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Performance-based functional outcome for children 12 years or younger following anterior cruciate ligament injury: a two to nine-year follow-up study

Håvard Moksnes · Lars Engebretsen · May Arna Risberg

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Abstract There is limited scientific knowledge on ACL injuries in children 12 years or younger. Substantial controversy exists on treatment algorithms and there are no published data on performance-based functional outcome. Classification of adult ACL injured subjects as copers and non-copers is common, but no study has classified knee function in children using performance-based functional test after ACL injury. The aim of the present study was to evaluate the medium-term functional outcome among children with ACL injury and to classify them as copers and non-copers. Children 12 years or younger who were referred to our institution from 1996 to 2004 with an ACL injury were included. Twenty non-operated subjects (21 knees) and six ACL reconstructed subjects (7 knees) were examined at a minimum of 2 years after ACL injury or reconstruction. Four single-legged hop tests, isokinetic muscle strength measurements, and three functional questionnaires (IKDC 2000, KOS-ADLS and Lysholm) were used as outcome measurements. Children who had resumed their pre-injury activity level and performed above 90% on all hop tests were classified as copers following non-operative treatment and ACL reconstruction. The 26 children were on average 10.1 years at the time of injury. Of the non-operated children, 65% had returned to pre-injury activity level, and 50% were classified as copers. Copers scored significantly better than non-copers on single hop for distance, IKDC 2000, and Lysholm score. Of the non-operated children, 9.5% had suffered a secondary meniscus injury. Of the ACL reconstructed subjects, 67% were classified as copers at follow-up. Non-operated ACL-deficient children demonstrated excellent knee function on performance-based single-legged hop tests and 65% had returned to pre-injury activity level. Delayed ACL reconstruction resulted in success for a majority of the ACL-reconstructed children. Treatment algorithms for ACL-injured children are discussed.

Keywords Knee · ACL · Prepubescent · Children · Copers · Non-copers · Single-legged hop tests · IKDC

Introduction

Intrasubstance tears of the anterior cruciate ligament (ACL) in children with open physes has been described with increasing frequency over the last 10 years [2, 3, 49]. Controversy exists on the management of these serious knee injuries in this population, and the classical approach is non-operative treatment with physical therapy, activity limitations, and bracing until the child nears the end of his growth [5, 8, 36]. The development of new and allegedly safer surgical techniques has increased the number of orthopedic surgeons who practice early ACL reconstructions in children with open physes [3, 30, 52].

Despite the increased frequency of ACL injury in children, no long-term studies including performance-based functional outcome measurements have been reported. A recent systematic review by Mohtadi and Grant [41] concluded that there are no published studies, with the level of

H. Moksnes (✉) · M. A. Risberg
The Norwegian Sport Medicine Clinic
and Norwegian School of Sport Sciences,
NAR, Orthopaedic Centre, Ullevaal University Hospital,
NIMI Ullevaal, Sognsveien 75 D, 0805 Oslo, Norway
e-mail: h.m@nimi.no

L. Engebretsen
Orthopaedic Center,
Ullevaal University Hospital and Medical School
and Oslo Sports Trauma Research Center,
Kirkeveien 166, 0407 Oslo, Norway

evidence higher than level III in the literature, on the management of ACL injury in skeletally immature individuals (Table 1). According to Mohtadi and Grant [41], the literature mainly consists of case series with heterogeneous materials and reviews with expert opinions. Furthermore, no study that includes performance-based functional outcome has been reported, regardless of the level of evidence. Previous studies are limited to outcomes of knee arthrometer measurements, questionnaires and return to sport [41]. Performance-based functional tests to guide in the decision process of whether or when a child should undergo ACL reconstruction are unavailable. For adult ACL-deficient subjects, some clinical treatment algorithms have been proposed based on functional hop tests and knee surveys [15, 16, 42]. Adult ACL-deficient subjects who are able to return to sports at their pre-injury activity level without ACL reconstruction are referred to as copers [50], while subjects who experience dynamic instability and are unable to participate at their pre-injury activity level are termed non-copers or adapters [9, 15, 50]. Fitzgerald et al. [16] proposed a decision-making algorithm in which subjects who met specific single-legged hop test and functional scoring criteria were classified as potential copers, while those who did not were classified as non-copers. Of the subjects classified as potential copers, 79% were able to continue high-level sports without symptoms of dynamic knee instability for a limited period subsequent to rehabilitation [15]. A similar decision-making algorithm is needed for children with ACL injury.

