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Coping with Anterior Cruciate Ligament injury from Childhood to Maturation

- **A prospective case series of 44 patients with mean 8 years follow-up**

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Abstract
Background: There is no consensus regarding the best treatment approach for skeletally immature children with anterior cruciate ligament (ACL) injuries. High-quality studies with long-term follow-up are lacking, and evidence to support decision-making is limited.
Purpose: To evaluate functional and patient-reported outcome, surgical history and complications in young adults who sustained an ACL injury before the age of 13 years and were treated with active rehabilitation and the option of delayed ACL reconstruction if needed.

Study design: Prospective case series

Methods: Forty-six children younger than 13 years of age with a total, intrasubstance ACL injury were included. None of these patients had additional injuries that warranted early surgery. At final follow-up at mean 8 years after time of injury, 44 patients remained in the study. The same test battery was conducted at baseline, 1 and 2 years and at final follow-up at approximately 18 years of age. The test battery included functional tests (hop tests and isokinetic muscle strength tests of quadriceps and hamstrings), patient-reported outcome measures (including the Knee and Osteoarthritis Outcome Score KOOS and the International Knee Documentation Committee Subjective Knee form IKDC) and clinical examination. Medical records were reviewed to assess surgical history and complications.
Results: At mean 8 years follow-up, 24 patients (55 %) had undergone ACL reconstruction, and 16 patients (36 %) had undergone meniscal surgery. Quadriceps muscle strength symmetry was above 90 % for 30 patients (68 %). Mean leg symmetry indexes for hop and strength tests were consistently above 90 %, except for the single hop and hamstrings muscle strength for ACL-reconstructed patients. Mean IKDC scores were 86.3 ± 13.7 for the ACL-reconstructed patients and 90.6 ± 11.8 for the non-reconstructed patients. Forty patients (91 %) remained active in sports, but 29 patients (66 %) reduced their activity level to non-pivoting sports.

Conclusion: Active rehabilitation may have a role in treatment of ACL injured children. Approximately 50 % of children may cope well even through to adulthood without a surgical intervention. The other half may develop instability which warrants ACL reconstruction and one third may require meniscal surgery.

Introduction

Anterior cruciate ligament (ACL) injuries are increasing in our youngest athletes, the skeletally immature children[13]. Children are vulnerable, their short- and long-term knee health and quality of life are in jeopardy[49]. As a result, management of pediatric ACL injuries is a much debated topic. A consensus does not exist regarding the optimal treatment approach. The current evidence on management of pediatric ACL injuries is limited due to bias and poor methodology[4, 14, 34]. The International Olympic Committee (IOC) consensus statement on pediatric ACL injuries was published in 2018[4]. This consensus statement addresses these controversies in management and provides a best practice guideline for clinicians[4]. In children with ACL injury and additional injuries (e.g., bucket handle meniscal tears), early ACL reconstruction and meniscal repair are recommended. In those without such additional injuries, a recommendation regarding treatment approach could not be agreed upon due to conflicting opinions[4].

A main goal in treatment decision-making is to mitigate the risk for developing secondary knee injuries[14]. Many surgeons advocate early surgery to mechanically stabilize the injured knee and prevent secondary injuries to cartilage and menisci[40]. However, surgery in the growing knee is not without risk. These risks include growth disturbances[17, 37], inadequate graft developement[7] and, most importantly, more unpredictable results in children compared to adults[6, 12]. The rate of re-injury may be as high as 30 %[12]. Therefore, some choose a primary non-surgical approach pending growth and the option of delayed ACL reconstruction for those without additional injuries warranting early surgery.

Few prospective studies exist, and so far no study has followed ACL injured children, treated with active rehabilitation and the option of delayed ACL reconstruction, through to adulthood.
We aimed to investigate long-term outcomes in young adults who sustained an ACL injury in childhood (skeletally immature and younger than 13 years) and were treated with active rehabilitation and optional delayed ACL reconstruction. Our primary aim was to evaluate knee function and activity level with performance-based and patient-reported outcome measures. The secondary aim was to describe knee surgeries, complications and secondary knee injuries.

Materials and methods

Patients and eligibility criteria

This is a prospective follow-up study of 46 individuals included in the Oslo Pediatric ACL cohort [33]. Functional outcomes and MRI findings at 2 years were published in 2013[33, 36].

Consecutive patients were recruited from the Division of Orthopedic Surgery, Oslo University Hospital from March 2006 to October 2010. Out of 52 eligible patients, 46 were included and 44 remained in the study at final follow-up when reaching 18 years of age. A flow diagram illustrates flow of study participants (Fig. 1).

