Paediatric anterior cruciate ligament injuries

a review of controversies and treatments

BACKGROUND

Injuries to the anterior cruciate ligament (ACL) in the paediatric and adolescent population are becoming more frequent. A recent large analysis of a United States national database of 45 000 cases showed an increase in incidence in the five- to nine-year-old and ten- to 14-year-old populations of 4.5% and 18.9%, respectively, over a four-year period.[1] Similarly, an Australian review found an increase in the five- to 14-year-old population of 147.8% over a ten-year period to 6.79 per 100 000.[2] Although this is still a lot less common than adult ACL injuries, which have an incidence of around 68.6 per 100 000,[3] one can no longer consider these injuries to be rare.

Potential theories to account for this increasing incidence vary from the increased availability and sensitivity of MRI scans, to involvement in competitive sport at a younger age and an increase in female participation in sport.[1,4] Whatever the reasons, the rising frequency of ACL injuries in the paediatric population has led to similar and contrasting controversies that we have seen in the adult population. It is therefore of paramount importance to understand what the long-term effects of ACL injuries are, and to assess the various ways in which we can treat these injuries.

Currently, the goals for treatment of children with an ACL injury are as follows: to restore knee stability and function to enable patients to have an active lifestyle; to prevent further intra-articular injuries, which may lead to joint degeneration; and to minimize the risk of growth disturbance

TO OPERATE OR NOT TO OPERATE?

Treatment options for isolated ACL injuries broadly consist of rehabilitation with or without surgery – but what happens if we choose not to operate? Unfortunately, high-quality evidence is lacking. Whether we operate or not, ACL injuries are known to be associated with arthritis. In the adult population, rates of osteoarthritis approach 50% at ten to 20 years post-diagnosis in those patients that have sustained an ACL rupture or meniscal injury.[5-8] In the paediatric population, one small study has shown a 43% rate of arthritis in those treated nonoperatively,[9] while another study showed arthritis occurring in 61% of those who did not receive surgical treatment.[10]

With regards to operative intervention, Woods and O'Connor[11] showed that in a group of 130 paediatric patients, there was no difference between those treated operatively (n = 100) and those treated nonoperatively (n = 30). However, other studies (albeit involving low patient numbers) have shown a 50% to 65% rate of meniscal tears, severe instability, and poor function in those treated without surgery.[10,12,13]

This finding has been reiterated in a recent systematic review of the outcomes of paediatric ACL injuries treated operatively and nonoperatively.[14] This comprehensive review concluded

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Table I. Studies featuring operative treatment for paediatric anterior cruciate ligament injuries

Study	Patients, n	Follow-up, mths	Failures, n	Complications, n	Technique
Lipscomb and Anderson[17] (1986)	24	35	0	1	All extra-articular
McCarroll et al[18] (1988)	24	26	2	0	10 extra-articular, 14 intra-articular
Lo et al[19] (1997)	5	89	0	0	2 BTB, 3 HT transphyseal
Shelbourne et al[20] (2004)	16	41	0	0	All BTB
Sankar et al[21] (2008)	246	76	17	3	All achilles allograft
Bollen et al[22] (2008)	5	35	0	0	All HT transphyseal
Kumar et al[23] (2013)	32	72	1	2	All HT transphyseal
Cruz et al[24] (2017)	103	21	11	3	All epiphyseal

BTB, bone tendon bone; HT, hamstring tendon

that patients treated nonoperatively had a high incidence of knee instability, associated injuries, and joint degeneration, with subsequent conversion to operative management.[14]

Therefore, the 'best guess' that we can make from the evidence available is of the importance of a stable knee in allowing an active lifestyle and preventing meniscal or chondral damage, no matter how this is achieved. In some patients, this may solely be via high-quality, intensive rehabilitation.[15] However, the extent of the resources, individualization of protocols, time, and patient motivation required is not to be underestimated. The role of surgery is to ensure knee stability, but again it must be combined with suitable expert rehabilitation.