The outcome of conservative treatment of ACL tears in skeletally immature patients has been reported to be poor, with chronic instability and increased risk of meniscus and cartilage injury [18, 27, 39]. Chronic instability may increase the possibility of meniscus injuries, early knee osteoarthritis (OA) and major functional limitations [13, 18, 27]. Even though surgical treatment of adolescents with ACL injury is increasing, the risk for iatrogenic growth disturbance due to physeal damage to the distal femoral physis or the proximal tibial physis has restricted the use of surgical reconstruction especially in the youngest patients [30]. In addition, inferior outcome has been reported after ACL reconstruction in children compared to adults, seen as higher instability rates and increased knee joint laxity [12, 14]. Despite the lack of high quality studies, a number of case series have reported that a majority of ACL-reconstructed adolescents successfully return to pivoting sports [12, 30, 38, 48].

The treatment algorithm for children with ACL ruptures in our country is conservative with regard to early ACL reconstruction. Children with ACL injury are advised to take part in structured rehabilitation supervised by a physical therapist for 3–6 months after the ACL injury. They are encouraged to continue to be physically active at their desired activity level, and to wear a brace when they perform sports that may put them at risk for pivoting their knee. ACL reconstruction is delayed until they reach skeletal maturity, unless they have numerous subluxations or one subluxation event leading to a displaced meniscus,

Table 1 Overview of studies from Mohtadi and Grant [41]. The present study included

Authors	Level of evidence	Patients with early reconstruction	Patients with nonsurgical or delayed reconstruction	Reconstruction technique	Outcomes evaluated
Aichroth et al. [1]	Type III	45 (47 knees), average age 13	23 (23 knees), average age 12.5	4 Stranded hamstrings	Lysholm, Tegnèr, IKDC
Graf et al. [18]	Type III	4 (4 knees)	8 (8 knees)	2 Extra-articular, 2 intra-articular semitendinosus	Return to sport, instability symptoms, meniscal tears
Janarv et al. [26]	Type III	5, age 9.9–15.0	7 Nonsurgical, 15 delayed	Semitendinosus and patellar tendon	Lysholm, Tegnèr, KT arthrometer, Kin-Com
McCarroll et al. [35]	Type III	24, average age 13.3	16 Nonsurgical, average age 13	10 Extra-articular, 14 patellatendon	Return to sport, meniscal tears, KT arthrometer
McCarroll et al. [37]	Type III	22, age 12–15	38, age 12–15	Bone–patellar tendon–bone	Return to sport, KT arthrometer
Pressman et al. [46]	Type III	7, average age 14.4	8	Semitendinosus and patellar tendon	Lysholm, Zarins and Rowe, KT arthrometer
Woods and O'Connor [54]	Type III	13, average age 14.5	13, average age 13.8	Bone–patellar tendon–bone	Meniscal or cartilage injury, IKDC
Moksnes et al. (present study)	Type III	0	20 (21 knees) Non-surgical, 6 (7 knees) delayed, average at injury 10.1	6 Hamstrings, 1 patellar tendon	Hop tests, isokinetic strength, IKDC, KOS-ADLS, Lysholm

in which case their meniscus is repaired and the ACL reconstructed with a hamstring graft.

The purpose of this study was to investigate and describe the medium-term outcome for children who all acquired their ACL rupture before turning 13 years and who were subjected to the treatment algorithm in our country. The first aim of the study was to examine the medium-term functional outcome in children who injured their ACL before turning 13 years old using established functional knee surveys, functional hop tests, isokinetic muscle strength measurements, and knee joint laxity measurements commonly used in adult ACL-injured subjects. Secondly, the aim was to classify those who had undergone non-operative treatment as copers or non-copers, based on functional hop tests, and their pre-injury and current activity level. Thirdly, we wanted to classify those who had gone through ACL reconstruction as copers or non-copers, based on functional hop tests, and their pre-injury and current activity level.