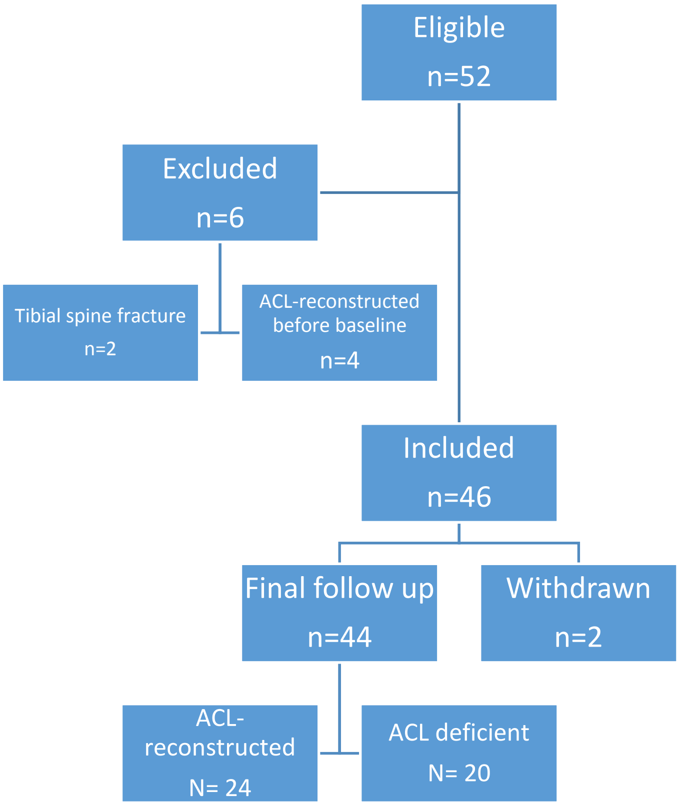

Fig. 1 Flow diagram of study participants

The eligibility criterion was a confirmed traumatic, complete intrasubstance ACL injury sustained before the age of 13 years and no concurrent ligament injury requiring surgery. Exclusion criteria were prior ACL reconstruction and having an ACL avulsion fracture in the index knee.

The diagnosis of an ACL injury was confirmed when all the three following criteria were present; ACL injury verified by magnetic resonance imaging (MRI)[31], a positive Lachman test[27], and a side-to side difference in anteroposterior translation over 3 mm on an instrumental sagittal knee laxity measurement (Manual maximum test, KT 1000, Med-Metric, San Diego, California, USA)[10]. The diagnostic MRI confirmed open growth plates in all patients.

Treatment algorithm

All children were treated with active rehabilitation and the option of having delayed ACL reconstruction if needed[35]. In Norway, this is the standard of care for skeletally immature patients with ACL injury who do not have additional injuries that warrant early surgery. This treatment protocol includes a structured rehabilitation program involving three phases supervised by a sports physical therapist and use of a custom-fitted knee brace during pivoting sports and school-based physical education. Return to sport was allowed after passing functional criteria after completing rehabilitation[35]. No activity modifications apart from using the knee brace during pivoting activities were advocated.

Delayed ACL reconstruction was considered if the rehabilitation program did not lead to adequate knee function and functional stability[35]. Indications for ACL reconstruction were multiple episodes of giving-way, unacceptable reduction in activity level, or symptomatic meniscal injury. Patients who underwent ACL reconstruction followed the same rehabilitation program postoperatively.
The rehabilitation protocol is described in detail by Moksnes et al[35].

Follow-up

Patients were closely monitored throughout the study. Initially, they had weekly training sessions with the physical therapist and visits by request with the orthopedic surgeon (LE). After the 2 year follow-up, patients had yearly visits at our orthopedic clinic and appointments by request with the physical therapist (HM) and/or orthopedic surgeon (GE/LE). All patients were invited to a final follow-up at approximately 18 years of age.

Outcome measures

After completing the second phase of rehabilitation (following the initial injury), all children completed a baseline test battery including performance-based tests, patient-reported outcome measures (PROMs) and clinical examination[35]. The same test battery was performed after one and two years and at final follow-up. Patients who required an ACL reconstruction underwent these tests pre-operatively as well.

The performance-based tests were isokinetic concentric muscle strength measurements (knee extensors and flexors) and four single-leg hop tests[39] (single hop test, triple crossover test, triple hop test and 6 m timed hop test). Testing was performed without the knee brace, after a 10-min warm-up on a stationary bike and led by senior sports physical therapists (HG and HM). The uninjured leg was routinely tested first. A Biodex 6000 dynamometer (Biodex, Medical Systems Inc., Shirley, New York, USA) at a test velocity at 60°/s was used to measure isokinetic quadriceps and hamstrings muscle strength. The participants performed four sub maximum trial repetitions and had one minute rest, before five test repetitions were recorded at maximum efforts.

