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Epidemiological study of pediatric ACL injuries

Y. El Qadiri [1, 2, *], Y. El Andaloussi [1], AR. Haddoun [1], M. Raad [2], M. Brax [2] and M. Fadili [1]

[1] *Department of Orthopaedic Traumatology Wing 4 CHU Ibn Rochd Casablanca Morocco.*
[2] *Orthopaedics Department HAGUENAU hospital HNA group, France.*

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Abstract

ACL rupture in children is a serious injury that exposes the knee to meniscal damage and then, in the medium term, to osteoarthritis. The incidence of this type of injury has been rising steadily since the 1990s with the everincreasing practice of "pivotal" sports such as football, basketball, handball, rugby and gymnastics. The aim was to study the characteristics of the population of subjects affected and to identify risk factors for meniscus and cartilage damage. This was a retrospective, descriptive and analytical epidemiological study of 80 children who had consulted an orthopaedic clinic for an ACL rupture. At the orthopaedic consultation centre at Haguenau Hospital, from March 2014 to November 2022, with an average age of 13.8 years. Diagnosis was based on questioning, clinical examination and MRI as paraclinical examinations. The 15 parameters analysed were as follows: age at the time of the initial trauma, sex, corrected body mass index (BMI), side, type of sport practised, sporting level, Tegner score, circumstances of the causal trauma, time to consultation, time to MRI, attempt at functional treatment, time to surgery, associated meniscal lesions. The age at the time of surgery, and at the end the operative report. There is still a debate on the optimal treatment of ACL ruptures. Most surgeons who specialise in this area support early surgery, with the aim of preventing secondary damage and returning to the previous level of physical activity as quickly as possible. Of the 80 cases, 88.75% were treated surgically and 11.25% functionally, with a median corrected BMI of 19.7. 41.25% of cases had associated meniscal lesions. The 3 most frequently practised sports were handball, rugby and football. We also found a close relationship between meniscal injury and corrected BMI. Our results are in line with the literature, which is in favour of early repair of the anterior cruciate ligament in adolescent athletes, especially those with a BMI.

Keywords: ACL; Menisque; BMI; Sport.

1. Introduction

The main function of the anterior cruciate ligament (ACL) is to prevent anterior translation of the tibia. It acts as a secondary stabiliser against internal rotation of the tibia and valgus of the knee [1-2], and as the primary passive stabiliser against anterior translation of the tibia in relation to the femur [3-4]. Passive knee stability is provided by the ligament system and active stability by the neuromuscular system. The ACL runs from the front of the tibial plateau to the medial aspect of the lateral femoral condyle. Due to its specific orientation, the ACL contributes to rotational stability in both the frontal and transverse planes. This is not obvious from a frontal view of the knee [5-6]. An intact ACL protects the meniscus from the shearing forces that occur during sporting manoeuvres, such as landing a jump, pivoting or decelerating from a run. ACL ruptures often result in joint effusion, muscle weakness, altered movement and reduced functional performance, and can lead to the loss of an entire season in young athletes [7]. The ACL is one of the most frequently injured ligaments in the knee. The prevalence of an ACL rupture in a paediatric athlete with traumatic knee haemarthrosis is approximately 65% [8]. ACL ruptures account for 50% or more of all knee injuries, making this ligament particularly important in any discussion of knee injuries [9]. This was not the case in a new epidemiological study of high school sportsmen, which showed an ACL injury rate of 20.5% [10]. The ACL is one of the most frequently

* Corresponding author: Y. El Qadiri.

studied structures in the musculoskeletal system over the last few decades, and has been the subject of a large number of anatomical and biomechanical studies. ACL injuries are among the most common and devastating injuries to the knee and are mainly caused by sporting activity [7]. ACL injuries frequently affect active people, young people and women. Women are two to ten times more at risk than men playing the same sport [11-18]. ACL injuries are also associated with long-term clinical sequelae, including meniscal damage, cartilage damage and an increased risk of early onset of post-traumatic osteoarthritis [19-23]. Doctors treating young athletes have noted an increase in the number of ACL injuries over the last 2 decades. Recent literature suggests an increase in the incidence of ACL injuries in children and this increase is due to greater participation in organised and high-demand sports at an early age [24-25]. However, this increase may be due to increased awareness that ACL injuries can occur in children and advances in diagnostic methods as no epidemiological studies are available to support this in paediatrics. In view of this increase in the diagnosis of ACL rupture in the paediatric population and the risk that this rupture may entail, we had the idea of carrying out an epidemiological study to try to find a certain link between the various parameters in order to prevent long-term sequelae such as meniscal lesions and cartilage lesions.