Materials and methods

A total of 37 consecutive children with ACL rupture were referred to our institution between 1996 and 2004. Inclusion criteria in the present study were ACL rupture before turning into the age of 13 years and a minimum of 2 years from the ACL injury or ACL reconstruction to the follow-up examination. Additional inclusion criteria were intra-substance ACL rupture confirmed by magnetic resonance imaging (MRI), clinical examination by one experienced orthopedic surgeon (LE) and an instrumented Lachman test [a side-to-side difference in anterior tibiofemoral laxity of 3 mm or more, using maximum manual force measured with a knee arthrometer (KT-1000, Med-Metric, San Diego, CA, USA)] [29, 34, 55]. Exclusion criteria were ACL avulsion injury, posterior cruciate ligament injury or intraarticular fractures.

We classified non-operated subjects as copers at the follow-up examination if they (1) had resumed their pre-injury activity level, and (2) performed single-legged hop test indexes $\geq$90% of the uninjured limb. Subjects who failed any of these two criteria were classified as non-copers at follow-up. Identical criteria were used to evaluate outcome after ACL reconstruction: subjects who fulfilled the two criteria were classified as copers, while subjects who failed any criteria were classified as non-copers. The subjects' activity level was classified based on the children's reports of regular pre-injury activities and current activities in the last month before follow-up, according to the criteria described by Hefti et al. [20]. We classified children who regularly participated in pivoting sports (e.g., soccer) as level 1, while participation in physical education in school, alpine skiing and sports requiring less cutting and pivoting (e.g., racket sports) were classified as level 2. Children who participated in regular sports activities without cutting or pivoting (e.g., cross-country skiing and running) or did not participate fully in physical education in school were classified as level 3.

The study was approved by the Data Inspectorate and the Regional Committee for Medical Research Ethics (REC). All children and parents gave informed written consent on a form approved by REC prior to inclusion.

Performance-based functional hop tests

Prior to the functional examination, all children performed a standardized warm-up protocol of 10 min on a stationary bike. All single-legged hop tests were supervised by the same physical therapist (HM). The functional examination consists of four previously described and validated single-legged hop tests [11, 15, 17, 43]. The tests include (1) the single hop test, (2) the triple hop test, (3) the triple cross-over hop test, and (4) the 6 m timed hop test. Subjects performed one practice trial followed by two measured trials of each single-legged hop test on both legs. The test was considered valid only if the subject managed a firm landing without twisting the foot or excessive balance movements. The hop test score for each leg was reported as the better of the two measured trials. The uninjured leg was tested first. No brace was used during the hop tests.

The single hop, triple hop, and triple crossover hop indexes were expressed as a percentage of the injured extremity score divided by the uninjured extremity score. The 6 m timed hop index was expressed as a percentage of the uninjured extremity time divided by the injured extremity time.

Isokinetic muscle strength

Isokinetic muscle strength test equipment (Technorev 9000, Gambettola, Italy (August 2005) and Biodex 6000, Shirley, NY, USA (October 2006)) was used to evaluate the quadriceps and hamstrings muscle performance. In August 2005, using the Technorev 9000 borrowed from another institution, 16 subjects were tested and 10 were tested in October 2006 using our own new Biodex 6000 dynamometer. We included isokinetic muscle strength testing at an angular velocity of 60°/s. The subjects performed four practice trial repetitions before the five measured repetitions. Peak torque was used as the isokinetic parameter to evaluate muscle performance. The work performed by the involved limb was normalized to

the uninvolved limb [(involved/uninvolved) × 100] and expressed as a percentage.

Laxity measurements

Saggital knee joint laxity was measured by one experienced senior physical therapist (MAR) with a KT-1000 arthrometer (Med-Metric, San Diego, CA, USA) to record anterior displacement of the tibia relative to the femur [10]. Maximum manual force measurement was used in the analysis.

Clinical examination

One experienced orthopedic surgeon (LE) performed the clinical examination. Kocher et al [29] has shown that sensitivity in evaluating intraarticular knee disorders by MRI is lower in children younger than 12 years old compared with children 12–16 years old (61.7 versus 78.2%). The gold standard for diagnosis is arthroscopy [51, 53], but this is not the usual examination for children with knee injuries in our country. The ACL injured children were diagnosed with a combination of the Lachman test, pivot shift test and MRI findings, as this has been shown to give the most accurate diagnosis in children with acute knee injuries [28, 29, 31, 34].