The following PROMs were included: the Knee and Osteoarthritis Outcome Score (KOOS)[43], the International Knee Documentation Committee Subjective Knee form (IKDC)[24], the Knee Outcome Survey Activities of Daily Living (KOS-ADLS)[26] and the Visual analogue scale for knee function (VAS). IKDC, KOS-ADLS and VAS give a total score from 0 to 100 (worst to best). KOOS has 5 subscales (Pain, Symptoms, Activities of Daily Living (ADL), Sports and Recreation (Sports/Rec) and Quality of Life (QoL)). A score from 0 to 100 (worst to best) is calculated for each subscale.

The children completed these PROMs with their parents at all follow-ups, except at the final follow-up when they were completed by the patient alone. Main pre-injury sports activity at baseline and current sports activity were reported at all follow-ups. Activity level was categorised according to Hefti et al[21] modified to Norwegian sports[20]. (Table 1)

Level 1	Pivoting	Soccer, team handball, basketball, floorball, rugby
Level 2	Some pivoting	Squash, tennis, alpine skiing, twin-tip skiing, martial arts, dancing
Level 3	No pivoting	Running, strength training, cycling, spinning, swimming, cross-country skiing
Level 4		No sports activity

Table 1 Classification of activity level according to pivoting sports activity

The clinical exam consisted of Lachman[47] and Slocum[45] tests performed by the senior author (LE). The patients reported their surgical history, re-injuries and knee giving-way episodes. Medical records were obtained for the 44 patients at final follow-up to include data on ACL reconstructions, additional surgeries and complications.

Ethics: Regional Ethics committee has approved the study. REC nb: 684-06288 1.2006.78**.**

Data management and Statistical analysis:
Muscle strength and hop performance were reported as limb symmetry index (LSI). The number of patients with LSI above 90 % were calculated. The methods for calculating LSI were the following:

1. Muscle strength: (peak torque of involved leg)/(peak torque of uninvolved leg) x 100
2. Distance hop tests: (distance of involved leg)/(distance of uninvolved leg) x 100
3. Timed hop test: (time of uninvolved leg)/(time of involved leg) x 100

Predictive Analytics Software Statistics (V24.0 SPSS Inc., Chicago, Illinois, USA) was used for all statistical analyses.

The proportion of patients reaching Patient Acceptable Symptom State (PASS) tresholds[38] for IKDC and KOOS was calculated. For IKDC the defined PASS threshold is 75.9 and for KOOS subscales: 88.9 for pain, 57.1 for symptoms, 100 for ADL, 75 for Sports/Rec and 62.5 for QoL[38].

Changes in continuous variables (PROMs and LSI for muscle strength and hop tests) from 2 years to final follow-up were analyzed with a paired t-test or Wilcoxon signed rank test depending on data distribution. Data distribution was explored by histograms (SPSS). Data with substantial outliers or non-normal distribution were analyzed with Wilcoxon signed rank test. The proportion of patients showing Minimal Important Change (MIC) for the KOOS subscales Sports/Rec and QoL[23] was calculated. MIC is defined as improvement more than 12.1 for Sports/Rec and 18.3 for QoL[22].

Results

Patient characteristics

Of 46 included patients, 44 (96 %) (15 females, 29 males) attended the final follow-up at a mean age of 19 ± 1.6 years. The mean time from injury to final follow-up was 8.0 ± 1.7 years. All, but 1 patient had closed growth plates at final follow-up.

Baseline

Mean age at injury was 11 ± 1.5 years. One patient had bilateral ACL injuries, 15 had a right knee ACL-injury and 28 a left knee ACL-injury. All patients participated in pivoting sports before injury. Patient characteristics are described in Table 2.

Variable	At injury mean ± SD (min., max.) or n (%)	At follow up mean ± SD (min., max.) or n (%)
Age (years)	11 ± 1.5 (7-13)	19.1 ± 1.6 (16-23)
Time since injury (years)		8.0 ± 1.7 (5-11)
Female	15 (34 %)	15 (34 %)
Height (cm)	155 (134-193)	176.8 (154-201)
BMI		24.7 (17.6-40.8)
Activity level		
Level 1	33 (75 %)	9 (20 %)
Level 2	11 (25 %)	6 (14 %)
Level 3	0	25 (57 %)
Level 4	0	4 (9 %)

Table 2 Patient characteristics

Index ACL reconstruction

At final follow-up, 24 of 44 (54.5 %) patients had undergone ACL reconstruction. The reasons for ACL-reconstruction were instability (n=20), secondary injuries (n=2; bucket handle meniscal tears) and unacceptable activity limitation (n=2). For all 24 ACL reconstructions a transphyseal technique was used. Those operated before the growth spurt (n=3) had a pediatric transphyseal technique including soft tissue graft (in all cases hamstrings) and post screw fixation in tibia to avoid hard wear or bone block crossing the epiphysis. The majority of patients were skeletally mature or close to skeletal maturity at the time of surgery. Those who were considered skeletally mature had appropriate interference screw fixations in tibia and screw or suspensory device in femur depending on the graft (hamstring n=18, bone to bone patellar tendon n=2 and quadriceps n=1). In total, 12 surgeons were involved in the ACL surgeries. All, but one ACL reconstruction was performed at the study center. Details regarding the index ACL reconstruction are described in Table 3.