2. Materials and methods

Ethical approval for this study was obtained from the Institutional Ethics Committee. This is a retrospective descriptive and analytical epidemiological study. It included 80 children who consulted for an ACL rupture. The consultation took place at the Haguenau Hospital, from March 2014 until November 2022. The age range was between 7 and 17 years. Patients with tibial spine fractures were excluded. Fifteen parameters were recorded and analysed: operation, age at operation, sex, age of initial trauma, corrected BMI, side, time to ligamentoplasty, type of sport, Tegner score, level of sport, circumstance of initial trauma, time to MRI, time to consultation, attempt at functional treatment and associated meniscal lesions. Regarding surgical treatment, it was necessary to specify whether it had been performed and at what age. We included 13 types of sport. The Tegner score specifies the level of activity from 0 to 10, thus defining the level of sport, whether it is competitive or only recreational. The initial trauma may be direct or indirect. A direct trauma can be either a trauma by an opponent on the knee or a fall on the knee. Indirect trauma, on the other hand, is when nothing comes into contact with the knee.

Indirect trauma, on the other hand, is when nothing comes into contact with the knee. In a number of children, functional treatment has been tried, defined by a very precise protocol of physiotherapy for 6 months. Associated meniscus injuries may be acute or secondary. An acute lesion is one that is discovered on the first MRI scan performed during the first 5 months after the initial trauma. A secondary lesion is any lesion diagnosed from the 5th month after the initial trauma, i.e. a lesion visualised on a 2nd scan or during ligamentoplasty. The diagnosis of ACL rupture was made on MRI for all children, but at different intervals depending on the patient's presentation at the consultation. Ligamentoplasty was performed using different techniques: either through the growth plate (transphyseal), or sparing the growth plate (epiphyseal). A DT4 graft and different types of graft fixation were chosen. The operations were performed under arthroscopy by different operators in the department. From a statistical point of view, the study was divided into two parts:

2.1. Descriptive study with a simple reading of the results.

Analytical study to find links between all these parameters. We used: reduced variance (Z), Odds ratio (OR), chi 2 test (chi 2), ANOVA test.

3. Results

3.1. Descriptive study

Patients operated on: Of the 80 cases, 71 (88.75%) were treated surgically, whereas 9 (11.25%) were not treated surgically. The average age of the patients operated on was 13.81 years +/- 1.97. Sex: 57 (71.25%) of the children were male and 23 (28.75%) female. The mean age at initial trauma (IT) was 13.03 years +/- 1.94. Mean corrected BMI was 20.78 +/- 4.59 and CI (18.49 and 23.08). The activities carried out by the patients included in this study were spread across different sports: Rugby 22 (27.5%) , Football 21 (26.25%) , Ski 11 (13.75%) , Basketball 5 (6.25%) , Handball 4 (5%) , Tennis 4 (5%) , Athletics 3 (3.75%) , Kick-boxing 2 (2.5%) , Motocross 2 (2.5%) , Gymnastics 2 (2.5%) , Judo 2 (2.5%) , Cycling 1 (1.25%) , Swimming 1 (1.25%). These activities were classified according to the Tegner score between 0 and 10, with 32 patients (40%) having a Tegner score of 9, 27 (33.75%) a score of 7, 11 (13.75%) a score of 6 and 6 (7.5%) a score of 8.

- 50 children (62.5%) were involved in competitive sport and 30 (37.5%) in leisure activities.

- Regarding the circumstances of the initial trauma, 52 (65%) were by indirect mechanism and 28 (35%) by direct mechanism.
- The majority of ligamentoplasties were performed after 255.55 days.
- The average time to MRI was 81.63 days and the average time to first consultation was 123.41 days.
- Similarly for the side of the lesion, the prevalence was the same for both sides, right and left.

47 (58.75%) had an isolated ACL lesion, while 33 (41.25%) had an associated meniscal lesion. These meniscal lesions were divided into 22 secondary lesions (27.5%) and 11 acute lesions (13.75%). Secondary meniscal lesions included 25 (15.6%) lateral lesions, 17 (10.6%) medial lesions and 2 (1.3) medial and lateral lesions. Acute meniscal lesions included 6 (7.5%) lateral lesions and 5 (6.25%) medial lesions.