Functional questionnaires

Validated questionnaires for children with ACL injury, to our knowledge, have not been developed. The International Knee Documentation Committee Subjective Knee Form (IKDC 2000) is validated for subjects older than 18 years and was included as one of two functional knee surveys. The IKDC 2000 includes questions related to knee symptoms: pain, stiffness, swelling and instability, and knee function [23]. The questionnaires were primarily filled in by the children, with help from their parents and the test team.

Global rating of knee function was measured on a linear visual analogue scale (VAS), with 100 points being the subject's level of knee function prior to injury and 0 points being inability to perform any activities of daily living. The patients were asked to draw a slash on a hundred millimeter horizontal line with a mark of 0 and 100 at each end of the line [24].

Knee function was also evaluated with the Knee Outcome Survey Activities of Daily Living scale (KOS-ADLS) [24] to provide information regarding the children's knee function during daily activities such as stair climbing, running and squatting. Lysholm score [33] was included to compare results with previous research on populations of young ACL-injured subjects.

Statistical analysis

Statistical analyses were performed using NCSS97 (Number Crunches Statistical System, version 2.0.0.406, NCSS, Kaysville, UT, USA). Mean, standard deviation (SD), and minimum (min) and maximum (max) were calculated for all parametric values, and median and minimum/maximum was used for ordinal or nominal data. Two sample *t*-tests were used for group comparisons (copers/non-copers) when normality distribution was presumed, and similarly Mann–Whitney *U* test for difference where used when normality distributions were rejected. Alpha levels were set at 0.05.

Results

From 1996 to 2004, 37 children 12 years old or younger were referred to our institution with ACL injury. Of the 37 children, 30 met the inclusion criteria and were invited to participate in a follow-up examination in January 2005 and October 2006; 26 subjects (87%) were available and attended the follow-up sessions. Four subjects were not able to be present at the follow-up examinations, while the remaining seven subjects had a follow-up time of less than 2 years since injury or ACL reconstruction and were therefore excluded from the investigation.

There were 11 girls and 15 boys included in this study. The children were mean 10.1 years (minimum 5.3, maximum 12.7 years) at the time of ACL rupture. The presence of open growth plates was documented on all subjects at the post-injury MRI. The mean age of the children was 14.1 years (minimum 7.9, maximum 18.6 years) at follow-up, with a mean time from injury of 3.9 years (minimum 1.9, maximum 9.0 years). Twenty subjects (21 knees) had undergone non-operative management, while six subjects (7 knees) had undergone ACL reconstruction. Characteristics of the non-operated and the ACL-reconstructed children are presented in Table 2. Alpine skiing (32.1%) and falling from heights (21.4%) were the two most frequent activities that caused ACL injury (Table 3).

Among the 20 non-operated children, 65% ($n = 13$) reported that they had resumed their pre-injury activity level, while 35% ($n = 7$) had lowered their activity by at least one level. About 58% (7/12) of the children participating in level 1 activities had resumed their activity level, 71% (5/7) resumed level 2 activities, and one subject remained at level 3 activities. Results of the functional

Table 2 Descriptive summary of the characteristics of non-operated and ACL reconstructed subjects

	Non-operated	ACL reconstructed	*P*-value
Individuals	20 (21 knees)	6 (7 knees)	
Female/male (n/n)	9/11	2/4	
Age at injury (years)	10.2 (5.3–12.7)[a]	10.8 (9.6–12.7)[a]	0.25
Age at follow-up (years)	12.7 (7.9–16.9)[a]	17.6 (16.2–18.6)[a]	<0.01
Follow-up time (years)	2.9 (2.0–5.2)[a]	6.7 (4.2–9.0)[a]	<0.01

[a] median (minimum–maximum)

Table 3 The frequency distribution of activities performed at the time of injury

Activity at injury	Frequency
Alpine skiing	9
Fall from a height while playing	6
Soccer	3
Bicycle	2
Gymnastics	1
Handball	1
Martial arts	1
Ice hockey	1
Skating	1
Motocross	1
Ski-jumping	1
Unknown	1
Total	28

outcomes are reported in Table 4. Of the non-operated children, 50% (n = 10) were classified as copers and 50% (n = 10) as non-copers. Copers performed significantly better on the single-hop test, IKDC 2000, and Lysholm score compared to non-copers (Table 5).Two children had undergone arthroscopy and were treated with partial medial meniscus resections without ACL reconstruction. ACL reconstructions were not performed due to the two subjects' young age at the time of surgery (5.5 and 10.0 years). Results from the pivot shift test showed that 10% had pivot shift test grade 0, 5% had grade I, 45% had grade II, and 40% had grade III. There were no significant differences in the number of children with pivot shift test grade 0, I, II, or III between copers and non-copers (P = 0.29).