Variable	n (%) or mean ± SD (min.,max.)
ACL- reconstruction	24 (54.5 %)
Age at surgery (years)	15.3 ± 1.7 (13.2-19.5)
Time since injury at surgery (years)	4.1 ± 2.4 (0.6-8.4)
Time since ACL-R at follow-up (years)	3.8 ± (0.5-9.4)
Not skeletally mature at ACL-reconstruction	18 (out of 24)
grown <5 cm after surgery	13 (mean growth in cm 3.2 (1-5))
>5 cm growth after surgery	5 (growth in cm 8, 8, 13, 19, 26)
ACL- graft	
Hamstring	21 (out of 24)
Patellar tendon (BTBPT)	2 (out of 24)
Quadriceps	1 (out of 24)
Surgical technique	
Transphyseal (pediatric)	3 out of 24
Post screw in tibia + Endobutton ®Smith & Nephew in femur	
Transphyseal (adult	21 out of 24
BTBPT: Softsilk ®Smith & Nephew in tibia and femur	
Hamstrings: RCI in tibia + Endobutton ®Smith & Nephew in femur	

	Quadriceps: Softsilk ®Smith & Nephew in tibia + Endobutton ®Smith & Nephew in femur

Table 3 Primary ACL-reconstruction prior to time of follow-up

Thirty-six percent of patients (16 of 44) underwent meniscal surgery during the study period. Injury to a previously healthy meniscus was found in 9 of 16 patients (6 bucket handle meniscal tears). Of these 16 patients with meniscal injuries that required surgery, 3 patients were never ACL reconstructed and did not have further meniscal surgery. However, 2 patients who had meniscal repair initially without ACL reconstruction, experienced failure and had later meniscal resection and ACL reconstruction. The remaining patients had ACL reconstruction.

In 6 of 16 patients, an initial incomplete or stable meniscal injury (observed on diagnostic MRI) progressed and required surgery. Of these tears, the majority progressed before ACL-reconstruction (n=5). One additional patient had an incomplete meniscal tear seen on diagnostic MRI, which was later confirmed as incomplete on diagnostic arthroscopy. Meniscal surgeries and re-surgeries are listed in Supplementary file A.

Complications

Surgical complications included post-operative infection (n=1) and injury to the tibial nerve during post screw placement in tibia (n=1) which resulted in short foot syndrome. One ACL reconstructed patient had a 4 cm leg length discrepancy at final follow-up. This patient had a recognized leg length discrepancy > 2.5 cm prior to the ACL injury, and his condition was not believed to be the result of surgery.

One patient sustained a graft rupture less than 10 months after ACL reconstruction and subsequently underwent ACL revision surgery with a quadriceps tendon autograft. Another patient had graft insufficiency based on symptoms and clinical examination (Lachman 2 + without endpoint, and Slocum pivoting +2) at final follow-up. The graft was intact at the follow-up MRI. There were no contralateral knee injuries during the follow-up period. Complications and secondary surgeries after index ACL reconstruction are displayed in Supplementary file B.

Eight out of the 24 ACL reconstructed patients had additional surgery after the index ACL reconstruction. These secondary surgical interventions were due to surgical complications or re-injuries as mentioned above. Five patients had surgical treatment without ACL reconstruction and 2 patients had meniscal surgery prior to ACL reconstruction. In total, 29 patients had knee surgery between injury and final follow-up. Surgeries in non-reconstructed knees or prior to ACL reconstruction are described in Supplementary file C.

Activity level

At the final follow-up, the majority of patients (91 %) remained physically active. The majority in both groups participated in level 3 sports (not-pivoting). Strength training was the most commonly reported non-pivoting sport in both groups ($n^{non\text{-}R}$ = 4, $n^{ACL\text{-}R}$= 11). Eight of 24 patients in the ACL-reconstructed group, and 7 patients of 20 in the non-reconstructed group still participated in level 1 or 2 sports. In both groups, soccer was the most commonly reported pivoting sport ($n^{non\text{-}R}$ = 5, $n^{ACL\text{-}R}$= 3). Two patients competed at a national level; cross country (n=1, non-reconstructed) and alpine skiing (n=1, ACL reconstructed). Fifty-seven percent of patients (25 of 44) reported return to pre-injury activity level. Nineteen patients did not return to pre-injury activity level, and for 13 of these the self-reported reason for not returning was due to either reduced knee function, fear of giving way or fear of sustaining a new knee injury. Further details regarding activity level at baseline and follow-up are found in Table 2. Details regarding activity levels for the treatment groups are found in Table 4.