3.2. Analytical study

- Surgery / corrected BMI: The mean corrected BMI in patients who underwent surgery was higher than in those who had conservative treatment (21 +/- 5 versus 19.4 +/- 2.9; p=0.05).
- Operation/functional treatment: 28 of 80 patients received an attempt at conservative functional treatment initially but 20 (71.42%) ended up with surgical treatment. 52 children were scheduled for surgery, 51 were operated on and one case was lost to follow-up.
- Sport / Age of initial trauma TI: The mean age of initial trauma was 13 years. The distribution of mean age at TI by type of sport is as follows: Handball: 13.8 +/- 1.2; Rugby: 13.6+/- .8; Tennis: 13.3 +/- 1.6; Basketball: 13.2 +/-1.3; Football: 12.7 +/- 2.1; Skiing: 12.3 +/- 1.9.
- Gender / Level of sport: 12 (52.17%) of the 23 girls included in the study were competitive sportsmen, and 38 (66.66%) of the 57 boys were competitive.
- Gender / Tegner : The majority of the boys took part in a sport with a higher average Tegner score than the sports taken part in by the girls.
- Sports / Tegner : The breakdown of sports by Tegner score was:
- Rugby and football had the highest Tegner score.
- The rest of the sports had a lower Tegner score.
- Meniscal injury / corrected BMI : Among patients with an ACL injury, those with an associated secondary or acute meniscal injury had a mean corrected BMI of 22.7 and 20.7 respectively, whereas those with an isolated ACL injury had a mean corrected BMI of 19.9.
- Meniscal injury / Ligamentoplasty time: Secondary meniscal injuries resulted in a ligamentoplasty time of 341.1 days.
- Meniscal damage/functional treatment: Of the 28 patients undergoing functional treatment, 17 (60.71%) had no meniscal damage, but 11 (39.28%) had secondary meniscal damage. Among the 52 patients without functional treatment, 29 (55.76%) had no meniscal lesions, 12 (23.07%) with secondary meniscal lesions and 11 (21.15%) with acute meniscal lesions.

4. Discussion

With regard to gender, 71.3% of the children were male and 28.7% female. The mean age at initial trauma (IT) was

13.03 years. Contrary to what has been noted in the literature, namely that the majority of patients with ACL injuries are girls and that the difference in frequency depends on age, our study did not find such a correlation [26-27].

Over the last 30 years, there has been a rapid increase in ACL injuries in girls, due to the high risk of ACL injuries in young girls playing sport, 10 times more at high school and 5 times more at university. This significant change is due to anatomical and hormonal development [26-27]. This increase is probably a multifactorial phenomenon due to extrinsic and intrinsic factors. The intrinsic neuromuscular factor plays an important role in the risk of injury and is the most modifiable factor. Granan LP et al [28] show in a study that the incidence of injury in girls is approximately 2 times higher, but this figure underestimates the true incidence of ACL injuries, as the study does not include those that are treated conservatively [29].

The risk of ACL injury begins to increase significantly between the ages of 12 and 13 in girls, and 14 to 15 years in boys, which corresponds to puberty [29-30]. Pre-adolescent athletes show no gender difference in ACL injury rates [30]. Although ACL injury rates increase with age in both sexes, girls have higher rates immediately after the growth spurt. [29-30-31] In our study we did not find this age distribution, but we did find a mean age of initial trauma of 13.03 years +/- 1.94 with CI [12.06-14].

It is likely that the increase in body weight, height and bone length during pubertal development increases the risk of ACL injury with age.

Increased body weight is associated with greater joint strength which is more difficult to balance and cushion during the high speed of athletic movements. In pubescent boys, testosterone controls the significant increase in power, strength and muscular coordination, giving them greater neuromuscular control of these body dimensions. Pubescent girls do not have the same muscle growth spurt, which probably explains their higher rate of ACL injury compared with boys of the same age. [32].

The majority of the boys played a sport with a higher average Tegner score than the sports played by the girls. And most of the boys were also competitors. So we can see that this high level of sport in boys increases the risk of ACL injury. In the literature, there is little discussion of the relationship between level of sport and risk of ACL injury.

The activities carried out by the patients included in this study were spread over different sports, the most frequent of which were rugby and football, but there was no link between sex and the distribution of sports, a notion that has been demonstrated by other studies [10]. In fact, a link was found between sport and the age of the initial trauma, given that the mean age of TI was 13.03 years.

The majority of children had a high Tegner score and a competitive level of sport.

The initial trauma was indirect in the majority of cases (65%). The typical position for an indirect mechanism (dynamic valgus of the knee) was: hips in internal rotation and adduction, tibia in external rotation, knee in extension and foot in eversion [34-35-36]. Similarly, the literature shows that at least 70% of ACL injuries are due to an indirect mechanism [37-38].

In this study, 65% of children received non-functional or even surgical treatment from the outset, and 35% received conservative treatment in the first instance. In the end, however, 90% of patients were operated on, indicating that conservative treatment, which was planned for 6 months, had failed and surgery was required. The average age of the patients operated on was 13.81 years.

28 of the 80 patients received an initial attempt at conservative functional treatment, of whom 20 (71.42%) ended up undergoing surgical treatment. There was a significant relationship between functional treatment and the rate of surgery (p=0.001).

