Surgical treatment of ligamentous injuries of the knee in children

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Knee trauma is very frequent in children. Hemarthrosis is a sign of severity and is found in up to 18% of patients presenting with knee trauma [1]. When hemarthrosis is encountered, three main types of lesions should be suspected:

1- Ligamentous injuries (1/3 of cases)
2- Meniscal injuries (1/3 of cases)
3- Femoropatellar lesions (1/3 of cases)

This chapter will focus on ligamentous injuries of the knee and their surgical treatment.

Particularities of the ligaments of the knee in children:

The ligaments in children are more elastic in their younger years. Since the growth plate presents a lower resistance than the ligaments in young children, epiphysial separations and/or apophyseal avulsions are more frequently encountered. In preadolescents and adolescents, ligaments are less elastic, and the resistance of the cartilage becomes superior to that of the ligament. According to Young's principle of elasticity, the higher the stretching forces, the greater the elastic deformity of the ligament, until reaching plastic deformity (or even rupture), a threshold after which ligaments could never return to their original state.

These ligamentous injuries are increasingly frequent, and for a multitude of reasons:

- Modifications of the sporting activities of children and adolescents

- Increasing pressure by trainers and parents
- Easier access to MRIs
- Development of arthroscopic techniques

According to the 2006 French Society of Orthopedic Surgery & Traumatology (SOFCOT) symposium [2], the different ligaments of the knee are injured in the following proportions: 70% medial collateral ligament (MCL), 20% lateral collateral ligament (LCL), 10% cruciate ligaments.

Peripheral sprains (MCL/LCL)

Injuries to the collateral ligaments of the knee are more frequently the causes of sprains. Hemarthrosis is not usually found in these types of injuries, except if they are associated with injuries to the cruciate ligaments. The classification into 3 grades is of both therapeutic and prognostic importance:

- Grade 1: stretching (no laxity at 20° of knee flexion)
- Grade 2: partial tear (joint laxity but with a firm end point)
- Grade 3: complete tear (joint laxity without an end point)

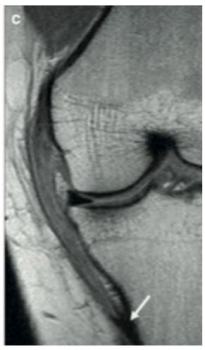
Treatment depends on severity of the injury :

- Grades 1 and 2: immobilization for 1 to 3 weeks in order to relieve pain (plaster knee brace or removable knee brace depending on the age) with full weight-bearing being authorized.
- Grade 3: cast immobilization or hinged knee brace for 4 to 6 weeks. If there is associated cruciate ligament injury, collateral ligament management would be surgical with suture ± ligamentous reinforcement.

MCL: Jacob el al. Insights imaging 2013 [3]

a/ Normal aspect of the MCL, appearing thicker in its proximal compared to its distal end.

b/ Grade 1 sprain: low-grade partial tear of the deep fibers with tear of the medial meniscofemoral ligament with intact superficial fibers.



c/ Grade 2 sprain: high-grade tear of both the deep and superficial fibers which remain attached at their proximal and distal ends

d/ Grade 3: complete MCL tear at the level of the joint space

e/ Grade 3: complete MCL tear at its tibial insertion

Central sprains:

Age plays an important role in treatment decision-making:
In children younger than 12 years of age, cruciate ligament injuries are in 80% of cases associated to bony avulsions [2] or a tibial eminence fracture (TEF). In children younger than 8 years of age presenting with hemarthrosis and a normal radiograph, a purely cartilaginous avulsion must be considered [4]. In children older than 12 years of age, ligamentous tears are more frequent and represent approximately 90% of cruciate ligament injuries. Lesions of the PCL and multi-ligamentous injuries are far less frequently found.

Tibial eminence fracture

The global incidence of TEF is around 1 per 300,000 inhabitants [5] and is more frequently found in children aged between 8 and 13 years old.

