyseal technique when compared with adolescents operated with the partial transphyseal and complete transphyseal techniques.

One possible explanation for the higher revision rates in pediatric patients is that they have residual skeletal growth that may alter the anatomy and kinematics of the operated knee in the first years after the ACL reconstruction, as intra-articular hamstring graft diameter has previously been shown to decrease with continuing knee growth after ACL reconstruction in patients with open physes.[3] Although smaller graft size has been correlated with higher revision rates in adults,[32] Cruz et al[6] found no statistically significant differences in the mean graft size and overall distribution of graft diameter between patients with rerupture and those without in a case series of 103 children operated with an all-epiphyseal ACL reconstruction.[6] Many of the skeletally immature patients had also been away from sports for a long time (1-3 y), when taking into account the time spent waiting for skeletal growth before ACL reconstruction and the rehabilitation time after surgery before returning to sport. As a result, these individuals most frequently return to sport at a higher and more intense level than they had before the injury.[4,8] Even though the adolescent patients may not have been away from sport for as long as the pediatric patients, they also usually return at another level than they had before the injury, with peers who have trained and played consistently during their absence. Unfortunately, the SNKLR does not include information on activity level before and after the injury or the time of return for the patients, only the type of activity at the time of injury.

According to previous studies, younger patients experience an earlier return to sport; within this population, an earlier return to sport and a greater exposure to injury risk have been associated with a greater risk of a second ACL injury.[8,30] Early return to sport among the youngest patients has previously been explained to a certain degree by their eagerness to return to training and competition, whereas older patients may have a better understanding of the importance of thorough rehabilitation.[10,37] Older patients may also impose lower demands on their knees and might accept a reduction in their level of physical activity after the ACL reconstruction. Most young athletes undergo a thorough rehabilitation program for 9 to 12 months after ACL reconstruction before returning to sport. Graziano et al[18] recommended using a combination of quantitative measures as well as qualitative evaluation of movements before deciding on return to sport for skeletally immature athletes. Some clinics even recommend up to 24 months before returning to competition because of the increased risk of rerupture during the first 12 months after ACL reconstruction.[27] However, a recent cohort study from Norway and the United States reported that there was no association between age and second ACL injury after adjusting for return to level 1 sport within the first postoperative year and fulfilling return-to-sport criteria, suggesting that the risk of a new ACL injury can likely be attributed to sports exposure.[19]

The present study is a large population-based registry study. The free, unrestricted access to health care in Sweden is also an important factor in contributing to the SNKLR with a relatively unselected study population as the SNKLR includes all ACL patients in Sweden, not only 1 group of patients such as elite athletes or certain insurance patients. We regard the different age grouping of the male and female participants in the present study as a strength. This grouping may have produced more accurate data in terms of skeletal maturity than many previous studies that included male and female patients of the same ages in the same groups despite physeal closure usually occuring later in boys than girls. The main limitation of this study is the small number of patients in the pediatric age group, which might have increased the risk of a type 2 error, resulting in statistically nonsignificant results. With an early return to sport and the high activity levels of younger patients in mind, the comparison group was defined as not being older than 35 years to include patients who were as similar as possible. However, we consider it a possible weakness of the present study to have included too many in the reference group of 20- to 35-year-olds. As that group was much larger than the other 2 groups, and taking into account that a lot of lifestyle changes occur between the ages of 25 and 35, we consider that a smaller reference group of 20- to 25-year-olds may have been sufficient; it may perhaps have even resulted in a more accurate comparison with the pediatric and adolescent groups.

Another limitation of the present study is the number of patients lost to follow-up between 2 and 5 years. This is due to the fact that they underwent surgery more than 2 years after their ACL injury. This might have the greatest effect on the youngest age group, because of the common practice of letting these patients wait for months to years for skeletal growth to finish before surgery. A further limitation is that skeletal maturity was not determined on an individual basis using radiographs, but the age of skeletal maturity was instead set at 14 years in girls and 16 years in boys, as is generally estimated.[7,14,20,22] Because of this, some individuals may have fallen into the wrong category. One example of this could be a skeletally mature 15-year-old male, verified by radiographs, who undergoes surgery before the age of 16. He would therefore fall into the category of pediatric patients instead of adolescents. An error of this kind could, subsequently, cause the calculated revision rate for the pediatric patients to be falsely too low.

CONCLUSION

Adolescents had a revision rate that was almost twice as high compared with young adults. From these results, we

therefore conclude that our hypothesis seems reasonable, in that patients who suffer an ACL rupture in adolescence run a higher risk of revision surgery than young adults.

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