The main accepted indications for surgery are: the presence of reparable associated injuries that require surgery (e.g. meniscal tears); instability despite attempts at rehabilitation; and restrictions in activity level despite rehabilitation.[15]

The first indication for surgery of reparable associated injuries makes sense, in that one would not want to risk persisting instability in an ACL deficient knee after repairing a crucial structure such as the meniscus. In the above case, the ACL reconstruction is then undertaken to 'protect the meniscus'. There are surgeons who would argue either way with the second two indications. One may argue that, as instability can lead to permanent joint damage, why risk this potential instability by undergoing a trial of rehabilitation, especially in a population where adherence to regimens may be unreliable? In contrast, surgery does not guarantee a return to previous activity levels, and carries with it additional risks in the paediatric population. However, it has been suggested that a compromise involving a trial of nonoperative management, with surgical reconstruction if this fails, leads to good strength and functional outcomes at long term follow-up, as shown recently in a small group of 46 paediatric patients.[16]

Due to the lack of conclusive evidence, surgeons are advised to counsel the patient and their parents of the potential risks and benefits of surgical *versus* non-surgical treatment and decide a shared treatment algorithm that is tailored to the individual patient. In those patients who elect for surgical treatment, our suggested surgical strategy is detailed below.

OPERATIVE TREATMENT

When considering operative treatment, factors to be considered include surgical technique, timing, and graft choice. Surgical techniques commonly used include transphyseal, partial transphyseal, and physeal sparing (extraphyseal and all epiphyseal). All are reported in the literature in relatively small series with variable technique and follow-up (Table I).[17-24] With regards to failure rates, quoted failures appear similar in all surgical techniques, although these reports are generally from specialist centres where failure rates would be expected to be both consistent and lower than in the general orthopaedic surgeon's hands.

However, what is clear from modern literature involving large patient numbers is that there is a definite increased failure rate in paediatric ACL reconstructions compared with adults, ranging from two to four times the adult rate (Table II).[25-28]

SURGICAL TECHNIQUE: TRANSPHYSEAL

Apart from the risk of failure, the main concern in the paediatric group is of growth disturbance due to physeal disruption during transphyseal drilling. Transphyseal ACL reconstruction is the most common technique used on adults by ACL surgeons, hence one can understand the desire to use this technique in the younger population. However, drilling through an open physis risks angular deformity, shortening, and even overgrowth (Fig. 1).

An MRI imaging study of ten patients undergoing ACL reconstruction showed that six months post-reconstruction, there was marked corticalization around the drill holes visible in all patients.[29] Radiological follow-up of 39 skeletally immature patients from Denmark showed 24% were > 10 mm shorter than the contralateral limb, with 82% in > 2° of valgus.[30] This observation is reflected in a paper from New York, showing symptomatic growth disturbance in a case series of four patients.[31] A more recent series of 15 patients by Kohl et al[32] reported > 10 mm of leg-length discrepancy in two patients, a 10 mm discrepancy in one patient, and another patient with > 6° valgus deformity.[32]

Table II. Studies reporting re-rupture rate of children and adolescents *versus* adults for paediatric anterior cruciate ligament reconstructions

Study	Re-rupture rate: children and adolescents *vs* adults
Shelbourne et al[25] (2009)	8.7% < 18 years *vs* 1.1% > 25 years (5-year follow-up)
Bourke et al[26] (2012)	34% < 18 years *vs* 14% > 18 years (15-year follow-up
Lind et al[27] (2012), Danish Registry	8.7% < 20 years *vs* 2.8% > 20 years, (5-year follow-up)
Fältström et al[28] (2016), Swedish Registry	6% < 16 years *vs* 1.7% > 25 years (3.8-year follow-up)

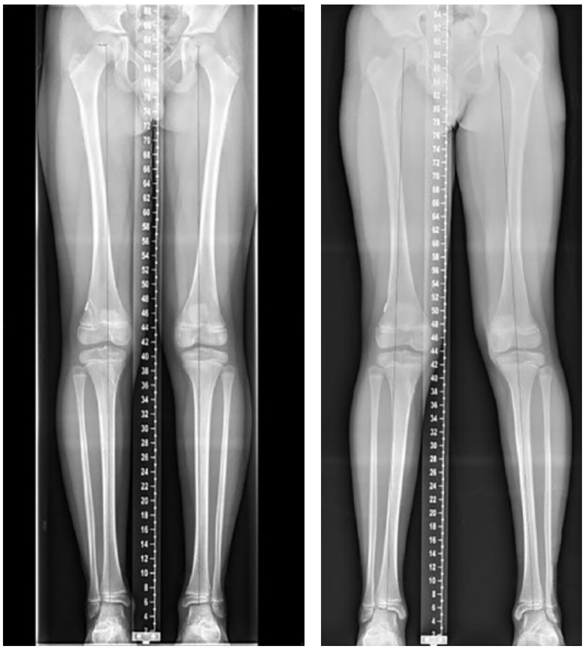

Fig. 1a **Fig. 1b**

Fig. 1 a) and b) Valgus deformity of right femur following anterior cruciate ligament (ACL) reconstruction.