The mechanism of injury is a direct blow to the knee in flexion. The ligament has higher resistance than its bony insertion, thereby leading to avulsion fractures. However, this does not prevent distension of the ligaments before the avulsion has occurred, a notion described by Noyer in 1974 [6]. Association with meniscal injury (6 to 8%) is far less frequent than in ligamentous injuries (50%). The diagnosis is generally made on conventional radiographs (lateral views). The most frequently utilized classification is that of Meyers and Mckeever (figure 1) and is of therapeutic importance, including 4 different types:

- Type 1: Non-displaced (20%)
- Type 2: Anterior displacement but with posterior continuity (50%)
- Type 3: Complete displacement
- Type 4: Complete displacement with rotation and comminution

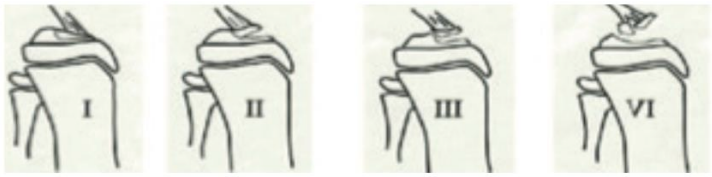


Figure 1: Meyers and McKeever classification of tibial eminence fractures

Treatment:

- Type 1: treatment is conservative and involves immobilization in a long leg cast or a leg cylinder cast for a period of 4 to 6 weeks with slight (10° to 20°) flexion on the knee.
- Type 2: even though treatment leans toward surgical repair, conservative treatment may be attempted if anatomic reduction of the avulsed fragment is ensured without secondary displacement with minimal flexion. In this case, treatment is similar to that of type 1 fractures. Surgical treatment is indicated if an anatomic and stable reduction is impossible to achieve or if the anterior horn of the medial or lateral menisci or the inter-meniscal ligament is entrapped within the fracture site, an often-encountered

entity (54% of cases according to Kocher) [7]. The treatment of entrapment is either by retraction or resection of the incarcerated fragment [8].

- Types 3 and 4: treatment is surgical and involves arthroscopic or open repair with the aim of stabilizing the avulsed fragment and reestablishing articular congruency.

Means of fixation: The aim of treatment is to reestablish the articular congruency and to secure a stable fixation. This is achieved either by sutures, anchors, screws, or endobuttons. Hunter showed comparative results between arthroscopic suture and screw fixation techniques [8].

Results

An anatomic reduction does not eliminate the risk of residual laxity. This may be due to the plastic distension due to stretching of the ligament. Nevertheless, multiple studies have shown excellent functionality (absence of instability) regardless of residual laxity [9-11].

Complications

1. Joint stiffness is the most frequent complication and is essentially due to prolonged immobilization. Rigid fixation systems are recommended for early mobilization (figure 2).

Figure 2: *Stage 3 tibial eminence fracture with screw fixation [12].*

2. Residual laxity is a frequent complication: Smith et al. showed that 100% of cases were found to have residual laxity at 7 years follow-up and 50% of patients were still symptomatic [13]; Willis et al. reported 74% laxity at 4 years follow-up and 10% were symptomatic [14]. More recent publications have shown lower numbers, with Janarv et al. reporting 38% of cases with residual laxity [15] and Iborra et al. reporting 33% at 7 years follow-up [3]. Moreover, this laxity is rarely associated with clinical instability or secondary meniscal injury. Countersinking, which involves fixing the fracture fragment below its original position, allows to counteract the potential stretching and distension of the ACL.

Ligamentous tears of the ACL

Acute phase:

The acute primary repair of an ACL tear has been regaining traction lately, and the two following conditions must be met:

- Proximal tears, as classified on an MRI according to the remaining percentage of ligament distal to the site of ACL rupture: Type 1 (distal remainder > 90%), type II (75%-90%), and type III (25%-75%)
- Good quality of the tendon based on an evaluation by an MRI, classified into good, fair, and poor.