Muscle strength

Thirty of 44 patients (68 %), had quadriceps muscle strength symmetry above 90 % (whereof 16 were not ACL reconstructed), and 25 of 44 patients (57 %) had hamstrings muscle strength symmetry above 90 % (whereof 14 were not ACL reconstructed). In total, 22 of 44 patients (50 %) had a leg symmetry index above 90 % for both quadriceps and hamstring muscle strength (whereof 13 were not ACL reconstructed). Muscle strength measurements are presented in Table 4.

Hop performance

In total, 17 of 42 patients (40 %) had a leg symmetry index above 90 % for all hop tests (whereof 10 were not ACL reconstructed). Two out of 24 ACL reconstructed patients were not able to perform the hop tests at follow-up due to either ACL surgery 6 months prior to testing (n=1) or having sustained an ankle sprain few weeks prior to testing (n=1). Hop performance is presented in table 4.

Patient-reported outcome measures

For 36 of 44 patients (82 %) IKDC scores were above the PASS threshold[38]. Six ACL reconstructed and 2 non-reconstructed patients reported IKDC scores below PASS[38]. Out of 44 patients the number of patients exceeding PASS thresholds for KOOS[38] were: 39 patients (89 %) for pain, 43 patients (98 %) for symptoms, 32 patients (73 %) for ADL, 38 patients (86 %) for Sports/Rec and 40 patients (91 %) for QoL. Mean PROM scores are presented in table 4. The individual KOOS scores are illustrated as a spaghetti plot (fig. 2) to show the variance between patients.

	Non-Reconstructed N=20 Mean ± SD (min-max)	**ACL-Reconstructed N=24** Mean ± SD (min-max)
Single hop test, LSI (%)	95.3 ± 9.8 (77-114)	88.2 ± 17.9 (27-110)
Triple crossover test, LSI (%)	95.8 ± 9.3 (76-115)	90.7 ± 12.1 (53-111)
Triple hop test, LSI, (%)	95.8 ± 8.6 (78-117)	90.0 ± 15.7 (35-109)
6 m timed hop test, LSI (%)	94.0 ± 8.1 (78-117)	94.4 ± 12.0 (54-121)
Quadriceps muscle strength, ((nm/kg)x100)	264.1 ± 52.7 (173-351)	252.6 ± 70.7 (99-384)
Hamstring muscle strength, ((nm/kg)x100)	141.3 ± 36.6 (87-202)	137.4 ± 59.9 (48-360)
Quadriceps muscle strength LSI (%)	99 ± 10.8 (80-123)	91.7 ± 10.9 (69-112)
Hamstrings muscle strength, LSI (%)	98.7 ± 11.8 (70-115)	89.3 ± 12.6 (70-127)
KOS-ADSL	95.5 ± 6.5 (80-100)	91.7 ± 10.1 (61-100)
Visual Analogue scale Function	94 ± 7.9 (71-100)	87 ± 19.9 (22-100)
IKDC2000	90.6 ± 11.8 (53-100)	86.3 ± 13.7 (52-100)
KOOS pain	96.6 ± 5.8 (78-100)	92,4 ± 10,4 (56-100)
KOOS symptom	90.8 ± 11.2 (61-100)	87.9 ± 12.5 (61-100)

KOOS activities of daily living	99.4 ± 1.35 (96-100)	97.0 ± 8.4 (60-100)
KOOS sport and recreation	86.5 ± 19.2 (40-100)	85.6 ± 15 (40-100)
KOOS quality of life	84.2 ± 17.7 (44-100)	79.3 ± 19.6 (25-100)
Activity level	Patients (n)	Patients (n)
Level 1 (pivoting sport)	6	3
Level 2 (some pivoting)	1	5
Level 3 (non-pivoting)	11	14
Level 4 (no sports activity)	2	2