Six children (seven knees) had undergone ACL reconstruction due to functional instability or repairable meniscus injury. Tables 6 and 7 summarize the results for the children who had undergone ACL reconstruction. Their median age was 11.7 years (minimum 9.6, maximum 12.7 years) at the time of injury, and average 14.2 years (minimum 12.8, maximum 15.5 years) at the time of surgery. Of the ACL reconstructed subjects, 67% (n = 4) were classified as copers at follow-up. Between the two non-copers, one subject presented a knee with clinical re-rupture of her ACL at follow-up examination, while the other was not able to meet the success criteria on the triple-hop test. Six of the reconstructions were performed with soft-tissue hamstring graft and endo-button fixation, while the seventh knee had bone patellar tendon bone graft.

Table 4 The results for non-operated subjects, mean (±SD)

	Results (n = 20)
Age at injury (years)	10.0 (±2.0)
Age at follow-up (years)	13.1 (±2.3)
Height (cm)	162 (±11.9)
Weight (kg)	51 (±12.9)
Activity level (pre-injury, 1–4)	2 (1–2)[a]
Activity level (present, 1–4)	2 (1–2)[a]
VAS	85 (68–90)[a]
KOS-ADLS	96 (86–97)[a]
IKDC 2000	85 (71–95)[a]
Lysholm	88 (76–100)[a]
Single hop (% of uninjured)	96.5 (±8.0)[b]
Triple hop (% of uninjured)	94.7 (±8.2)[b]
Triple crossover hop (% of uninjured)	96.3 (±7.4)[b]
6 m timed hop (% of uninjured)	96.9 (±6.0)[b]
Quadriceps index (% of uninjured)	92 (±16)[b]
Hamstring index (% of uninjured)	99 (±26)[b]
KT 1000 (mm difference)	5.5 (±2.4)[b]

[a] Median (95% confidence intervals)

[b] Bilateral injured subject excluded, n = 19

Discussion

The present study is the first to report medium-term results on performance-based functional outcome in children who were under the age of 13 years at the time of ACL injury. Performance-based data are commonly used in the evaluation of adult ACL-injured individuals and should also be included for ACL-injured children to optimize the knowledge of clinicians with regard to treatment options.

The average results for the children in this study were excellent with regard to performance-based functional single-legged hop tests and isokinetic muscle strength measurements. The Scandinavian community traditionally encourages free and unrestricted physical activity for children, and our treatment algorithm for children with ACL injury reflects the active Scandinavian lifestyle with continued pre-injury activities if the child has a functional stable knee. This approach is fundamentally different from the algorithms suggested by Mohtadi and Grant [41] and

Table 5 The results for non-operated subjects, copers compared to non-copers, mean (±SD)

	Copers (n = 10)	Non-copers (n = 10)	P-value
Age at injury (years)	10.5 (±1.3)	9.3 (±2.9)	0.14
Age at follow-up (years)	13.6 (±1.7)	12.5 (±2.7)	0.28
Height (cm)	160 (±9.3)	163 (±11.0)	0.63
Weight (kg)	48 (±13.3)	51 (±12.7)	0.71
Activity level (pre-injury, 1–4)	1.5 (1–2)[a]	1.5 (1–2)[a]	0.83
Activity level (present, 1–4)	1 (1–2)[a]	2.5 (2–3)[a]	<0.01
VAS	88 (80–99)[a]	75 (61–96)[a]	0.11
KOS-ADLS	97 (89–100)[a]	94 (70–97)[a]	0.07
IKDC 2000	93 (80–100)[a]	74 (62–94)[a]	0.02
Lysholm	95 (87–100)[a]	80 (67–84)[a]	<0.01
Single hop (% of uninjured)	100.0 (±7.2)	92.2 (±7.2)[b]	0.04
Triple hop (% of uninjured)	98.1 (±5.1)	90.9 (±9.5)[b]	0.05
Triple crossover hop (% of uninjured)	98.2 (±5.3)	94.2 (±9.0)[b]	0.25
6 m timed hop (% of uninjured)	99.3 (±5.1)	94.3 (±6.1)[b]	0.07
Quadriceps index (% of uninjured)	93 (±14)	90 (±20)[b]	0.77
Hamstring index (% of uninjured)	101 (±21)	97 (±32)[b]	0.74
KT 1000 (mm difference)	5.7 (±2.7)	5.2 (±2.0)[b]	0.66