The ACL has a poor healing capacity, with a high failure rate (40 to 100%), even after repair by surgical suture. The disappointing results of primary ACL repair led to the abandonment of this technique and the widespread adoption of ACL reconstruction. The treatment of ACL injuries in paediatric athletes is difficult and controversial. ACL rupture in children is not a surgical emergency [39-45].

In the past, delay in surgical treatment was very common; orthopaedic surgeons recommended non-operative treatment, including splinting, rehabilitation and restriction of sport for several months until the skeleton matured so that traditional ACL surgery could be performed safely [46-48].

Non-surgical treatment has been successful in a number of patients, but for reasons that are unclear [49].

Delayed surgery allows greater skeletal maturation, avoids iatrogenic disruption of the growth plate creating length inequalities or angular deformity, and allows the patient to gain psychological maturity, allowing for better post-operative follow-up. Despite these advantages, the risk of recurrent instability, the appearance of meniscal lesions and osteoarthritic change cannot be neglected [25-50-51].

Open growth plates on both sides of the knee joint warrant particular caution prior to ACL reconstruction in children [52-53].

The treatment of ACL injuries in the paediatric population remains controversial as previously mentioned, as standard ACL reconstructions require the excavation of two bone tunnels, tibial and femoral, which traverse the open physes.

Treatment algorithms for ACL tears in the paediatric population are universally different, and there is still debate about the optimal treatment for these injuries, creating a therapeutic dilemma for the treating physician [54-55].

Surgery is not absolute. General indications for surgery include the patient's inability to participate in their preferred sport, instability that affects activities of daily living, the presence of an associated repairable meniscal lesion or the existence of several knee injuries.

Many paediatric athletes and their parents refuse to limit their sporting activity. In such cases, ACL rupture in these non-surgically treated sports children may lead to further episodes of instability, meniscal damage and the development of early osteoarthritis as has been reported [56-25-57-58-59]. Therefore, the most recent literature supports early surgery for athletes in the paediatric population with ACL rupture and recurrent episodes of instability [56-60-55-25-57-61].

There are different surgical techniques:

- Either by passing through the growth plate: transphyseal surgery
- Or sparing the growth plate: Extraepiphyseal or Epiphyseal.
- There is no consensus on the best method for treating an ACL rupture in a paediatric athlete [62-63].

Regardless of the type of treatment, athletes with ACL injuries are up to 10 times more likely to develop early onset knee osteoarthritis, a condition that not only limits their ability to participate in sports, but also often leads to secondary pain and functional disability [64-65]. A systematic review of a series of long-term studies suggests that after 10 to 20 years of ACL injury, the rate of knee osteoarthritis is over 50% [65].

However, one of the 5-year prospective studies showed that patients who had ACL reconstruction had a higher level of knee osteoarthritis on X-ray and bone scan, compared with patients who did not have ACL reconstruction [66].

An accurate understanding of the athlete's physical maturity, by determining bone age and Tanner stage, helps to identify the best treatment for the patient [68-69]. When surgical treatment of paediatric ACL injuries is performed, it is essential that appropriate measures of skeletal development are assessed preoperatively and postoperatively.

Furthermore, the maturation and adaptation of the graft during the growth of the remaining skeleton is still unknown, and there is debate regarding the possibility of an increased risk of recurrence in adulthood related to disturbances in biomechanical properties. [70-71-72].

High activity levels and early sports specialisation may predispose children and adolescents to early failure [73-74]. We must therefore consider the possibility that a thinner graft in adolescents may predispose them to recurrence in adulthood following low-energy trauma.

Studies of competitors, most of whom were over 18 years of age, in a variety of sports have shown that 78% to 91% returned to sporting participation after ACL reconstruction [75]. However, only half returned to their previous level.

ACL reconstruction remains the technique of choice, especially for young individuals and athletes aiming to return to a high level of activity (19,23 - 39,45). Without surgery, few athletes are able to return to the same level they had before the injury [7], and even ACL reconstruction cannot guarantee a return to the initial level [76]. Thus, those athletes who do return successfully to activity are at high risk of recurrent injury [77], with a less favourable outcome [78].

Patients who underwent surgery had a higher mean corrected BMI than those who did not (21 +/- 5 versus 19.4 +/- 2.9; p=0.05).

There is therefore an association between the incidence of ACL injury and an increase in corrected BMI. In the literature, a high BMI has been associated with an increased risk of ACL injury [79].

With regard to meniscal lesions associated with ACL rupture, in the study 58.75% of patients had an isolated lesion, whereas 41.25% had an associated meniscal lesion. Secondary lesions were more frequent than acute lesions. Involvement of the lateral meniscus was more frequent in acute and secondary cases, but this was statistically insignificant. In the literature on the adult population, it is well known that acute meniscal lesions tend to be lateral and secondary meniscal lesions tend to be medial [79].