Table 4 Functional and patient-reported outcome by final treatment

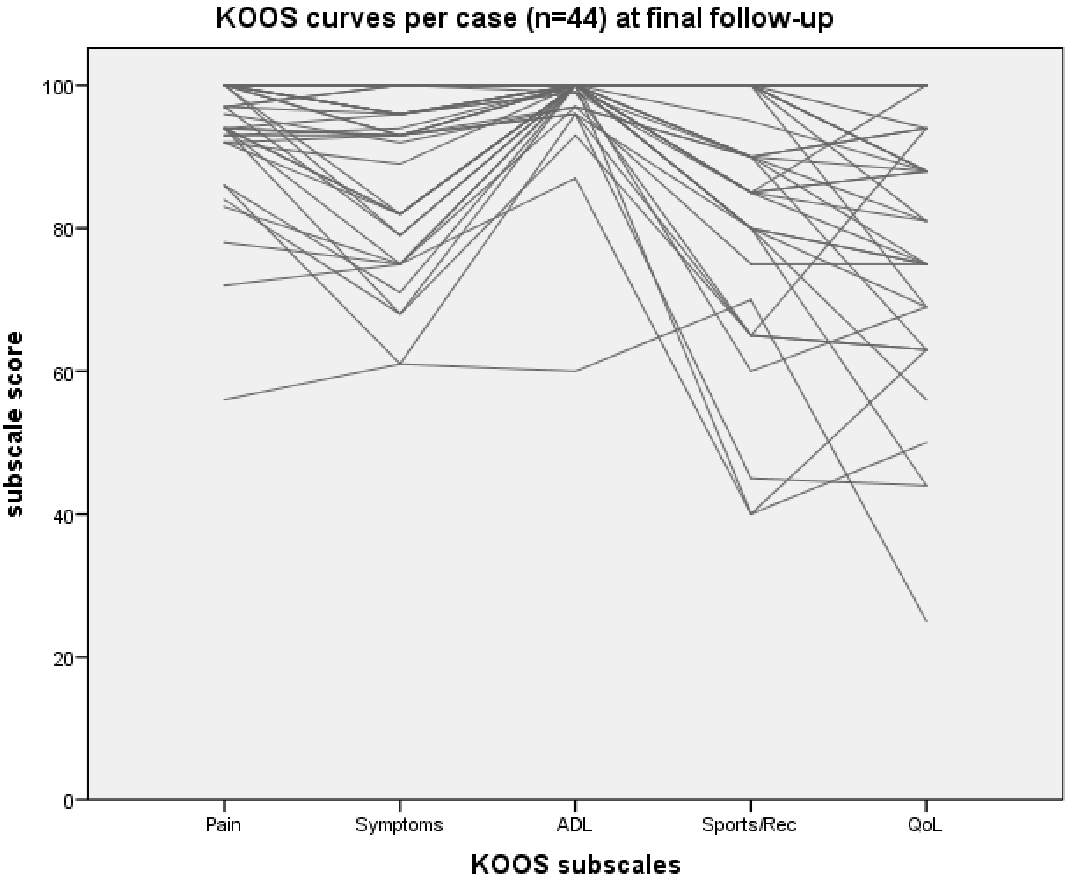

Fig.2 Spaghetti plot of individual KOOS scores

Change from 2 years to final follow-up
IKDC, KOS-ADLS, VAS and KOOS QoL scores improved significantly from 2 years to final follow-up. LSI for muscle strength and hop tests did not change significantly except for the single leg hop test. Means of repeated measures, statistical tests and p-values are listed for these variables in Supplementary file D. For the KOOS subscale Sports/Rec, 8 of 44 (18 %) patients improved more than the defined Minimal Important Change (MIC) of 12.1. For the subscale QoL, 16 of 44 (36 %) patients improved more than the defined MIC of 18.3.

Clinical examination
Of 20 patients who did not undergo ACL reconstruction, all had a positive Lachman test[47] without endpoint and 19 had pivoting on the Slocum test[45].

Sixteen of the 24 ACL reconstructed patients had a side-to-side difference in clinical examination based on Lachman and Slocum tests (in anterior translation (n=1) or pivoting (n=4) or both (n=11)).

Discussion

This study examined long-term results of ACL injured children treated with active rehabilitation and the option of later ACL reconstruction. Our results showed that 45 % of the ACL injured children coped well even through to adulthood without an ACL reconstruction. These findings, show that copers do exist in the pediatric ACL injured population. In the remaining 55 % of the patients, delayed ACL reconstruction was warranted mainly due to instability. Irrespective of final treatment, most patients reported high PROM scores and showed near symmetrical muscle strength and hop performance at final follow-up. Most patients remained physically active, though only 34 % participated in pivoting sports at final follow-up.

The functional tests and PROMs used in this study are appropriate measuring tools for ACL injured patients. Isokinetic dynamometry is reliable and valid[8], and the four hop tests[39] are reliable and valid measures of hop performance[42]. IKDC is a valid, reliable and responsive patient reported outcome measure[24, 25]. Furthermore, KOOS [43] is an adequate score for evaluating adult patients with ACL injuries[44] and is commonly used in this population. Reference data is therefore available in large ACL cohorts such as the Scandinavian ACL registries[18]. The Patient Acceptable Symptom State (PASS) is a defined threshold for predicting knee satisfaction and is useful in interpreting IKDC and KOOS scores in research and clinical practice[38].