This repair is undertaken by arthroscopy with anchors ± internal brace. Recent studies in skeletally immature children have reported good results as long as the prerequisites have been strictly respected (type I proximal rupture and good ligamentous quality). Nonetheless, these studies included only small sample sizes and sometimes utilized synthetic braces:

- Smith et al. (KSSTA 2016): 3 patients with internal brace (removed 3 months post-operatively), 2-year follow-up [17].
- Bigoni et al. (Knee 2017): 5 patients without internal brace with 4-year follow-up (figure 3) [18].

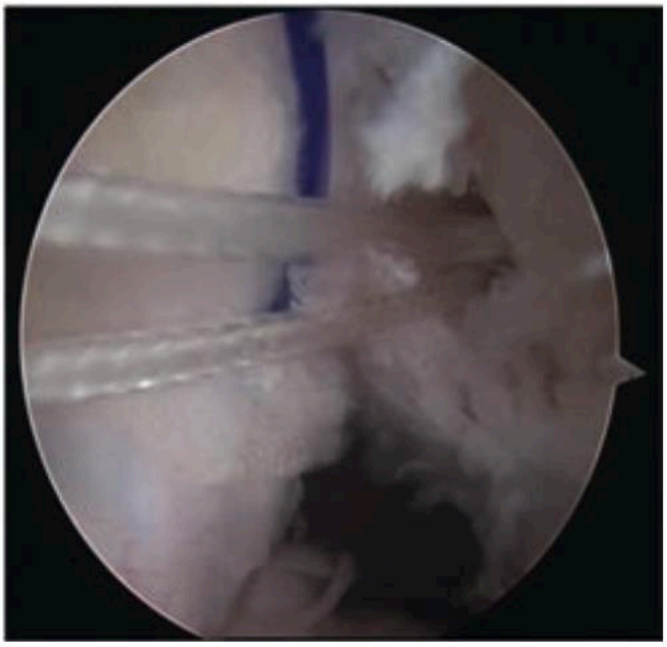


Figure 3 : *Anchor-lacing without internal brace [18].*

Chronic phase:

When an ACL tear has been confirmed in skeletally immature children, two therapeutic options exist: conservative or operative treatment.

Conservative treatment does not signify abstention of therapy. A rigorous rehabilitation program is necessary along with frequent medical follow-ups allowing for the child to return to pivoting. Adepts of conservative treatment base their arguments on the potential growth of the knee in children which is at increased risk with adult ACL reconstruction techniques. Surgical treatment is indicated when there is knee instability after conservative treatment has been attempted (failure of conservative treatment with episodes of clinical instability and meniscal lesions evidencing instability). Adepts of surgical treatment base their arguments on pediatric-specific surgical techniques (extraphyseal, transphyseal, epiphyseal or mixed).

Multiple studies during the 1990s [19-21] argued that conservative treatment of ACL ruptures in children is no different than its natural history with the following consequences (figure 4):

1- Instability in over 90% of patients at 2 years follow-up.
2- Secondary medial meniscal lesions in 50% of cases at one-year follow-up.
3- Cartilaginous injuries and early osteoarthritis with 50% of patients having abnormal radiographs at 5 years follow-up.

In a study by the Francophone Arthroscopy Society (SFA) in 2017 [22], conservative treatment was assessed in a cohort of 53 patients with a mean follow-up of 31.5 months with a rigorous rehabilitation program (OSLO protocol). Specific inclusion criteria were adopted: children complaining of major clinical instability (>2 episodes of instability); children with an initial meniscal tear were excluded. The rate of success of conservative management was 81%, with 17% developing secondary meniscal tears, 36% complaining of instability, and 40% undergoing ACL reconstruction. Factors that predicted the eventual need for surgery included clinical instability and meniscal injuries.

Review of conservative management of ACL rupture in literature.

