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CURRENT TREATMENT UPDATE FOR ANTERIOR CRUCIATE LIGAMENT TEARS IN ADOLESCENCE: A NARRATIVE REVIEW

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ABSTRACT

To follow up regarding orthopedic updates in respect of the treatment of ACL tears in adolescence. The methods with we performed a comprehensive literature search from four databases to synthesize a narrative review of available evidence on the recent update of ACL treatment in adolescence. The results is conservative treatment remains preferred for partial ACL tears in adolescence. Some surgeons have favored non-operative or delayed surgical treatment until skeletal maturity has reached or after a failed trial of non-operative management. However, adolescent patients who delayed ACLR for more than 12 weeks had increase risk of meniscal pathology and irreparable meniscal tears by 4.3 and 3.2 times, respectively. Various ACL reconstruction techniques for adolescents have developed to respect growing physes, these are physeal sparing (extraphyseal and all-epiphyseal), partial transphyseal, and transphyseal. The conclusions is Early operative treatment of ACL injury is preferred compared to non-operative or delayed treatment. The reconstruction techniques were adjusted to each patient's potential for growth, the facilities' capabilities, and the surgeons' skills. High-growth potential patients should still undergo surgery using a technique with the slightest manipulation of growth cartilage.

Keywords: Anterior Cruciate Ligament Reconstruction, Adolescent, Early Or Delayed, Physeal Sparing, Transphyseal

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INTRODUCTION

Anterior Cruciate Ligament (ACL) tear is one of the most frequent orthopedic injuries. Based on implant usage, it is estimated that 400,000–500,000 ACL reconstruction (ACLR) procedures are carried out annually in the United States. In Indonesia, implant usage for ACLR from 2018 to 2019 increased by 42% (1.575 implants in 2018 vs. 2.236 in 2019) and is expected to rise (1). ACLRs were performed yearly at 32.4 per 1000 orthopaedic surgeries. From 2004 to 2014, there was a substantial rise in the number of ACL reconstructions, increasing by 5.7 times. In contrast, there was only a modest increase of 1.7 times in orthopedic surgeries during the same period. Furthermore, the relative increase of ACLRs in relation to the total number of pediatric orthopedic surgeries was 2.8 times higher (2).

ACL tears in adolescents have increased in frequency due to several factors, including increased clinical suspicion, better diagnostic techniques, increased competitive physical activity, and early sport specialization among adolescents. Adolescence is a developmental stage between childhood and adulthood, typically ranging from 10 to 19 years of age (3). ACLR in patients younger than 15 years old in Italy was highest in the age range 10–14 years, accounting for 97.3% of surgeries (4). However, ACL tears in adolescence are less frequent than in adults. The greater strength of the ligament over open physis has been linked to a lower frequency of this injury (5). Among adolescent athletes, the risk of suffering from an ACL injury is almost 1.5 times higher for females than males across various sports, with soccer, basketball, lacrosse, and football being the most risky sports for both genders (6).

Skeletally immature patients' distal femoral and proximal tibial physis were at risk in ACLR surgery during tunnel drilling (7). This procedure involves tunnel drilling at the distal femoral and proximal tibial physis risks the growth plate. To avoid this, some surgeons prefer to wait until the patient reaches skeletal maturity or try non-surgical treatment before resorting to surgery. However, delaying treatment can lead to chronic knee instability, increasing the risk of further injuries and inability to return to sports. There are debates regarding the best treatment strategy for ACL tears in adolescence.

MATERIAL AND METHODS

A comprehensive literature search regarding the available evidence on the recent update of ACL treatment in adolescents was done through four databases: PubMed, Medline via EBSCO, ProQuest, and Google Scholars. Through a prudent discussion among the authors, this review was synthesized.