However, many other studies have shown that the rate of clinically important growth disturbance with the transphyseal technique is low.[23,33-36] A recent systematic review has shown no significant differences in rates of growth disturbance when comparing transphyseal and physeal sparing cohorts (0.81% *vs* 1.2% and 0.61% *vs* 0%, respectively).[37] This finding was confirmed in an additional systematic review that also found no difference in leg-length discrepancy or coronal plane deformity between the two types of surgery ($p = 0.32$ and $p = 0.48$, respectively).[14] However, such low rates of growth disturbance in the literature may be due to under-reporting, as many surgeons may not evaluate for growth disturbance at follow-up. Indeed, a survey by the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA) in 2016 showed that 21% of the 491 surgeons surveyed did not assess for growth disturbance, and so there is almost certainly a cohort of patients with an unrecognized growth disturbance.[38]

Animal models have been used to quantify the cross-section of physeal disruption that can be tolerated before growth disturbance ensues. Mäkelä et al[39] found that drilling 3% of the physeal cross-section of the femur had no effect on the growth of rabbits, but drilling 7% did affect growth. Guzzanti et al[40] also showed that drilling 3% of the femur did not affect growth, but drilling 4% of the tibia did lead to angular deformities or shortening in rabbits. In children between ten and 15 years, an 8 mm drill hole in the femur and tibia represents 2.4% and 2.5% of the growth plate, respectively, and so in this age group, the overall risk of growth disturbance is, based on this animal work, likely to be minimal.[41]

For those using the transphyseal technique in the paediatric population, some adaptations can be incorporated to reduce the risk of growth disturbance. For the tibial tunnel, a more vertical tunnel (from 45° to 70°) is recommended to reduce the transgression of the growth plate. It has been shown that 25% less growth plate is damaged by changing the angle from 45° to 70°.[41] In addition, more medial and distal tunnels further reduce the physeal violation of the tibia.[42] Low power reaming with intermittent stopping to reduce thermal ablation of the physis is also recommended.[43] In the tibia, a bioabsorbable screw may be used, together with radiological guidance, to confirm the screw is not within the physis.

When using the transphyseal technique, bone-tendon-bone (BTB) grafts should not be used in the skeletally immature due to the significant risk of tibial growth arrest. For this reason, hamstrings are recommended.[44] The use of allograft is also not recommended due to the significantly higher failure rates.[45]

The results of the transphyseal technique have been shown to be good in small series. Kumar et al[23] published the results of 32 patients with an average age of 11.3 years and 72-month follow-up, with one re-rupture and one valgus deformity. Similarly, Kocher et al[46] had two re-ruptures out of 35 patients with an average age of 14.7 years at 34-month follow-up. Due to the low risk and familiarity of the procedure, the transphyseal technique is used by the senior author in children with one to two years of growth remaining.

SURGICAL TECHNIQUE: PHYSEAL SPARING

The physeal sparing (extra-articular) technique described by Kocher et al[47] utilizes the iliotibial band (ITB). The ITB is harvested and freed proximally and left attached to Gerdy's tubercle distally. The graft is brought through the knee in the 'over-the-top' position posteriorly by a clamp placed through the anteromedial portal. It is then brought under the intermeniscal ligament anteriorly and fixed with sutures to the periosteum over the tibia anteriorly (Fig. 2).

The most obvious benefit of this technique is the lack of risk to the growth plate and sparing of the hamstrings. Therefore, this technique is particularly attractive and may be most indicated in younger patients with more than five years growth remaining. A series by Kocher et al[47] of 44 patients showed two re-ruptures at a mean of 5.3 years post-surgery, with no limb deformities. A more recent review by Kocher et al[48] of 237 patients treated with this technique showed a re-rupture rate of 6.6% at 33.5 months' follow-up and excellent functional outcome scores.

