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Prospective evaluation of the incidence of new meniscus and cartilage injuries following a non-operative treatment algorithm after anterior cruciate ligament tears in skeletally immature children: A MRI study

ABSTRACT

Background: The increased risk of long-term osteoarthritis following concomitant injuries to the menisci or cartilage after an anterior cruciate ligament injury (ACL) in adults is well established. ACL reconstruction is often recommended to skeletally immature children to reduce the risk of new intraarticular injuries. However, the prevalence and incidence of new injuries following non-operative treatment of ACL injuries in skeletally immature children is unknown.

Purpose: To prospectively investigate the incidence of new injuries to the menisci and joint cartilage in non-operatively treated skeletally immature children with a known ACL injury using bilateral 3.0T magnetic resonance images (MRI).

Methods: Prospective cohort study. Forty skeletally immature children with a ruptured ACL (41 knees) followed a non-operative treatment algorithm, and were evaluated with bilateral 3.0T MRI on two occasions (MRI1 and MRI2). The intraarticular structures were analyzed by two independent MRI radiologists, and described according to previously published guidelines. Monitoring of participation in physical activities was accomplished through a monthly online activity survey. Descriptive statistics and frequencies were extracted from the scoring forms and compared using Fisher's Exact test.

Results: Fourteen girls (35%) and 26 boys (65%) with a mean age of 11.0 ± 1.4 years at time of injury were included. Time from injury to the final follow-up was 3.8 ± 1.3 years. Eighty-eight percent of the ACL deficient children confirmed monthly participation in pivoting sports and/or physical education classes in school. The prevalence of meniscus injuries in the 28 non-reconstructed children was 28.5% at MRI1 and MRI2, and the incidence of new meniscus and cartilage injuries in the non-reconstructed knees was 3.6% from MRI1 to MRI2.Thirteen children underwent ACL reconstruction with a prevalence of meniscus procedures of 46.2%. The

incidence of new meniscus injuries, from the diagnostic MRI to final follow-up was 19.5%. Among the 41 knees, surgical treatments for meniscus injuries were performed in eight.

Conclusion: The incidence of new injuries to menisci and joint cartilage was low between MRI1 and MRI2 in the 28 non-reconstructed knees. Thirty-one percent of the knees required ACL reconstruction, and 19.5% required meniscus surgeries during the 3.8 ± 1.3 years follow-up from injury. Further follow-up is needed to evaluate the long term knee health in these children.

Key terms: anterior cruciate ligament, skeletally immature, meniscus, cartilage, magnetic resonance imaging

What is known about the subject: Reports from national knee ligament surgery registries suggests that the incidence of pediatric ACL reconstructions is increasing. Conventional wisdom in the orthopedic community is that ACL reconstructions are needed to prevent secondary injuries to menisci and cartilage. However, to our knowledge no prospective studies have evaluated the incidence of new injuries to the intraarticular structures following non-operative treatment in this population.

What this study adds to existing knowledge: This is the first study to prospectively evaluate secondary injuries following non-operative treatment after ACL injuries in skeletally immature children. A prospective documentation on the incidence of secondary injuries in ACL injured skeletally immature children have value with regard to clinical decision making for this population.. The risks involved with surgical treatment can better be balanced against the risks of secondary injuries based on the documented incidence in the presented population.

Prospective evaluation of the incidence of new meniscus and cartilage injuries following a non-operative treatment algorithm after anterior cruciate ligament tears in skeletally immature children: A prospective MRI study.