[a] Median (95% confidence intervals)

[b] Bilateral injured subject excluded, n = 9

Table 6 Individual characteristics and surgical records for the ACL reconstructed subjects

	1, male	2, male	3, female	4, female	5, male	6, male
Age at injury (years)	9.6	9.9	11.9	11.7	12.7	9.7 (left) ? (right)
Age at surgery (years)	15.4	15.5	15.1	13.3	13.9	12.8 (left) 13.5 (right)
Age at follow-up (years)	18.6	18.2	18.4	16.2	16.9	16.5
Height at follow-up (cm)	177	185	166	166	181	Missing
Weight at follow-up (kg)	68	73	65	58	71	Missing
ACL reconstruction technique	Hamstring	Hamstring	Patellatend.	Hamstring	Hamstring	Hamstring (left) Hamstring (right)
Additional surgical procedures	Lateral suture	Lateral partial resection	No	Medial suture, lateral partial resection	No	No
Secondary meniscus surgery	Lateral partial resection	No	No	Medial partial resection	No	No

Woods and O'Connor [54]. Contrary to several studies [13, 18, 27, 30, 39], we observed that only 11% (n = 3) of the included children had to undergo ACL reconstruction due to secondary repairable meniscus injury, while only 9.5% (n = 2) of the non-operated subjects suffered a minor unrepairable secondary meniscus injury, which gives a total incidence of meniscus injury of 18% in the 28 knees investigated in this study. The children averaged well above 90% on all functional single-legged hop tests and isokinetic muscle strength measurements, results which have been suggested as normal knee function in previous literature [25, 44, 45, 47]. With regard to the functional single-legged hop tests, there are no studies on comparable populations, but in a study by Gustavsson et al. [19] on adult ACL-injured subjects, only 10% of the subjects had restored single-leg hop performance 11 months after ACL injury, using 90% of uninjured leg as success criteria. The subjects in the present study also performed equally well or better than the adult subjects reported by Fitzgerald et al. [15], who averaged 90–95% (copers) and below 90% (non-copers) on single-legged hop tests after non-operative treatment.

In contrast to previous published data for non-operated ACL-injured children [1, 2, 40], we found good results on Lysholm score [88 (95% CI 76–100)] and the IKDC 2000 [85 (95% CI 71–95)]. Lysholm score >95 is considered to be excellent, while 84–95 is regarded as good [33]. Mizuta et al. [40] reported an average Lysholm score of 64, while

Table 7 The results for ACL reconstructed subjects

	1, male	2, male	3, female	4, female	5, male	6, male
Coper/non-coper	Coper	Non-coper	Coper	Non-coper	Coper	Coper
Activity level (pre-injury, 1–4)	2	1	3	1	1	1
Activity level (present, 1–4)	2	1	3	3	1	1
VAS	78	70	99	36	92	85
KOS-ADLS	86	81	100	83	91	97
IKDC 2000	70	92	97	61	97	94
Lysholm	76	89	95	62	99	84
Single hop (% of uninjured)	94.3	94.7	95.4	–[a]	103.0	–[b]
Triple hop (% of uninjured)	102.6	89.3	102.6	–[a]	101.8	–[b]
Triple crossover hop (% of uninjured)	107.5	92.5	109.0	–[a]	101.7	–[b]
Timed hop (% of uninjured)	105.9	93.8	100.0	–[a]	100.0	–[b]
Quadriceps index (% of uninjured)	116	82	98	64	102	–[b]
Hamstrings index (% of uninjured)	112	73	103	88	97	–[b]
KT1000 (mm difference)	0	7	3	9	6	–
Pivot shift (0–3)	0	1	2	3	1	0 (bilateral)