SURGICAL TECHNIQUE: ALL EPIPHYSEAL

An alternative physeal sparing technique is that of the 'all inside' transepiphyseal or all-epiphyseal

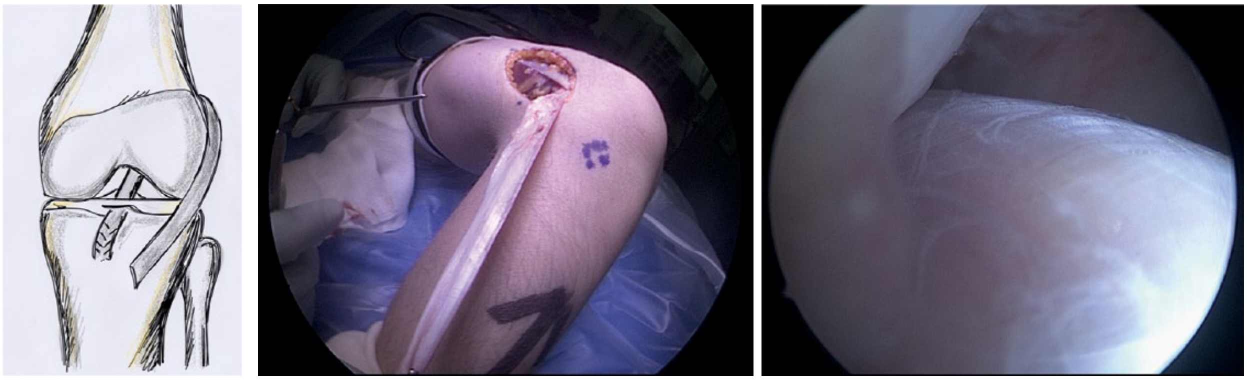

Fig. 2a Fig. 2b Fig. 2c

Fig. 2 a) Extra-articular reconstruction, b) harvesting of iliotibial band (ITB), and c) ITB graft *in situ* entering posterior to femoral condyle.

Fig. 3 All-epiphyseal reconstruction (lines demarcate tunnel positions).

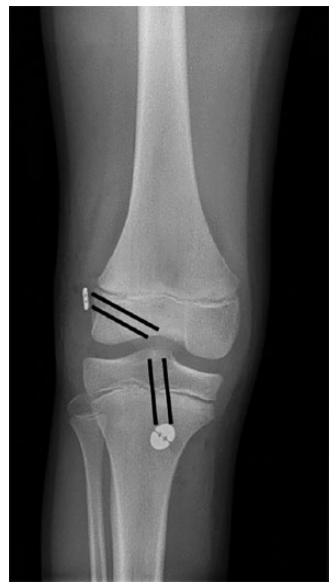

Fig. 4 Partial physeal sparing reconstruction (lines demarcate tunnel positions).

method. This utilizes hamstring grafts placed in a more anatomical and isometric position secured through epiphyseal femoral and tibial tunnels (Fig. 3).

The largest reported series of 103 patients showed 11 re-ruptures (10.7%) and one case (1.0%) of clinical leg-length discrepancy of < 1 cm at a follow-up of 21 months.[24] Other smaller series of this technique have shown acceptable reoperation rates of around 8.7% to 15% and excellent functional outcomes at two- to four-year follow-up.[49,50] MRI follow-up has also been reported and, in general, shows that some tibial physeal violation is hard to completely avoid, suggesting that this is a technically demanding procedure.[51] However, the low overall complication rate of this procedure means that in trained hands it certainly has its merits,[24] especially in those with more than five years of growth remaining.

SURGICAL TECHNIQUE: PARTIAL PHYSEAL SPARING

Partial physeal sparing involves placing an anatomical tunnel through the tibial physis, but combining this with fixation on the lateral femur, either via the 'over-the-top' or the all-epiphyseal technique. Therefore, this is a hybrid technique (Fig. 4).

Three small studies involving a total of 37 patients have shown one case of growth disturbance and no re-ruptures.[19] This hybrid procedure may well be best utilized in the 'in between' child with two to five years of growth remaining.

SURGICAL TECHNIQUE: REPAIR

Contemporary ACL repair has little published evidence to support the technique;[51-53] however, popularity appears to be growing. History tells us that the results of attempts to repair the paediatric ACL have generally been poor, although this refers to open surgical techniques.[52] It is an attractive option that avoids harvesting of the autograft in this cohort who are at high risk of re-rupture. Repair can be via an absorbable suture anchor with or without a temporary internal brace. The timing of surgery and rehabilitation are controversial, with basic science suggesting that early repair aids healing, but with a significant risk of arthrofibrosis. It is the authors' belief that the only indication for attempted repair is in those patients with proximal or distal ACL avulsions, particularly with a small fragment of bone or cartilage attached to the avulsed ACL. Surgery should be performed as soon as the knee is quiet and prehabilitated. In a very small cohort of children, repair may have a role to play, but patients should be carefully counselled regarding the lack of evidence that exists at present.