Previous studies have suggested that persons who have suffered an anterior cruciate ligament (ACL) injury have an increased likelihood of developing long-term knee osteoarthritis (OA).[28, 40, 53] A concurrent or secondary injury to the menisci and/or joint cartilage has been shown to significantly increase the risk of OA further.[10, 15, 21] Consequently, the potential concerns of an ACL injury are particularly serious for individuals sustaining such an injury at a very young age. Although recent evidence suggests that the risk of sustaining an ACL injury during childhood or adolescence is increasing,[41] the true incidence of ACL injuries in the skeletally immature population is unknown.[3, 45] Additionally, the incidence of new secondary meniscus and cartilage injuries in skeletally immature children with ACL injury is unknown due to the lack of prospective studies.[25] The literature is limited to retrospective studies and case series, in which the presence of meniscus injuries in children who have had ACL reconstructions has been described.[12, 19] Our recent review[38] reports the prevalence of concurrent meniscus injuries to range from 26% to 90% in studies on surgical treatment of ACL injuries in skeletally immature patients. [4, 13] Lawrence et al[26] reported a significant increase in non-repairable medial meniscus tears and lateral compartment chondral injuries at the time of surgery in children undergoing ACL reconstruction more than 12 weeks after injury. Furthermore, Dumont et al[8] recently described an association between increased weight (>65 kg), age (>15 years), and time from injury to surgical treatment (>150 days), and medial meniscus and cartilage injuries in 370 patients under 19 years of age. Tissues in children and adolescents are believed to have a better ability to regain normal structure and function after traumatic injury compared to matured

tissues.[18, 29, 47] Hence, it is of utmost importance that reliable and accurate diagnostic modalities are used in prospective studies to monitor the intraarticular structures in individuals who sustain an ACL injury at a young age. Magnetic resonance imaging (MRI) is recommended as the preferred imaging modality in diagnosing ACL injuries and concomitant injuries in skeletally immature children and adolescents.[16]

Conventional wisdom in the pediatric ACL community is that early surgery is needed to avoid meniscal and joint cartilage injuries. However, to our knowledge no studies have prospectively investigated the integrity of the menisci and joint cartilage following a non-operative treatment algorithm of ACL injuries in skeletally immature children. The aim of the present investigation was to investigate the incidence of new injuries to the menisci and joint cartilage, using bilateral 3.0T MRI, in a prospective cohort of ACL injured skeletally immature children following a non-operative treatment algorithm.

MATERIAL AND METHODS

The present study prospectively investigated the integrity of the ACL, the menisci, and the joint cartilage in 40 consecutively recruited skeletally immature children, after traumatic ACL injuries sustained at age 12 years and younger. The study was approved by the Regional Ethical Committee, and all subjects and their parents signed a written informed consent prior to inclusion. The rights of the subjects were protected by the Declaration of Helsinki. All children were recruited from an ongoing prospective cohort study in which the functional and clinical outcomes of ACL injuries in skeletally immature children are investigated. The prospective cohort study was initiated in 2006, and the inclusion criteria were a traumatic complete intrasubstance ACL tear sustained at age 12 and younger.[27] Tibial and femoral ACL avulsion

fractures were exclusion criteria in the study. The diagnosis was confirmed through conventional diagnostic MRI (dMRI), a positive Lachman test, and an instrumented measured sagittal side-to-side difference of 3 mm or more using maximum manual force (KT-1000, Med-Metric, San Diego, California, USA).[6] The present study results are based on the dMRI of the injured knee, and two subsequent bilateral MRI investigations using a 3.0T machine (MRI1 and MRI2). All 3.0T MRIs were performed in one unit, while the dMRI were performed prior to referral to our center, in numerous locations with various protocols and lower magnet field strength.

Recruitment and treatment algorithm

The first 40 children enrolled in the prospective cohort study underwent bilateral 3.0T MRI scans of both knees in 2009/10 (MRI1) and in 2011/12 (MRI2), with a time interval between investigations of one to two years. All children had undergone the treatment algorithm of Moksnes et al[37] which advocates a primary non-operative treatment approach in skeletally immature children after ACL injury. The aim of the treatment algorithm was initiated after diagnosis to provide individually tailored rehabilitation programs that enabled the child to return to activity without ACL reconstruction. As part of the algorithm the children were provided with a custom-made and individually adjusted knee brace which they were instructed to wear during physical education (PE) in school and all other recreational sports activities. ACL reconstruction was considered if a child reported two giving way episodes with subsequent knee effusion and/or pain within any given period of three months, or if they sustained a secondary symptomatic meniscus injury.[37]

To monitor the activity level of the children, an online activity survey regarding participation in specific activities was e-mailed to the families monthly during the course of the study, starting at MRI1 and ending at MRI2. No specific activity limitations were advocated.