It is important to clarify that this is not a comparative study, our results describe the clinical treatment course following our treatment algorithm. Those who had instability problems, functional limitations or sustained major new injuries were scheduled for surgery. The design of this study therefore, prevents a fair comparison of outcomes following active rehabilitation alone versus active rehabilitation and delayed ACL reconstruction.

Our main finding, that some children with ACL injury may cope without an ACL-reconstruction, is not consistent with previously published literature[40] which favors early ACL reconstruction over delayed or no ACL reconstruction to restore knee stability, prevent secondary injuries and maintain activity levels. Several authors have concluded that the risk of sustaining secondary meniscal injuries increase with delay of ACL reconstruction[3, 30]. The majority of these studies, are retrospective or cross-sectional and include only ACL reconstructed patients operated early or delayed. It is likely that the outcomes of these patients do not represent all children with ACL injury who are treated without ACL reconstruction. Selection bias is a major limitation in current literature[4], and this may explain why the patients in this prospective study show far better outcomes and fewer secondary injuries than previously described.

Despite a high follow-up rate and long follow-up time (96 % at mean 8 years), the rate of secondary meniscal injuries (new and aggravated preexisting injuries combined) was still lower than previously reported[46]. New or aggravated preexisting meniscal injuries also occurred after patients underwent ACL reconstruction. In total, 9 of 44 patients had a new injury to a previously healthy meniscus (after active rehabilitation (n=7) or after ACL reconstruction (n=2)). In addition, 6 patients had a concomitant meniscal injury that progressed and required surgery. At final follow-up, no meniscal injuries were identified at clinical examination in the non-reconstructed patients. Secondary meniscal injuries remain a concern in ACL injured children, both following non-surgical treatment and ACL reconstruction. This population should be followed closely to assess instability, need for meniscal repair and ACL reconstruction or revision.

The relatively high number of surgical complications (4 of 24) and re-surgeries (8 of 24), is consistent with previous publications. DeFrancesco et al.[11] reported that 1 in 6 ACL reconstructed patients required additional surgery within the first 3 years. Interestingly, like us, they found that graft ruptures were the reason for less than half of these re-surgeries. In a case series including 27 skeletally immature children treated with all-epiphyseal ACL reconstruction, Wall et al.[48] found a high complication (48 %) and re-surgery rate (37%). The graft failure rate in our series (2/44) was similar to the rates reported in two studies by Kocher et al.[28, 29], but substantially lower than reported by Wall et al.[48] and Dekker et al.[12]. Dekker et al reported an ACL re-injury rate (graft rupture or contralateral ACL injury) of 32 % in 112 ACL reconstructed patients under the age of 18 years[12]. Time to return to sport was associated with a second ACL injury[12]. In the studies by Wall[48] and Dekker[12], 81 % and 91 % of patients respectively returned to sport. In our case series, the low graft failure rate may be explained by most patients restricting themselves only to non-pivoting sports, close follow-up, and older age at the time of surgery. In the final year of high school, 3 of 4 young athletes in our country have quit organized sports[1]. This trend may influence activity levels and contribute to improved PROMs at final follow-up, which seem consistent with our finding that only 13 patients in our case series reported that they reduced their activity level due to their knee function.
Both the symmetrical functional performance and high PROM scores are consistent with previous high-quality studies. Interestingly, several studies in adults with medium to long-term follow-up found no significant differences in patient-reported outcome measures[16, 19, 32], hop performance[32] and muscle strength[2, 19] between ACL reconstructed patients and those treated with active rehabilitation alone. However, the surgically treated patients in these studies may be biased towards a worse outcome as a result of failed non-surgical treatment.

Kocher et al[28] reported a mean IKDC score of 96.7 (SD 6) in 42 children in Tanner stages 1 and 2 at mean 5.3 years after physeal-sparing ACL reconstruction, and mean 89.5 (SD 10.2) in 57 children in Tanner stage 3, mean 3.6 years after transphyseal ACL reconstruction[29]. These IKDC scores were higher than scores reported by ACL reconstructed patients in our case series, but children in Tanner stage 3[29] reported similar scores as those reported by our non-reconstructed patients. In comparison, the ACL reconstructed patients in our case series underwent ACL reconstruction due to instability, functional limitations or secondary injuries and were thus likely to be biased towards a worse outcome. Furthermore, follow-up time is shorter in the aforementioned studies by Kocher et al., and patients who sustained a graft rupture were not included in the analysis (2 patients in each study).