Study	Year of publication	Number of patients	Mean age at inclusion (years)	Mean follow-up (years)	Meniscal tears at last follow-up	ACL reconstruction
Graf et al. [10]	1992	12	14.5 (11.7–16.3)	Min 2.0	7 (58%)	0
Muzuta et al. [4]	1995	18	12.8 (10–15)	4.3	6 (33%)	6 (33%)
Woods et al. [11]	2004	13	13.8 (11.0–16.0)	5.8	6 (46%)	13 (100%)
Moksnes et al. [12]	2013	46	11.8 (9.0–14.5)	3.2 (± 1.1)	4 (9%)	10 (22%)
Madelaine et al.	2017	53	11.7 (9.2–14.2)	3.2 (± 2.0)	9 (15%)	21 (40%)

Figure 4: Results of conservative treatment found in the literature [22].

Anterior cruciate ligament reconstruction techniques:

Multiple techniques have been described for the reconstruction of the ACL in children (figure 5). These techniques differ depending on the type of graft that is used (hamstrings [quadrupled hamstring autograft], bone-patellar tendon-bone, tensor fascia latae, soft baguette technique) and the location of the tunnels (epiphyseal, extraphysial, transphysial, or mixed).

The key in these techniques is avoiding any iatrogenic injury to the physes may hamper the growth of the knee while keeping in mind that femoral and tibial tunnels used in adult reconstructions transverse the growth plate. In fact, these growth plates are responsible for 65% of the growth of the knee in children (1.2cm per year at the level of the femur and 0.8cm per year at the level of the tibia). These risks require surgeons to respect certain security measures:

- Bone should not be harvested from the tibial tuberosity (Kenneth-Jones technique) thus avoiding any damage to tibial tuberosity growth plate which may lead to recurvatum.
- The transphyseal tunnel must not surpass 9mm in diameter.
- Reaming must be slow when approaching the physis.
- Respect the perichondrial ring.
- The tibial tunnel must be more vertical than in adult techniques.
- The bone tunnels must be filled with fibrous tissue.
- Avoid placing interference screws across the physis.

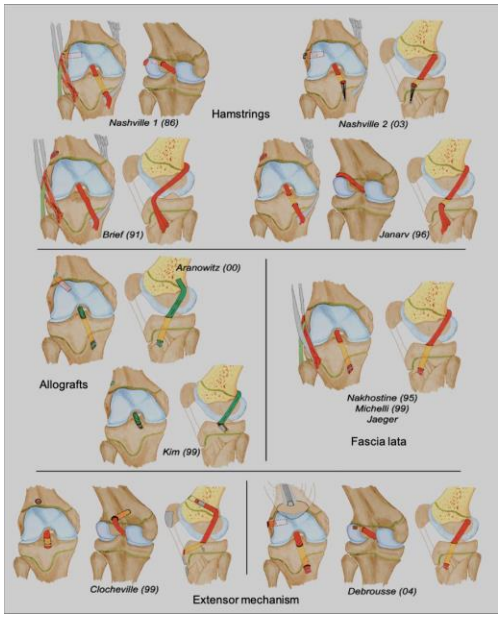


Figure 5: Anterior cruciate ligament reconstruction techniques in children (Chotel collection)

A study by the SFA published in 2017 [23] on 71 skeletally immature patients having undergone ACL reconstruction did not find clinical or radiographic evidence of growth disturbances (limb length discrepancy >10mm or axis deviations >5°). In contrast, MRI analysis found that 20% of cases developed physeal bone bridges. Risk factors for the development of physeal bone bridges include (figure 6):

- Femoral: type of graft (BPTB) as well as diameter (≥9mm) and location of the tunnel (epiphyseal).
- Tibial: Type of graft (patellar tendon) and type of fixation (interference screws)

Relative risk of the occurrence of physeal bone bridges at the femur.

Parameter	RR and 95% CI	*p*
STG	2.1 [0.6–7.6]	NS
SG	0.5 [0.1–2.1]	< 0.05
QT	0.8 [0.1–5.7]	NS
FL	1.3 [0.2–9.1]	NS
Tunnel Ø ≥ 9 mm	1.7 [0.3–9.2]	NS
Epiphyseal tunnel	1.6 [0.4–5.9]	NS
Transphyseal tunnel	1.2 [0.2–6]	NS
Over-the-top	0	< 0.05

Relative risk of the occurrence of physeal bone bridges at the tibia.