Magnetic Resonance Imaging

The overall sensitivity and specificity of MRI for the detection of ACL tears in children is reported to be 95% and 88%, respectively.[27] The sensitivity for acute ACL tears have been reported to be 94% for an abnormal angle with the Blumensaat's line, 79% for increased signal intensity in the substance of the ligament, and 21% for discontinuity in the ligament[27]. With regard to meniscus injuries in adolescents, MRI has been shown to demonstrate injuries with a sensitivity and specificity of 92% and 87% for the medial meniscus, and 93% and 95% for the lateral meniscus.[30] However, in children under 12 years of age the sensitivity and specificity for diagnosing meniscus injuries is reported to be significantly lower with 62% and 78%, respectively.[22] Sensitivity and specificity for cartilage injuries in children have to our knowledge not been documented, although the von Engelhart et al[52] reported the probablity of corresponding arthorscopic findings with 3.0T MRI ws between 29% and 74% in adults.

Data from the dMRIs were described by different radiologists and extracted from the medical reports. At MRI1 and MRI2, all examinations were administered by the same MRI-physicist, using a standardized protocol in one single MRI unit (GE Medical, Signa HDxt 3.0T, United Kingdom) with a transmit/receive eight-channel phased-array knee coil. All patients had sagittal, coronal, and axial proton-density (PD)-weighted fat-suppressed (FS) images.[36, 46] The sagittal PD-weighted images had slice thickness of 3 mm, while the coronal and axial had 2 mm. Additionally, oblique T2-weighted sagittal images with slice thickness of 2 mm were acquired.

Oblique sagittal images along the plane of the ACL have been suggested to better detect subtle, incomplete tears.[16] Imaging matrix for all images was 384x288.

All 3.0T MRI scans, including the injured and contralateral uninjured side, were analyzed by two experienced MRI radiologists, with 15 and 13 years of musculoskeletal MRI experience, respectively. The radiologists analyzed images independently using a Centricity DICOM Viewer (Version 2.2). Both radiologists were informed about the study inclusion criteria, although they were blinded with regard to which side children had their ACL injury and treatments performed prior to MRI1 and MRI2. Following the classification of injuries from both radiologists, a consensus meeting was held to reach agreement in cases where discrepancies between the individual readings were present. Each case with initial disagreement was re-investigated by both radiologists together until consensus based on the classification criteria was reached.

MRI analysis and classification

The ACL was classified according to criteria as described by van Dyck et al.[49] An ACL that could be followed as a continuous band of low signal intensity from the femoral to the tibial attachment with the ACL fibers parallel to Blumensaat's line was considered a normal ACL. Replacement of the ACL by an edematous mass with non-visualization of its fibers and a wavy contour of the ligament were considered signs of a total ACL rupture.[22]

The vascularization and maturation of the menisci have been suggested to increase the difficulty in correctly diagnosing pathological conditions in children.[42, 54] However, Sanchez et al[44] and Major et al[30] reported the accuracy of diagnostic MRI for meniscus injuries in children and adolescents to be acceptable. From MRI1 and MRI2, the menisci were classified as being normal, or having a horizontal rupture, a longitudinal rupture, a radial rupture, or a high signal

without rupture.[22, 33, 48] A meniscus was considered torn if there was an abnormal signal which broke through the articular surface of the meniscus in two or more images (sagittal and coronal PD-weighted FS images),[5, 7] with particular attention to differentiation between normal vascular structures known to be present in children (high-signal without rupture) and grade 3 ruptures.[48] Articular cartilage was described as normal or injured using the International Cartilage Repair Society classification of cartilage injuries,[2] modified to MRI observations; grade 0 (normal signal intensity and surface contour), grade 1 (abnormal signal in the superficial cartilage with intact thickness), grade 2 (structural changes in < 50% of the thickness), grade 3 (structural changes in ≥ 50 % of cartilage thickness), and grade 4 (full-thickness abnormality to the subchondral bone). Bone Marrow Lesions (BMLs) were defined as areas of high-signal intensity located adjacent to the articular cartilage and present on 2 or more images.[11] At MRI1 and MRI2, the epiphyseal growth plates were classified as open when the distal femoral and proximal physes were not completely fused.[9]

Statistical analysis

Descriptive statistics were extracted from the patient's medical records and the scoring forms, and analyzed using the Predictive Analytics SoftWare (PASW) Statistics (version 18.0.2 (April 2, 2010); SPSS Inc., Chicago, IL, USA). The frequency of observed menisci with high signal without rupture between the ACL injured and the non-injured side was compared using the Fisher's Exact test.