Regardless of whether delayed ACL reconstruction was performed or not, the mean KOOS subscale scores reported in this case series were higher than scores reported by ACL reconstructed adults in the Norwegian Knee Ligament Registry[41], and for the subscales pain and ADL, similar to scores reported by uninjured adult controls[9]. KOOS ADL may not be a relevant outcome for this group[23] as scores are generally high throughout the treatment course.

The PROM scores improved from 2 years to final follow-up. However, regarding the KOOS subscales, only QoL improved indicating that aspects related to quality of life may be the main factor contributing to this improvement. Trends in activity level and common lifestyle change when maturing from childhood to adulthood may influence these changes in PROM scores.

Clinical examination verified a high degree of knee laxity in the non-reconstructed patients. The ACL reconstructed patients also had increased knee laxity, compared to their uninjured knee. Several factors may contribute to the high proportion of side-to side-differences in clinical examination in this study such as low age at surgery (mean 15.3 years) compared to most adult studies, the properties of the hamstrings graft that was predominantly used, possibly a more steep angle of the femur tunnel to avoid an oval injury zone to the femoral epiphysis (at expense of anatomic position) and possibly stretching of the graft over time due to growth, inherent hyper laxity in this population or hyper laxity changes in the injured knee as a response to the injury.

Strengths and limitations

This is the first prospective study to follow children with ACL injuries treated with active rehabilitation and optional delayed ACL reconstruction through to skeletal maturity and adulthood. The prospective design and inclusion of children treated non-surgically, strengthens the results of the study. The low number of patients lost to follow-up (n=2) and the high proportion of inclusion to eligible patients with ACL injury (46 out of 50), indicate that this is a representative sample of children with ACL injuries. Furthermore, all patients were skeletally immature and 12 years or younger at the time of inclusion.

Some children had a delay in diagnosis[33]. Meniscal injuries observed at baseline may have occurred after the index ACL injury and the number of new injuries to a healthy meniscus may be higher than 9. However, these potentially new injuries would have occurred before the injury was diagnosed and treatment initiated.

The PROMs used at the 2-year follow-up were not validated in children, and pediatric versions were not available at the time[33]. Also, MIC for deterioration is not defined[23] and therefore not described. The heterogeneity regarding surgical details in this cohort, prevents generalization of the results to a specific surgical method, surgeon or homogenous population at the time of surgery (i.e. age), but may be generalized to a surgical practice similar to ours.

This is a descriptive study, we have therefore not adjusted for confounding factors in the design. Because some patients develop instability with active rehabilitation alone, a key question is how to identify those who require ACL reconstruction. Due to the limited sample size, we are not able to identify robust predictors for instability warranting delayed surgery. However, we may speculate that female sex may increase the risk (11/15 females had ACL reconstruction due to instability problems). Furthermore, all patients who continued competing at a high level in a pivoting sport (soccer n=1, alpine skiing n=2) had ACL reconstructions, but a patient competing at a high level in a non-pivoting sport (cross-country) are still not ACL reconstructed. The Pediatric ACL Monitoring Initiative[37] and inclusion of non-surgically treated patients with ACL injury in The Norwegian Knee Ligament Registry[15], will provide larger data sets on children with ACL injuries, which may help to identify such important prognostic factors in the future.

Clinical relevance

Our suggestion that pediatric ACL copers do exist, and that some remain copers through to adulthood is a novel finding and a potential game-changer for the management of ACL injuries in children. Our findings can be used to inform clinicians and support them in shared decision-making[5]. This case series may be a useful reference for expected outcomes in children with ACL injuries following our treatment algorithm and can be used to inform patients and their caretakers. However, in this study, we closely followed the patients to be able to change our treatment approach if active rehabilitation did not provide adequate knee function. Some patients had instability problems or functional limitations and some sustained new injuries to their menisci after active rehabilitation or ACL reconstruction. Therefore, irrespective of treatment approach, children with ACL injuries need to be followed closely by both the orthopedic surgeon and physical therapist until skeletal maturity. We need to identify those who may benefit from surgery and those who cope well without. Management of pediatric ACL injuries may be about balancing risks rather than reducing one particular risk.

Conclusion

Primary non-surgical treatment with active rehabilitation may have a role in management of ACL injured children without additional injuries that warrant surgery. Approximately 50 % of these children with ACL injury may cope well and have healthy menisci even through to adulthood without a surgical intervention. The other half may need delayed ACL reconstruction due to instability, functional limitations or secondary injuries. It is likely that at least 1 in 3 will need meniscal surgery before they reach adulthood. As they reach adulthood, regardless of final treatment, the majority of patients had good function without much pain or symptoms in daily living and remained physically active, but 2 out of 3 reduced their level of activity to a non-pivoting sport.

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