[a] Not able to perform hop tests due to knee function

[b] Not able to perform hop or muscle strength test due to an ankle fracture at follow-up

Aichroth et al. [1] reported an average score of 79 on conservatively treated children after ACL injury. Our median Lysholm score of 88 points is equivalent to Janarv et al. [26], who reported an average of 87 points on the Lysholm score. A high proportion of non-operated subjects (65%) had resumed their pre-injury activity level, indicating that most children had confidence in their knee function and were able to participate in free and regular activities. In the present study, the percentage of children who resumed pre-injury activity level was lower among those who originally participated in level 1 activities, than those who participated in level 2 activities. The variability in return-to-sport rates among non-operated ACL-injured children was high [26, 37]. Janarv et al. [26] from Sweden reported that 88% of their non-operated children performed activities at their desired level. McCarrol et al. [37] described that 42% attempted to return to sport after conservative treatment (all failed), while no children in Woods and O'Connors [54] study continued at their pre-injury activity level, due to the restrictions in their treatment algorithm. There seems to be a difference in the return-to-sport rates after non-operative treatment between the Scandinavian countries and the USA, although the materials are small and not directly comparable. Our investigation supports the assumption that returning to level 1 activities is less likely than level 2 activities after non-operative treatment, which indicate that children in level 1 activities probably should be considered for ACL reconstruction when they near skeletal maturity. Due to the retrospective design of this study and the difference in follow-up time between the non-operated and ACL-reconstructed children, we are not able to provide enlightenment on the issue of which children are most likely to succeed from non-operative treatment.

The results of the present study showed that half (50%) of the non-operated children were classified as copers, based on the strict performance-based criteria. The ten children classified as copers had resumed their pre-injury activity level and scored above 98% compared to their uninjured leg on all four single-legged hop tests. Additionally, three children had resumed their pre-injury activity level, but did not meet the classification criteria for copers. Seven children reported that they had lowered their activity level and were thereby classified as non-copers, even though this classification does not take into consideration that some of the non-copers might be adapters. Adapters are described in previous studies as individuals who in spite of a stable, well-functioning knee choose to avoid high-risk activities. The causes for such a response are probably multifactorial, such as an unwillingness to go through a strenuous rehabilitation after an ACL reconstruction, social issues, or other significant reasons for the individual child and parents [9].

There were four outcome measurements that statistically distinguished between copers and non-copers: the IKDC 2000, the Lysholm score, present activity level, and the single-hop for distance test. Because activity level was part of the classification criteria, it was bound to be different between the two groups. Similarly, all the four single-legged hop tests were part of the classification criteria and we expected that all would be significant in distinguishing between copers and non-copers. But, since subjects classified as non-copers also performed high on the hop tests,

there were only the single-hop for distance test that was significantly different between the two groups. The same differences between copers and non-copers are seen in adult ACL-injured individuals [21, 22]. Significant statistical differences in the functional knee questionnaires support the utilization of functional surveys in the classification of ACL-injured children, and the limited ability of single-legged hop tests to distinguish copers from non-copers support the use of several functional tests in addition to questionnaires. There are no other published studies on hop-test performance in ACL-deficient children, even though these functional outcome measurements are widely used to classify adult ACL-injured subjects [17, 32, 43]. A major limitation in the literature on children with ACL injury is that nearly all previous research have reported data on older populations (adolescents), with high variation in age at the time of injury, and utilizing only questionnaires and outcome measurements such as return to sport or knee laxity. No statistical significant differences in KT1000 measurements or pivot shift grading were found between copers and non-copers in the present investigation, which may be due to the fact that children have greater laxity in their joints [4, 31]. We suggest that clinicians should be careful in using only the pivot shift test to decide on treatment options for young children.

Kannus and Jarvinen [27] reported poor outcome in non-operated children who had significant quadriceps and hamstring muscle strength weakness after ACL injury. Our study did not support these findings as there were no significant differences between copers and non-copers regarding isokinetic muscle strength tests. Kannus and Jarvinen [27] reported that four out of their seven subjects had post-traumatic arthritis evident on X-rays, which may have influenced the strength measurements because of pain or swelling. Janarv et al. [26] did not find statistical differences in knee extension strength between the uninjured and injured leg in seven well functioning non-operated subjects, which is supported by the results from our group of copers.