RESULTS

Forty skeletally immature children with a total intrasubstance ACL injury (41 knees) verified using dMRI and clinical examination (Lachman and KT-1000) were followed using 3.0T MRI scans (MRI1 and MRI2). There were 14 (35%) girls and 26 (65%) boys, with an average age at injury of 11.0 ± 1.4 years (mean ± standard deviation). The majority of injuries had occurred during alpine skiing or soccer (Table 1). Demographic data on all children are presented in Table 2. The response rate for the monthly survey regarding participation in activities was 88.3% (636 out of 720 surveys were returned), with 88.0% confirming monthly participation in pivoting sports and/or PE classes in school between MRI1 and MRI2.

At dMRI all children had open growth plates, while 36 (87.8%) and 27 (65.9%) of the injured knees were classified as having open growth plates at MRI1 and MRI2, respectively.

The final follow-up (MRI2) was performed 3.8 ± 1.4 years after injury, and 27 children (28 knees) were still non-reconstructed. In total eight (19.5%) of the 41 ACL injured knees underwent surgical treatment for meniscus injuries in the follow-up period. Six were performed concurrently with ACL reconstruction, and two without ACL reconstructions. No surgical procedures for cartilage injuries were performed.

At dMRI the number of knees with meniscus injuries was 19 (46.3%); five (12.2%) medial meniscus, 13 (31.7%) lateral meniscus, and one (2.4%) medial and lateral meniscus. At MRI1, seven of the meniscus injuries described at the dMRI were not recognized (six lateral meniscus and one medial meniscus). Furthermore, three new lateral and four new medial meniscus injuries were detected at MRI1 (Table 3).

The prevalence of meniscus injuries was 28.5% at both MRI1 and MRI2 in the 28 non-operated knees. The incidence of new meniscus injuries between MRI1 and MRI2 was 3.6% (n=1, lateral horizontal rupture) in the non-operated children (Table 4). An overview of meniscus injuries and

cartilage injuries with sub classification into type of injury at MRI1 and MRI2 is shown in Table 4. There was no significant difference in the frequency of menisci classified with high signal without rupture between the ACL injured knee and the non-injured knee at MRI1 (p=0.71), or MRI2 (p=0.32).

Among the 28 non-reconstructed knees the prevalence of meniscus injuries at dMRI was 28.6%; two (7.1%) medial, and six (21.4%) lateral. Two of these required surgical treatment without concomitant ACL reconstruction due to pain and restricted range of motion (one medial meniscus repair and one lateral meniscectomy). Among the 13 children who underwent ACL reconstructions the prevalence of meniscus injuries at dMRI was 84.6%; three (23.1%) medial, seven (53.8%) lateral, and one (7.7%) medial and lateral (Table 3). Six of these required meniscus surgery concurrently with the ACL reconstructions (two medial meniscus repairs, two lateral meniscus repairs, one medial meniscectomy, and one lateral meniscectomy). Thus, one medial meniscus injury and four lateral meniscus injuries observed at dMRI were not identified or judged insignificant by the surgeon when the ACL reconstructions were performed. One cartilage injury on the medial femoral condyle (MFC) was observed, and no treatment performed.

The prevalence of knees with cartilage injuries was 3.6% at MRI1 and 7.1% at MRI2, with one new injury to the medial tibial condyle (MTC) (Table 4). Four BMLs were identified at MRI1 (patella, n=2; MFC, n=1; lateral femoral condyle (LFC), n=1), while one new appeared and two remained at MRI2 (MFC, n=1; LFC, n=1; MTC, n=1). Both BMLs in the patella had resolved from MRI1 to MRI2.