In our study, secondary meniscal lesions appeared after a ligamentoplasty delay of 341.1 days, and the association between ligamentoplasty delay and the appearance of secondary meniscal lesions is statistically significant (p=0.01).

Consequently, we conclude that it is necessary to try to perform the ligamentoplasty before 341 days following the initial trauma in order not to increase the risk of having a medial or lateral meniscal lesion [80].

Among 28 patients who had undergone functional treatment, 17 (60.71%) showed no meniscal lesions, while 11 (39.28%) had secondary meniscal lesions. We also found a link between functional treatment and secondary meniscal lesions (p=0.001). Over time, when functional treatment is initiated, the risk of developing secondary meniscal lesions is high.

Children treated by ligamentoplasty after 150 days following an ACL injury have a higher rate of medial meniscal injury compared with those treated before 150 days [50].

Abnormal joint forces in an ACL-injured knee are associated with an increased risk of meniscal damage, the normal function of which is to absorb shock and transmit load between the tibia and femur [80].

With each episode of knee lift, meniscal lesions can become more complex and the possibility of repairing them becomes less and less obvious [86]. After ACL injury, increasing age, male gender and delayed surgery increase the frequency and severity of meniscal and/or articular cartilage damage [82].

The incidence of a medial meniscal lesion increases even after 1 year of an ACL rupture, and it is the reconstruction of the ACL that can halt the degradation of the meniscus even after 1 year of the initial trauma [83]. It has been well demonstrated that meniscal injuries lead to degenerative lesions [84-85].

Among patients with ACL injury, those with associated acute or secondary meniscal injury had a mean corrected BMI of 22.7 and 20.7 respectively. There was a link between corrected BMI and meniscal lesions (p=0.01).

It can be seen that as the corrected BMI increases, so does the risk of having a meniscal lesion, and more specifically a secondary lesion. Significant associations have been demonstrated between increased BMI and meniscal surgery in both sexes, including the obese, in the adult population [86]. In paediatrics, this correlation has never been found.

The limitations of this study are its retrospective nature, the relatively small sample size and the imprecise definition of secondary meniscal lesions.

The strengths are the presence of 2 groups of patients, one treated surgically and the other by functional treatment in the same study, which is not very common in the literature; the study of several parameters and the fact that it is both descriptive and analytical.

5. Conclusion

In the paediatric population, children who had functional treatment developed secondary meniscal lesions requiring delayed surgical management. It would therefore seem advisable for young athletes to undergo surgical treatment from the outset. There was a positive correlation between corrected BMI and meniscal lesions.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest in relation to the writing of this this article.

Statement of ethical approval

Ethical approval for this study was obtained from the Institutional Ethics Committee

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Buoncristiani AM, Tjoumakaris FP, Starman JS, Ferretti M, Fu FH. Anatomic double-bundle anterior cruciate ligament reconstruction. Arthroscopy. 2006;22:1000–6.

[2] Sakane M, Fox RJ, Woo SL-Y, Livesay GA, Li G, Fu FH. In situ forces in the anterior cruciate ligament and its bundles in response to anterior tibial loads. J Orthop Res. 1997;15:285–93.

[3] Butler DL, Noyes FR, Grood ES. Ligamentous restraints to anterior-posterior drawer in the human knee: a biomechanical study. J Bone Joint Surg [Am] 1980;62-A:259–270.

[4] Kiapour AM, Wordeman SC, Paterno MV, et al. Diagnostic value of knee arthrometry in the prediction of anterior cruciate ligament strain during landing. Am J Sports Med 2013.

[5] Levine JW, Kiapour AM, Quatman CE, et al. Clinically relevant injury patterns after an anterior cruciate ligament injury provide insight into injury mechanisms. Am J Sports Med 2013;41:385–395.

[6] Quatman CE, Kiapour AM, Demetropoulos CK, et al. Preferential loading of the ACL compared with the MCL during landing: a novel in sim approach yields the multiplanar mechanism of dynamic valgus during ACL injuries. Am J Sports Med 2014;42:177–186.

[7] Hewett TE, Di Stasi SL, Myer GD. Current concepts for injury prevention in athletes after anterior cruciate ligament reconstruction. Am J Sports Med 2013;41:216–224.

[8] Stanitski CL, Harvell JC, Fu F. Observations on acute knee hemarthrosis in children and adolescents. J Pediatr Orthop. 1993;13(4):506–510.

[9] Risberg MA, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? Phys Ther Sport. 2004;5(3):125–145.

[10] Allan M. Joseph, Christy L. Collins, Natalie M. Henke, Ellen E. Yard, Sarah K. Fields,R. Dawn Comstock. A Multisport Epidemiologic Comparison of Anterior Cruciate Ligament Injuries in High School Athletics. J Athl Train. 2013 Nov-Dec; 48(6): 810–817.