Parameter	RR and 95% CI	*p*
STG	1.4 [0.4–4.5]	NS
SG	0.3 [0.1–1.5]	NS
QT	3.6 [1.2–10.8]	< 0.05
FL	0	< 0.05
Epiphyseal tunnel	0	< 0.05
Screw fixation	3.7 [0.8–16.1]	NS
Hyperintensity/screw	2.4 [−0.3–7.7]	NS
Non-absorbable screw	1.2 [0.3–5.3]	NS
Transphyseal screw	1 [0.3–3.6]	NS

Figure 6: Relative risk of the occurrence of physeal bone bridges [23]

Return to sports and risk of graft failure:

In a French multicentric study conducted by the SFA in 2017 [24], return to sports and the risk of graft failure was evaluated in patients who had undergone ACL reconstruction. In the "open physis" group, 20% of patients had unsatisfactory results (graft failure or IKDC scores of C or D), with a risk of graft failure of 9% compared to 2.8% in the "closed physis" group.

Tibial and femoral transphyseal tunnels were created in 95% and 60% of cases, respectively (clear tendency for transphyseal techniques). These findings were independent of the technique utilized (epiphyseal, transphyseal, extraphyseal, or mixed techniques) and the choice of graft (BPTB, quadrupled hamstring autograft, or fascia latae). Return to sports was longer compared to adults (13 months for return to training and 14 months for return to competition), with a rate of return to competition of 63.5% in the "open physis" group and 55% in the "closed physis" group (table 1).

Physis	**Open**	**Closed**
Sample size	100	178
Running (months)	10.5	9
Training (months)	13	12
Competition (months)	14	12
Return to previous level	80%	77%
Return to competition	63.5%	55%
Graft failure	9%	2.8%
Contralateral rupture	6%	5%
Unsatisfactory result	20%	14.7%

Table 1: Summary of return to sports and graft failure risk in both the "open physis" and "closed physis" groups [24].

In conclusion, actual tendencies for the treatment of ligamentous ruptures of the ACL in children can be summarized as such:

- Increasing interest in arthroscopic repair of ACL tears in the acute setting, a technique that was long abandoned, if the prerequisites of proximal rupture and good ligamentous quality are met. Outcomes in the adult population are

encouraging. A small number of pediatric series have begun to emerge, and longer follow-up and larger sample sizes are required in order to validate this therapeutic option in the pediatric population.

- Well conducted conservative treatment is indicated when no clinical instability or initial or secondary meniscal tears have occurred, thus the necessity of regular follow-ups with annual MRIs allowing for the detection of secondary meniscal tears which may sometimes be asymptomatic.
- The different techniques for ACL reconstruction in the pediatric population have shown comparable results to adult techniques and confirm the definitive nature of reconstructions in the pediatric population, rather than merely spanning while the patient awaits definitive surgery after skeletal maturity has been reached. Recent French multicentric studies have shown a tendency toward transphyseal techniques (95% at the level of the tibia and 60% at the level of the femur) with an absence of postoperative complications in terms of limb length or lower limb axis. Nevertheless, MRI studies have shown the formation of physeal bone bridges at the level of the femur and the tibia, but which remain asymptomatic. This confirms the need for experienced pediatric surgeons when treating ACL injuries in the pediatric population, allowing to monitor of potential growth disturbances.
- The rate of graft failure is significantly higher in pediatric patients compared to adults, thereby inciting a longer return to sports than adults (13-14 vs. 6 months, respectively). This is due to a slower ligamentization of the graft in children [25]. Studies attempting to increase rotational stability, which is difficult to control, are actually underway and are evaluating the effect of combined ACL and anterolateral ligament (ALL) reconstruction techniques. This is an old concept that is once again gaining traction in an attempt to increase the stability of the construct. Graft failure and return to previous level of competition [24] are important notions to discuss with the patients and their parents during preoperative consultations. This would allow for the postoperative rehabilitation to integrate the required time for proper preparation and readaptation, and would allow ample time to reassess the high-level student-athlete future of the child.