Thirteen (32%) knees underwent ACL reconstruction according to the surgical indication criteria for the study. The specific indications for the ACL reconstructions were persistent instability

(n=8), a symptomatic meniscus injury (n=4), or unacceptable reduced activity level (n=1). The age at time of ACL reconstruction was 13.2 ± 0.9 years, and the time from injury to surgery was 1.6 ± 0.9 years.

In the contralateral uninjured knees two medial meniscus injuries (one horizontal and one longitudinal) and one knee with cartilage injury (MFC) were identified at MRI1 (Table 4). No new meniscus injuries occurred between MRI1 and MRI2, while the knee with MFC cartilage injury also had a cartilage injury at the LFC at MRI2. One BML in the MFC was present in the same knee at MRI1 and MRI2. No surgical procedures were performed in these knees.

DISCUSSION

This prospective cohort study is the first to evaluate the incidence of new meniscus and cartilage injuries from dMRI to the final follow-up (MRI2), in skeletally immature children following a non-operative treatment algorithm after ACL injury. The main results were that the incidence of new meniscus injuries was 19.5% (n=8) during the 3.8 ± 1.4 years prospective follow-up of 41 ACL injured skeletally immature knees. Thirteen (31.7%) of the included children underwent ACL reconstruction, of which six had a surgical procedure of the menisci performed (two medial meniscus repairs, two lateral meniscus repairs, one medial meniscectomy, and one lateral meniscectomy). Two (7.7%) of the children who remained non-reconstructed throughout the study underwent arthroscopic treatment for meniscus injuries (one medial meniscus repair and one lateral meniscectomy). Thus, the prevalence of meniscus surgery was 19.5% in the cohort of 41 knees. The prevalence of meniscus injuries in the whole cohort was 46.3% when injuries detected at the time of surgery (surgical treatment, n=15) and MRI2 (no surgical treatment, n=25) were combined. Twenty-five (63.4%) of the included children did not undergo any

surgical treatments during the follow-up, and the vast majority of the 40 children (88.0%) reported a high rate of participation in strenuous activities during the follow-up period, indicating that they were well functioning without restrictive symptoms.

The incidence of new meniscus injuries (19.5%) in this cohort of ACL injured skeletally immature children contrasts the common beliefs of orthopedic surgeons and previous retrospective studies.[26, 32] Dumont et al[8] reported an overall prevalence of 43.2% meniscus injuries in a retrospective study on 370 pediatric patients who had undergone ACL reconstructions. However, in their subgroup of 72 children who were aged ≤ 13 years they found that 29.2% had meniscus injuries at the time of ACL reconstruction, indicating that the youngest children may be less vulnerable for meniscus injuries compared to their older counterparts. They reported an association between the time from injury to surgery and the presence of meniscus injuries, although not in the youngest subgroup.[8] Conversely, Lawrence et al[26] retrospectively reviewed the surgical records from 70 skeletally immature children, from which they found a significant increase of non-repairable medial meniscus injuries and lateral cartilage injuries if ACL reconstruction was performed more than 12 weeks after injury. Additionally, Millet et al[35] found an association between time from injury to surgery with an increase in medial meniscus injuries. Four of the largest retrospective series published have reported prevalence's of meniscus injuries ranging from 35% to 69% at the time of ACL reconstruction.[17, 23, 39, 43] All the patients in these previous studies underwent ACL reconstruction within 12 months after the acute injury. Thus, the prevalence of meniscus injuries in the present investigation is comparable to what has been previously reported in ACL reconstructed children in the literature. However, all previous studies reporting the presence of meniscus injuries at the time of surgery are retrospective. Retrospective studies that have solely evaluated ACL reconstructed children may

be biased towards reporting high numbers of meniscus injuries because children who have been successful through non-operative treatment will not be included using this study design.