RESULTS

The knee ligaments are frequently injured, especially during sports. However, the injury also occurs in traffic accidents linked to fractures or dislocations. It is helpful if the patient can explain how the injury occurred. The typical story is that an injury occurs when the knee is twisted and loaded axially while it is slightly bent. This is thought to be caused by the relaxed state of the capsule and ligaments, allowing the

femur to rotate on the tibia. As the ligament tears, the patient may claim to have heard a 'pop' sound, followed by intense pain and swelling immediately. After the acute phase subsides, the patient may have a feeling of giving way, instability, and lack of trust in the knee.

The joint stability assessment is the most pivotal aspect of the examination. Partial tears may be present without any anomalous movement, although the attempt to move the joint may be uncomfortable. Full tears typically enable abnormal movement, which can be almost pain-free (8). The Lachman, anterior drawer, pivot shift, and Lever sign tests are commonly used physical examination to assess the stability of the ACL (9–11). The Lachman, anterior drawer, pivot shift, and Lever sign tests yielded sensitivities of 0.79, 0.78, 0.55, and 0.82, respectively, as well as specificities of 0.91, 0.91, 0.96, and 0.88, respectively. Out of the four tests, the pivot shift test presented the highest positive likelihood ratio (11.60), while the lever sign test had the lowest negative likelihood ratio (0.21) (10). These two tests provide the greatest diagnostic precision for affirming or excluding an ACL tear in the absence of concurrent knee ligament damage, with the pivot shift test being the superior choice for acute ACL injury confirmation (10-11). While MRI is deemed the gold standard imaging modality for evaluating knee ligament injuries, offering almost 100% sensitivity and more than 90% accuracy (8).

Non-Operative, Delayed Operative, And Early Operative Treatment with Some surgeons have favored non-operative or delayed surgical treatment, specifically until skeletal maturity has reached or after a failed trial of non-operative management. However, non-operative or delayed surgical treatment may increase the risk of secondary meniscal tears, chronic knee instability, and low rates of return to sports. Many patients who underwent non-operative treatment still had knee instability, which could range from 20% to 100%. Hence 32 to 100% of patients eventually experienced ACLR. Furthermore, in studies that included return-to-sport rates, 6% to 50% of patients returned to a preinjury level of athletic activity. Meniscal pathology and irreparable meniscal tears rose dramatically (4.3- and 3.2-times greater odds, respectively) when ACLR was in pediatrics and adolescence (7). Adolescents who delayed ACLR are at an increased risk of meniscal and cartilage damage due to repetitive micromotion from walking on the unstable knee, poor observance of sport-related restrictions, and denial of instability resulting in repeat traumatic episodes (12). According to the current meta-analysis, delayed ACLR was associated with a significantly higher risk of medial meniscal damage but not lateral meniscal damage. The medial meniscus's function as a secondary knee stabilizer may cause the difference (13).

Improved stability, function, and increased rates of return to sport are all features of early ACLR. According to a recent meta-analysis, 92% of pediatric and adolescents who receive ACLR will return to sports, with 79% performing at their pre-injury levels (14). The PLUTO (Pediatric ACL: Understanding Treatment Options) study

group has formally advocated early surgical intervention as a standard of orthopedic therapy when carried out by healthcare professionals with experience treating pediatrics and adolescents using age-appropriate procedures (15).

Partial ACL Tears Several factors suggest a partial tear of the anterior cruciate ligament, including an asymmetric Lachman test result in comparison to the uninjured knee, a negative pivot-shift test during anesthesia, a low-grade measurement of the KT-1000 arthrometer (less than or equal to 3mm), and arthroscopic confirmation of a partial injury to the ACL (16). A partial ACL tear that has preserved the ACL's functional integrity is identified in a patient if all four criteria are present during a patient evaluation (17).

Considering their likelihood of developing ACL deficiency, each patient's treatment needs to be individually customized. Individuals at low risk (low-demand lifestyle) generally exhibit few symptoms, and with a favorable pivot shift test result, non-operative treatment should be used. People who belong to the high-risk category due to their demanding lifestyle may initially undergo a non-surgical program. However, it is crucial to communicate the risk of re-injury (16). Individuals with unclear exam and MR findings suggesting a possible ACL insufficiency should have an intervention involving a diagnostic arthroscopy and an evaluation under general anesthesia. During anesthetic evaluation, the results of an insufficient ACL, particularly a positive pivot shift of any grade, should be followed by reconstruction (17).