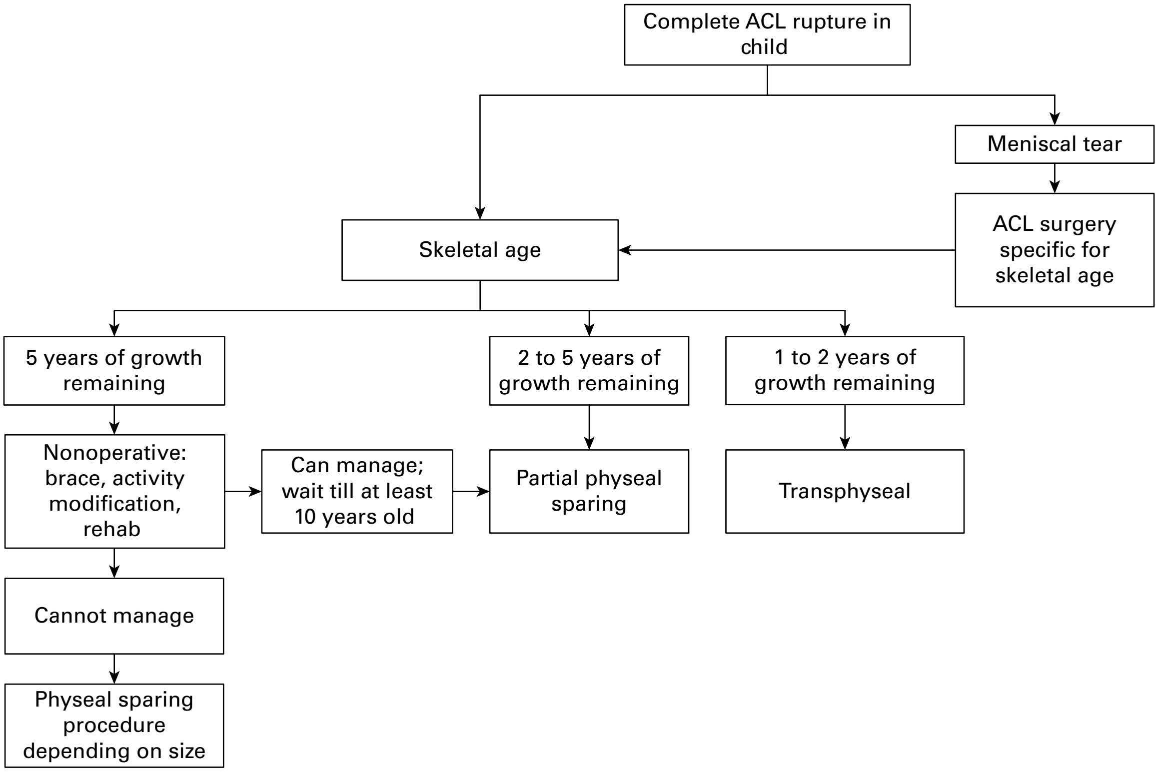

Fig. 5 Surgical strategy. Treatment should be based on: symptoms of instability, patient's activity level and goals, associated injuries, skeletal age, and remaining growth.

SURGICAL STRATEGY AND TIMING

Our suggested treatment algorithm relies on dichotomizing treatment decisions in patients necessitating surgical reconstruction by skeletal age to determine the surgical technique used, rather than chronological age (Fig. 5). Our preferred method is to use radiographs of the wrist and the Greulich and Pyle atlas to calculate skeletal age, followed by Anderson–Green charts to determine remaining growth. Another possible alternative method is Tanner staging, but the intimate nature of the examinations required to use this technique may make its use difficult. Most non-paediatric orthopaedic surgeons will be unfamiliar with these methods, and so a review by a paediatric orthopaedic surgeon is essential. For the reasons aforementioned, the surgical strategy is then decided.

Early surgery, roughly defined as surgery within 12 weeks of injury, has been associated with a significantly lower risk of medial meniscal and femoral, tibia, and patellofemoral chondral damage in a meta-analysis of 1353 paediatric patients, without an increase in postoperative complications.[53] In addition, a cohort study of 62 patients also found a reduction in such intra-articular pathologies in patients treated within six or 12 weeks.[54] Therefore, it is advised that the decision for surgery should be made early.