The strength of the present study is the prospective design and the use of a reliable measurement tool at MRI1 and MRI2. Technological advances has led to MRI systems with higher signal intensity, and preliminary clinical studies suggest that 3.0T MRI provides convincing visualization of the hyaline cartilage and menisci with good diagnostic values, although arthroscopy is still the gold standard for the evaluation of intraarticular pathologies.[14, 34, 50, 52] Although we do not have arthroscopic confirmation of the injuries, data from previous studies have indicated a high correlation between MRI findings and arthroscopy using the current classification of meniscus injuries.[5, 7] However, the magnetic susceptibility artifacts may be larger at 3.0T, and the suggested increased values of enhanced magnetic fields are still not confirmed.[16]

The prevalence of meniscus injuries in the 28 non-reconstructed knees was 28.5% at both MRI1 and MRI2. Among the non-reconstructed knees, who on average had been ACL deficient for 3.8 ± 1.3 years at the time of MRI2, five new meniscus injuries (three medial and 2 lateral) occurred after the dMRIs, with only one occurring between MRI1 and MRI2. Simultaneously, four injuries (one medial and three lateral) from the dMRIs were not observed at MRI1 or MRI2. Interestingly, we also found the prevalence for meniscus injuries in the uninjured knee to be 7.7% within our population. The results are comparable to the rate of meniscus injuries that Dumont et al[8] reported in ACL reconstructed children ≤ 13 years old, and indicate that non-reconstructed knees in the youngest skeletally immature children seem to be less susceptible to meniscus injuries than children who sustain ACL injuries at an older age.

Samora et al[43] found that lateral meniscus tears was more common than medial meniscus tears in skeletally immature children with ACL injury. The results from the dMRI in the present study showed that lateral injuries were more common after injury, although we were not able to reproduce this finding at MRI1 and MRI2, as the distribution of lateral and medial meniscus injuries then were comparable (Table 4). An explanation for the discrepancy may be that minor lateral meniscus tears heal in children, as have been suggested possible due to significant vascularization by several authors.[1, 24, 51] Hence, Samora et al[43] evaluated children at the time of ACL reconstruction, which was performed within 3 months of the ACL injury. The time from injury to follow-up was substantially longer in the present prospective investigation, which may have enabled the menisci to naturally heal with time.

The majority of meniscus injuries in the ACL injured knees were longitudinal ruptures (Table 4). Additionally, the prevalence of a high signal without tear in the ACL deficient knees at MRI1 was 28.6% in the medial menisci, and 7.1% in the lateral menisci. The corresponding prevalence's at MRI2 were 25.0% and 3.6% respectively. In the non-injured knees the equivalent prevalence for menisci with high signal without rupture at MRI1 were 11.5% (medial) and 3.8% (lateral), and at MRI2; 15.4% and 3.8%, respectively. There was no significant difference between injured and non-injured knees with regard to the observed high signals without rupture (MRI1, p=.71; MRI2, p=.32), indicating that the high signals found in this investigation were maturing healthy menisci and not signs of a degenerative process or rupture. Clinicians should be aware of this entity which is common in children, to make sure that unnecessary arthroscopic treatments are not initiated.[48]

The prevalence of cartilage injuries in ACL injured children have been investigated to a lesser extent than meniscus injuries.[29, 31] Jones et al[18] have demonstrated that the thickness of uninjured cartilage increases during adolescence in non-injured individuals, and that highly active healthy children develop thicker cartilage compared to more sedentary children. This knowledge supports the assumption that the joint cartilage in children is adaptable to load.[29] The dMRIs did not report any cartilage injuries in this investigation, however, due to the differences in magnet strength and the variety of radiologists involved we have focused on the changes from MRI1 to MRI2. We found that one (3.6%) new cartilage injury was observed in the ACL deficient knees between MRI1 and MRI2, and the overall prevalence in the ACL deficient knees was 7.1%. No surgical treatment procedures for cartilage injuries were performed in the cohort. One of the children also had cartilage injuries in the non-injured knee. These results are in contrast with previous retrospective studies,[8, 20, 26] in which an increase in lateral cartilage injuries has been associated with delayed surgical treatment after ACL injury. The majority of cartilage abnormalities were localized on the medial condyles which are comparable to reports in adolescent and adult ACL injured patients.[15] Minor changes in the grading of the observed cartilage injuries was observed (Table 4), although considering the relatively low accuracy in MRI based grading[47] of cartilage injuries these changes are to be considered tentative and should be interpreted with caution as they have not been arthroscopically confirmed. According to von Engelhart et al[52] 3.0T MRI provides convincing visualization of the hyaline cartilage with good diagnostic values. However, they also point out that the positive predictive values seem to be low for all grades of lesions, and arthroscopic evaluations cannot be substituted by 3.0T MRIs. One of the two observed BMLs resolved from MRI1 to MRI2, which is in accordance with the

relatively low incidence of meniscus and cartilage injuries as BMLs may be an indication of recurrent knee instability and repetitive subluxations.