[11] Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med 1995;23:694-701.

[12] Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. J Athl Train 1999;34:86–92.

[13] Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. Am J Sports Med 2000;28:98–102.

[14] Lindenfeld TN, Schmitt DJ, Hendy MP, Mangine RE, Noyes FR. Incidence of injury in indoor soccer. Am J Sports Med 1994;22:364–371.

[15] Messina DF, Farney WC, DeLee JC. The incidence of injury in Texas high school basketball. A prospective study among male and female athletes. Am J Sports Med 1999;27:294–299.

[16] Myklebust G, Maehlum S, Holm I, Bahr R. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. Scand J Med Sci Sports 1998;8:149–153.

[17] Renstrom P, Ljungqvist A, Arendt E, et al. Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. Br J SportsMed 2008;42:394–412.

[18] Stevenson H, Webster J, Johnson R, Beynnon B. Gender differences in knee injury epidemiology among competitive alpine ski racers. Iowa Orthop J 1998;18:64– 66.

[19] Chu CR, Beynnon BD, Buckwalter JA, et al. Closing the gap between bench and bedside research for early arthritis therapies (EARTH): report from the AOSSM/NIH U- 13 Post-Joint Injury Osteoarthritis Conference II. Am J Sports Med 2011;39:1569– 1578.

[20] Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years afteranterior cruciate ligament injury. Arthritis Rheum 2004;50:3145–3152.

[21] Nebelung W, Wuschech H. Thirty-five years of follow-up of anterior cruciate ligament- deficient knees in high-level athletes. Arthroscopy 2005;21:696–702.

[22] Von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. Ann Rheum Dis 2004;63:269–273.

[23] Quatman CE, Kiapour A, Myer GD, et al. Cartilage pressure distributions providea footprint to define female anterior cruciate ligament injury mechanisms. Am J Sports Med2011;39:1706–1713.

[24] Anderson AF, Anderson CN (2015) Correlation of meniscal and articular cartilage injuries in children and adolescents with timing of anterior cruciate ligament reconstruction. Am J Sports Med 43(2):275–281.

[25] Lawrence JT, Argawal N, Ganley TJ (2011) Degeneration of the knee joint in skeletally immature patients with a diagnosis of an anterior cruciate ligament tear: is there harm in delay of treatment? Am J Sports Med 39(12):2582–2587.

[26] NCAA. NCAA injury surveillance system summary. Indianapolis: National Collegiate Athletic Association; 2002.

[27] NFHS NFoSHSA. 2008-09 High School Athletics Participation Survey. Kansas City, Missouri: National Federation of State High School Associations; 2009.

[28] Timothy E. Hewett, Kevin R. Ford, Barbara J. Hoogenboom, Gregory D. Myer, UNDERSTANDING AND PREVENTING ACL INJURIES: CURRENT BIOMECHANICAL AND EPIDEMIOLOGIC CONSIDERATIONS - UPDATE 2010.

[29] Granan LP, Forssblad M, Lind M, Engebretsen L. The Scandinavian ACL registries 2004- 2007: baseline epidemiology. Acta Orthop. 2009;80(5):563–567

[30] Shea KG, Pfeiffer R, Wang JH, Curtin M, Apel PJ. Anterior cruciate ligament injury in pediatric and adolescent soccer players: an analysis of insurance data. JPediatr Orthop. 2004;24(6):623–628

[31] McCarroll JR, Rettig AC, Shelbourne KD. Anterior cruciate ligament injuries in the young athlete with open physes. Am J Sports Med. 1988;16(1):44–47

[32] Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. J Bone Joint Surg Am. 2004;86-A(8):1601–1608

[33] Allan M. Joseph, Christy L. Collins, Natalie M. Henke, Ellen E. Yard, Sarah K. Fields,R. Dawn Comstock. A Multisport Epidemiologic Comparison of Anterior Cruciate Ligament Injuries in High School Athletics. J Athl Train. 2013 Nov-Dec; 48(6): 810–817

[34] Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: part 1, mechanisms and risk fac factors. Am J Sports Med. 2006;34(2):299– 311.

[35] Hewett TE, Torg JS, Boden BP. Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. Br J Sports Med. 2009;43(6):417–422.

[36] Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. Am J Sports Med. 2009; 37(2):252–259.

[37] Boden BP, Dean GS, Feagin JA, Jr, Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. Orthopedics. 2000;23(6): 573–578.

[38] McNair PJ, Marshall RN, Matheson JA. Important features associated with acute anterior cruciate ligament injury. N Z Med J. 1990;103(901):537–539.