There are several limitations to this study. The retrospective design limits the possibility to examine changes in knee function over time in children with ACL injury. MRI scans at follow-up could have given data on menisci and cartilage injuries in the knee joint. The functional questionnaires utilized are not validated for children, and validated questionnaires on knee function in children do not exist. We lack data on the rehabilitation protocols used after the ACL injury and details regarding the children's physical activity level during the years after the injury. ACL injury in children compared to adult individuals is rare, and most studies like ours have limited number of subjects included. The statistical power of the study is therefore limited, and the differences found between our study and small populations of children with ACL injury reported by others might be due to sample size. Borderline statistical significances were found for the KOS-ADLS, the VAS for global rating of knee function, triple-hop for distance test, and the timed hop test. The possibility of a type II statistical error should be taken into consideration.

Mohtadi and Grant [41] suggested a treatment algorithm where pivoting sports is avoided and "adult" ACL reconstruction is delayed until skeletal maturity is reached for children without dynamic knee instability (copers). Children who experience dynamic knee instability (non-copers) should have an early anatomical ACL reconstruction using hamstrings autograft with fixation avoiding the growth plates [41]. They base their algorithm on the danger of meniscus injury for children without dynamic stability. This is supported by Graf et al. [18], who found an increase in meniscus injuries when delayed ACL reconstruction was performed in children/adolescents with ACL injury. The risk of meniscus injury is the main argument for orthopedic surgeons who advocate early ACL reconstruction even for the youngest children [8, 39]. A different approach was reported by Woods and O'Connor [54], who had success with a strict protocol where all children were taken out of specific activities until skeletal maturity was reached. They found that there was no increase in additional injuries in the knees of 13 ACL-deficient children. The present study does not provide support for a substantial benefit of restricting children's activities, as our population of ACL-injured children seem to adjust to an activity level suited for their knee function, without a high incidence of meniscus injuries (9.5% in the non-operated group). All the children in the present study were supplemented with an individually fitted functional brace, although the evidence for the protective effects of functional braces after ACL injury is weak [6, 7]. We do not have compliance data for the use of their brace, and are therefore not able to provide any results with regard to the effectiveness of ACL braces in children. A prospective study is needed to investigate this issue more thoroughly.

Copers demonstrated significantly higher performance on several functional outcomes. We suggest that these results provide a rationale for utilizing the four single-leg hop tests, KOS-ADLS, and IKDC 2000 as milestones or criteria for rehabilitation outcome and safe return to sport criteria. We observed that also non-copers, on average, scored above 90% on all hop tests and muscle strength measurements, which indicate that cut-off limits for hop tests and isokinetic muscle strength measurements should be set higher than 90%. We suggest that children who demonstrate hop test performance above 95% compared to the uninjured leg, IKDC 2000 score above 90% and KOS-ADLS score above 90%, may continue at their desired activity level until skeletal maturity is reached and an ACL reconstruction can be considered. Children with scores under the suggested cut-offs should not perform activities

which include pivoting movements. Monitoring the children closely with repeated functional tests and functional knee surveys may increase the possibility of success of any treatment algorithm.

The imperative question of interest for children with ACL injury is the weighing of the danger of growth disturbance and the child's compliance with rehabilitation related to ACL reconstruction versus the danger of early osteoarthritis subsequent to a possible meniscus injury after a period of non-operative management. Furthermore, we need more knowledge on significant baseline characteristics for children with ACL injury to predict long-term outcome, both for those who go through surgery and those who continue non-operative management. There is also a need for further development of functional tests and validated questionnaires appropriate for a clinical evaluation of knee function in order to pick out children who should lower their activity level or be referred to early ACL reconstruction. These questions can only be answered through long-term prospective multicenter studies, since ACL injuries in children are less frequent than ACL injuries in adult individuals. Our research group has started a prospective multicenter study.

Conclusion

This investigation is to our knowledge the first medium-term follow-up study using functional performance-based outcome measurements in young children who ruptured their ACL before turning 13 years. The results showed that the average performance on single-legged hop tests was excellent, and that 65% of the investigated non-operated ACL injured children were able to continue performing sports at their pre-injury activity level without a high risk of meniscus injury. Functional-based classification criteria used in adult ACL-injured subjects can also be used in children with ACL injury. Treatment algorithms and criteria for return to sport in children are discussed.

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