The present study is encouraging because the meniscus and cartilage injuries were few (3.6%), and the rate of participation was high in the non-reconstructed children, during the follow-up period between MRI1 and MRI2. However, 13 of the 41 knees had to go through an ACL reconstruction due to instability and meniscal symptoms, with a prevalence of meniscus injuries of 46.1%. The clinical challenge will be to identify these patients prior to a secondary meniscus tear.

This study was not designed or intended to compare the incidence of secondary injuries between non-operative and surgical treatment, as such a comparison would have required a randomized treatment study design. This study has some limitations. The dMRIs were of various qualities and described by different radiologists than the 3.0T MRIs. Thus, the changes in meniscus and cartilage injuries from dMRI to MRI1 must be interpreted with caution. Also, cartilage injuries were evaluated according to modified ICRS classification criteria which are not validated for MRI assessments. Additionally, although this is the first prospective study investigating the integrity of intraarticular structures following ACL injuries in skeletally immature children, the overall follow up time from injury of 3.8 ± 1.3 years may be too short to firmly conclude that non-operative treatment is associated with a low incidence of secondary injuries in the long term. Nonetheless, it might be sufficient time for individuals who would prefer to delay surgery until skeletal maturity.

CONCLUSION

The incidence of new meniscus injuries after the diagnostic MRI was 19.5%. The incidence of new meniscus and cartilage injuries in the non-reconstructed knees was 3.6% from MRI1 to MRI2. A minority (31.7%) of the included children underwent ACL reconstruction due to persistent instability or symptomatic meniscus injury during the 3.8 ± 1.4 years follow up. The vast majority (88%) of children continued being physically active in sports and their school community. The prevalence of knees that underwent surgical treatment for meniscus injuries was 19.5%, while the overall proportion of knees with observed meniscus injuries was 46.3%. The results from this prospective cohort study provide new valuable knowledge to physicians with regard to clinical decision making for skeletally immature children after ACL injury.

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Table 1 Activities at the time of ACL injury, n=41

Activity	**n**	**%**
Alpine skiing	20	48.4
Soccer	10	24.4
Team handball	2	4.9
Playground	2	4.9
Bicycle	2	4.9
Trampoline	2	4.9
Cross-country skiing	1	2.4
Motocross	1	2.4
Ski-jumping	1	2.4

Table 2 Descriptive statistics of total population and non-operated children

	Total population (n=40)		**Non-operated (n=27)**	
Sex, male/female	26/14 (65%/35%)		21/6 (78%/22%)	
Side, left/right	24/17 (59%/41%)		17/11 (61%/39%)	
	Total population (n=41 knees)		**Non-operated (n=28 knees)**	
	Mean (±SD)	**min – max**	**Mean (±SD)**	**min – max**
Age at time of injury (years)	11.0 (±1.4)	8.2 – 12.9	10.8 (±1.4)	8.2 – 12.9
Age at time of MRI 2 (years)	14.9 (±1.7)	11.0 – 17.8	14.5 (±1.8)	11.0 – 17.7
Time from injury to diagnosis (years)	0.8 (±0.8)	0.1 – 2.8	0.8 (±0.8)	0.1 – 2.8
Time from diagnosis to MRI 1 (years)	1.3 (±1.2)	0.1 – 3.2	1.2 (±1.2)	0.1 – 3.2
Time from MRI 1 to MRI 2 (years)	1.7 (±0.1)	1.4 – 2.0	1.7 (±0.1)	1.4 – 2.0

Table 3. Pathologic observations in meniscus and joint cartilage at diagnostic MRI, MRI1, and MRI2