[39] Feagin JA Jr, Curl WW. Isolated tear of the anterior cruciate ligament: 5-year follow- up study. Am J Sports Med 1976;4:95–100.

[40] Kaplan N, Wickiewicz TL, Warren RF. Primary surgical treatment of anterior cruciate ligament ruptures: a long-term follow-up study. Am J Sports Med 1990;18:354– 358.

[41] Marshall JL, Warren RF, Wickiewicz TL, Reider B. The anterior cruciate ligament: a technique of repair and reconstruction. Clin Orthop Relat Res 1979;143:97– 106.

[42] O'Donoghue DH, Frank GR, Jeter GL, et al. Repair and reconstruction of the anterior cruciate ligament in dogs: factors influencing long-term results. J Bone Joint Surg[Am] 1971;53-A:710–718.

[43] Sandberg R, Balkfors B, Nilsson B, Westlin N. Operative versus non-operative treatment of recent injuries to the ligaments of the knee: a prospective randomized study. J Bone Joint Surg [Am] 1987;69-A:1120–1126.

[44] Sherman MF, Bonamo JR. Primary repair of the anterior cruciate ligament. Clin Sports Med 1988;7:739–750.

[45] Strand T, Molster A, Hordvik M, Krukhaug Y. Long-term follow-up after primary repair of the anterior cruciate ligament: clinical and radiological evaluation 15-23 years postoperatively. Arch Orthop Trauma Surg 2005;125:217–221.

[46] Stanitski CL. Anterior cruciate ligament injury in the skeletally immature patient: diagnosis and treatment. J Am Acad Orthop Surg. 1995;3(3):146–158.

[47] Beasley LS, Chudik SC. Anterior cruciate ligament injury in children: update of current treatment options. Curr Opin Pediatr. 2003;15(1):45–52.

[48] Woods GW, O'Connor DP. Delayed anterior cruciate ligament reconstruction in adolescents with open physes. Am J Sports Med. 2004;32(1):201–210.

[49] Moksnes H,Engehretsen L,Risberg MA. Prevalence and incidence of new meniscus and cartilage injuries after nonoperative treatment algorithm for ACL tears in skeletally immature children: a prospective MRI study Am J Sports Med. 2013;41:1771-9.

[50] Dumont G, Hogue G, Podalecki J. Meniscal and chondral injuries associated with pediatric anterior cruciate ligament tears: relationship of treatment time and patient-specific factors. Am J SportsMed. 2012;40(9):2128-2133.

[51] Guenther Z, Swami V, Dhillon S, Jaremko J. Meniscal injury after adolescent anterior cruciate ligament injury: how long are patients atrisk? Clin Orthop Relat Res. 2014;472:990-997.

[52] Caine D, DiFiori J, Maffulli N (2006) Physeal injuries in children'sand youth sports: reasons for concern? Br J Sports Med 40(9):749–760.

[53] Kocher MS, Saxon HS, Hovis WD, Hawkins RJ (2002) Management and complications of anterior cruciate ligament injuries in skeletally immature patients: survey of the Herodicus society and the ACL study group. J Pediatr Orthop 22(4):452–457.

[54] Chotel F, Seil R (2013) Growth disturbances after transphyseal ACL reconstruction in skeletally immature patients: who is more at risk? Young child or adolescent? J Pediatr Orthop 33(5):585–586.

[55] Henry J, Chotel F, Chouteau J, Fessy MH, Berard J, Moyen B (2009) Rupture of the anterior cruciate ligament in children: early reconstruction with open physes or delayed reconstruction to skeletal.

[56] Aichroth PM, Patel DV, Zorrilla P. The natural history and treatment of rupture of the anterior cruciate ligament in children and adolescents: a prospective review. J Bone Joint Surg Br. 2002;84:38-41.

[57] Millett PJ, Willis AA, Warren RF. Associated injuries in pediatric and adolescent anterior cruciate ligament tears: does a delay in treatment increase the risk of meniscal tear? Arthroscopy. 2002;18:955 959.

[58] Graf BK, Lange RH, Fujisaki CK, Landry GL, Saluja RK. Anterior cruciate ligament tears in skeletally immature patients: meniscal pathology at presentation and after attempted conservative treatment. Arthroscopy. 1992;8(2):229–233.

[59] Mizuta H, Kubota K, Shiraishi M, Otsuka Y, Nagamoto N, Takagi K. The conservative treatment of complete tears of the anterior cruciate ligament in skeletally immature patients. J Bone Joint Surg Br. 1995;77(6):890–894.

[60] Anderson AF. Transepiphyseal replacement of the anterior cruciate ligament in skeletally immature patients: a preliminary report. J Bone Joint Surg Am. 2003;85:1255-1263.