REHABILITATION

Independent of the treatment method chosen, all patients should progress through a thorough rehabilitation programme led by a specialist therapist. A typical rehabilitation programme progresses children through four phases, with specific functional and clinical milestones required to be achieved before progression, rather than temporal measurements.[15] If operative treatment is selected, an additional prehabilitation phase should be used prior to surgery (Table III).

The risk of re-rupture in the paediatric population is up to six times higher than in adults.[55] Traditionally, children were restricted from returning to sports for at least nine months; however, literature has shown that functional movements and dynamic balance characteristics do not recover adequately in this time.[56] Therefore, delaying return to sport until one year post-surgery is probably advised. Even this may be too short a time period, especially in the very young who struggle with strength and proprioceptive recovery following surgery. Alternatively, children can be assessed for risk of re-rupture using functional tests such as the 'Functional Movement Screen' and 'Lower Quarter Y-Balance Test', and those who fare well can return to sport sooner.[56]

The importance of structured rehabilitation and delaying return to sports until functional outcomes are met must not be underestimated. Overall, around 25% to 30% of adolescents suffer a repeat ACL rupture (of same or contralateral side) in the first two years of returning to sport.[57] It is hoped that increased awareness of rehabilitation and injury prevention programmes, as mentioned below, will reduce this rate in the future.

INJURY PREVENTION

There is increasing evidence that neuromuscular training programmes reduce the incidence of ACL injuries in the paediatric population, both in men and women. A twice weekly 15-minute schedule combining balance, core stability, and knee alignment training has been shown to reduce ACL injuries by 64% in female football players.[58] A similar programme reduced the incidence of all knee injuries by 77% in female football players.[59]

The 'FIFA 11+' (previously named the '11+') focuses on the aforementioned physical training aspects, but also adds in hamstring strength, falling techniques, and more, and has been shown to reduce ACL injuries by 76% in a randomized controlled trial (RCT) involving male college football players.[60] In another RCT

Table III. Recommended functional tests and return-to-sport criteria for the child and adolescent with anterior cruciate ligament (ACL) injury. Adapted from **Ardern CL, Ekås GR, Grindem H, et al.** 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. *Br J Sports Med* 2018;52:422-438.

Phase	Criteria
For patients who choose ACL reconstruction	
Prehabilitation	Full active extension and at least 120° of active knee flexion
	Little to no effusion
	Ability to hold terminal knee extension during single-leg standing
	For adolescents: 90% limb symmetry on muscle strength tests
For patients who choose ACL reconstruction OR nonsurgical treatment	
Phase 1 to 2	Full active knee extension and 120° of active knee flexion
	Little to no effusion
	Ability to hold terminal knee extension during single-leg standing
Phase 2 to 3	Full knee range of movement
	80% limb symmetry on single-leg hop tests with adequate landing strategies
	Ability to jog for 10 mins with good form and no subsequent effusion
	For adolescents: 80% limb symmetry on muscle strength tests
Phase 3 to 4: sport participation (return-to-sport criteria) and continued injury prevention	Single-leg hop tests > 90% of the contralateral limb (with adequate strategy and movement quality)
	Gradual increase in sport-specific training without pain and effusion
	Confidence in knee function
	Knowledge of knee positioning with a high risk of injury and ability to maintain low-risk knee positioning in advanced sport-specific actions
	Gradual increase in sport-specific training without pain and effusion

involving paediatric football players, with a mean age of 10.8 years, the 'FIFA 11+' reduced lower limb injuries by 55% and knee injuries by 47%, although the 95% confidence interval was 0.19 to 1.13 in this category. A meta-analysis of four studies of the 'FIFA 11+' and '11+' showed a reduction in knee injures of 52% in pooled analysis.[61] However, it should be noted that neuromuscular training has not been shown to improve the actual movement patterns associated with ACL injuries.[62-64] Finally, compliance is key to any programme delivering benefits.[65,66]

CONCLUSION

Paediatric ACL ruptures are increasingly common, and diagnoses will no doubt continue to rise with better awareness, imaging techniques, and increased participation in sports. Knee instability in this population is associated with poor function, significant pain, and long-term morbidity. Surgery, in combination with intensive rehabilitation, can improve the outcomes for patients. Depending on the patient's skeletal age, the timing and techniques employed differ, and surgeons treating this cohort of patients must have the ability to assess and use whichever technique is best for each individual in order to achieve optimal outcomes.

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