Subject	Diagnostic MRI	3.0T MRI1	3.0T MRI2	Surgical meniscus procedures
1		ACLR+MM‡	ACLR+MM	
2	LM*			
3	LM*	ACLR	ACLR+MM‡	
4	LM*			
5				
6		MM‡	MM	MM repair before MRI1
7				
8		LM‡	LM	
9	LM	ACLR+LTC	ACLR+LM+LTC	LM repair
10		ACLR+LM‡+LTC	ACLR+LM+LTC	
11				
12				
13				
14	LM	ACLR+LM+MFC†	ACLR+LM	LM meniscectomy posterior horn
15 right				
15 left				
16	LM*	ACLR	ACLR	
17				
18				
19	LM	LM	LM	
20	LM	LM+MFC+LFC†	LM+MFC	
21	LM+MM	ACLR+LM	ACLR+LM	MM repair and LM meniscectomy posterior horn
22	LM	ACLR	ACLR	LM repair
23				
24	LM*			LM meniscectomy posterior horn
25	MM	MM+MFC+MTC	ACLR+MFC+MTC	MM resection bucket handle
26	MM	ACLR	ACLR	MM repair
27	MM	MM	ACLR+MM	
28				
29	MM	LM‡+MM	LM+MM+MFC+MTC	
30	LM	LM	LM+MM‡	
31				
32				
33				
34	LM*		ACLR	
35				
36				
37	LM	LM	LM	
38				
39	MM*			
40		MM‡	MM	

* injury resolved from diagnostic MRI to MRI1

† injury resolved from MRI1 to MRI2

‡ new meniscus injury

Abbreviations: LM, lateral meniscus; MM, medial meniscus: ACLR, ACL reconstruction; MFC, medial femoral condyle; LFC, lateral femoral condyle; MTC, medial tibial condyle, LTC, lateral tibial condyle

Table 4 Prevalence of pathologic findings in injured and non-injured knee at MRI1 and MRI2 for non-reconstructed children (n=27)

	ACL injured knees, n=28		Non-injured knees, n=26	
	MRI 1, n (%)	**MRI 2, n (%)**	**MRI 1, n (%)**	**MRI 2, n (%)**
ACL				
Normal	0	0	26 (100)	26 (100)
Total rupture	28 (100)	28 (100)	0	0
Medial meniscus, injuries	**4 (14.3)**	**4 (14.3)**	**2 (7.7)**	**2 (7.7)**
Normal	16 (57.1)	17 (60.7)	21 (80.8)	20 (76.9)
Horizontal	1 (3.6)	1 (3.6)	1 (3.8)	1 (3.8)
Longitudinal	3 (10.7)	3 (10.7)	1 (3.8)	1 (3.8)
Radial	0	0	0	0
High signal without rupture	8 (28.6)	7 (25.0)	3 (11.5)	4 (15.4)
Lateral meniscus, injuries	**6 (21.4)**	**7 (25.0)**	**0**	**0**
Normal	20 (71.4)	21 (75.0)	25 (96.1)	25 (96.1)
Horizontal	1 (3.6)	2 (7.1)*	0	0
Longitudinal	4 (14.3)	3 (10.7)	0	0
Radial	1 (3.6)	1 (3.6)	0	0
High signal without rupture	2 (7.1)	1 (3.6)	1 (3.8)	1 (3.8)
Knees with meniscus injury	**8 (28.5)**	**8 (28.5)**	**2 (7.7)**	**2 (7.7)**
Normal	20 (71.4)	20 (71.4)	24 (92.3)	24 (92.3)
Medial	2 (7.1)	2 (7.1)	2 (7.7)	2 (7.7)
Lateral	4 (14.3)	4 (14.3)	0	0
Medial and lateral	2 (7.1)	2 (7.1	0	0
Knees with cartilage injury	**1 (3.6)**	**2 (7.1)**	**1 (3.8)**	**1 (3.8)**
MFC	1 grade IV	2 grade III*	1 grade III	1 (grade II)
LFC	0	0	0	1 (grade I)*
MTC	0	1 grade II*	0	0
LTC	0	0	0	0
Patella	0	0	0	0
Trochlea	0	0	0	0
Bone Marrow Lesions	4 (14.3)	3 (10.7)	1 (3.8)	1 (3.8)

* new injury