[61] Ramski D, Franklin C, Baldwin K, Ganley T. Anterior cruciate ligament tears in children and adolescents: a meta-analysis of nonoperative versus operative treatment. Am J Sports Med. 2014;42(11):2769-2776.

[62] Mohtadi N, Grant J (2006) Managing anterior cruciate ligament deficiency in the skeletally immature individual: a systematic review of the literature. Clin J Sport Med 16(6):457–464.

[63] Moksnes H, Engebretsen L, Risberg MA (2012) The current evidence for treatment of ACL injuries in children is low: a systematic review. J Bone Joint Surg Am 94(12):1112–1119.

[64] Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. Arthritis Rheum. 2004;50(10):3145–3152.

[65] Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. Am J Sports Med. 2007;35(10):1756–1769.

[66] Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL- injured patient. A prospective outcome study. Am J Sports Med. 1994;22(5):632–644.

[67] Beynnon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE. Treatment of anterior cruciate ligament injuries, part I. Am J Sports Med. 2005;33(10):1579–1602.

[68] Kocher MS, Smith JT, Zoric BJ, Lee B, Micheli LJ. Transphyseal anterior cruciate ligament reconstruction in skeletally immature pubescent adolescents. J Bone Joint Surg Am. 2007;89(12):2632– 2639.

[69] Bollen S, Pease F, Ehrenraich A, Church S, Skinner J, Williams A (2008) Changes in the four- strand hamstring graft in anterior cruciate ligament reconstruction in the skeletally-immature knee. J Bone Joint Surg Br 90(4):455–459.

[70] Demange MK, Camanho GL (2014) Nonanatomic anterior cruciate ligament reconstruction with double-stranded semitendinosus grafts in children with open physes: minimum 15-year followup. Am J Sports Med 42(12):2926–2932.

[71] Lee K, Siegel MJ, Lau DM, Hildebolt CF, Matava MJ (1999) Anterior cruciate ligament tears: mR imaging-based diagnosis in a pediatric population. Radiology 213(3):697–704.

[72] Kvist J, Kartus J, Karlsson J, Forssblad M (2014) Results from the Swedish national anterior cruciate ligament register. Arthroscopy 30(7):803–810.

[73] Magnussen RA, Trojani C, Granan LP, Neyret P, Colombet P, Engebretsen L, Wright RW, Kaeding CC, Group M, Group SFARA (2015) Patient demographics and surgical characteristics in ACL revision: a comparison of French, Norwegian, and North American cohorts. Knee Surg Sports Traumatol Arthrosc 23(8):2339–2348.

[74] Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciateligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med. 2011;45 (7):596–606.

[75] Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitivesport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. Am J Sports Med 2011;39:538–543.

[76] Shelbourne KD, Gray T, Haro M. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. Am J Sports Med 2009;37:246–251.

[77] Spindler KP, Huston LJ, Wright RW, et al. The prognosis and predictors of sports function and activity at minimum 6 years after anterior cruciate ligament.

[78] LaBella CR, Hennrikus W, Hewett TE. Anterior cruciate ligament injuries: diagnosis, treatment, and prevention. Pediatrics. 2014 May;133(5):e1437-50. doi: 10.1542/peds.2014-0623.

[79] Rath E, Richmond JC. The menisci: basic science and advances in treatment. Br J Sports Med. 2000;34:252–257.

[80] Cipolla M, Scala A, Gianni E, Puddu G. Different patterns of meniscal tears in acute anterior cruciate ligament (ACL) ruptures and in chronic ACL-deficient knees: classification, staging and timing of treatment. Knee Surg Sports Traumatol Arthrosc. 1995;3:130–134.

[81] Slauterbeck JR, Kousa P, Clifton BC, Naud S, Tourville TW, Johnson RJ, Beynnon BD. Geographic mapping of meniscus and cartilage lesions associated with anterior cruciate ligament injuries. J Bone Joint Surg Am. 2009 Sep;91(9):2094-103.

[82] Zachary D. Guenther, Vimarsha Swami, Sukhvinder S. Dhillon , Jacob L. Jaremko . Meniscal Injury After Adolescent Anterior Cruciate Ligament Injury: How Long Are Patients at Risk? Clin Orthop Relat Res. 2014 Mar; 472(3): 990–997.

[83] Louboutin H, Debarge R, Richou J, et al. Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. Knee. 2009;16(4):239-244.

[84] Magnussen RA, Mansour AA, Carey JL, Spindler KP. Meniscus status at anterior cruciate ligament reconstruction associated with radiographic signs of osteoarthritis at 5- to 10-year follow-up: a systematic review. J Knee Surg. 2009;22(4):347-357.

[85] Ford GM1, Hegmann KT, White GL Jr, Holmes EB. Associations of body mass index with meniscal tears. Am J Prev Med. 2005 May;28(4):364-8.