Several non-surgical courses of action could be pursued, such as temporary immobilization, the implementation of a brace, a step-by-step recovery plan, and regular check-ups to monitor progress. In Kocher et al.'s study involving children, they detailed a non-surgical approach that involved several steps: (1) a period of limited weight-bearing for six to eight weeks followed by a gradual increase as tolerated; (2) the use of a hinged knee brace to prevent excessive stretching of the knee joint, with passive terminal extension avoided for six weeks and active terminal extension avoided for 12 weeks; (3) the implementation of an early physical therapy program that emphasized the strengthening of the hamstring muscles to provide dynamic support; and (4) most patients were able to resume physical activity within three months of the injury, with the continued use of a brace being recommended (18).

Complete ACL Tears with The optimal treatment method for ACL tears in adolescence remains a subject of debate, with no established consensus at this time. Several studies suggest conservative treatment for ACL tears is preferable to surgical reconstruction. However, the data used to support these conclusions is of low to extremely low certainty (19,20). Conservative treatment of ACL tears has been linked to persistent instability, worse rates of return to sport, and eventual cartilage damage in skeletally immature patients. Due to the risks associated with

non-operative management of complete ACL tears in adolescents and the requirement to consider growing physes, modern surgical techniques and equipment provide a variety of reconstructive alternatives. These can be categorized as physeal sparing (extraphyseal and all-epiphyseal), partial transphyseal, and transphyseal. These procedures are carried out according to the patient's age and level of bone maturity, and no one method has consistently outperformed others.

Table 1. Review of Clinical Outcomes Following ACLR in Pediatrics and Adolescents (Limited to Previous 5 Years)

Technique and Study	No. of participants	Level of Evidence	Re-rupture (%)	Side-to-side laxity (mm)	Negative Lachman test (%)	Lysholm score	IKDC score	Tegner score	Return to Sport (%)	Note
Extraphyseal										
Lucena et al (2022)[21]	1.210	4	4.2	1.41	57	93.3	94.4	6.8	89	
Pagliazzi et al (2023)[22]	814	3		0.22	90	93.6	94.5	7.6	80	
Knapik et al (2020)[23]	443	4	3.6			95.6	90.1	7.8	97	
All-epiphyseal										
Pagliazzi et al (2023)[22]	814	3			90	93.6	94.5	7.6	80	
Gupta et al (2020)[24]	545	4	5		100		90		93.2	
Knapik et al (2020)[23]	443	4	7.9			94.8	93.5	7.4	87	
Partial transphyseal										
Pagliazzi et al (2023)[22]	196	3		1.69	80		93.9		80	
Chambers et al (2019)[25]	24	4	8.3				94.8		91.7	Growth disturbance 16.7%
Transphyseal										
Pagliazzi et al (2023)[22]	2.250	3		1.98	80	94.3	93.2	6.7	80	
Ghosh et al (2019)[26]	100	3	12	2 (-1 to 5)	67		96		86	HT allograft
Petersen et al (2023)[27]	1.010	4	10.8 (TTD), 11.4 (IDD) 13.1 (HT) 10.3 (HT from living donor), 3.8 (BTB), 6.5 (QT)							
Pennock et al (2019)[28]	83	3	21 (HT), 4 (QT)			94 (HT), 96 (QT)		7.1 (HT), 6.6 (QT)		
Bayomy et al (2018)[29]	90	3	10							Contralateral ACL tear (5%) Radiographic deformity (17%)

				Clinically evident deformity (5%)

*Abbreviation: TTD = Transtibial drilling, IDD = Independent drilling, HT = Hamstring tendon, BTB = Bone patellar bone tendon, QT = Quadriceps tendon

Several authors have divided patients into different treatment categories to decide on the best ACLR methods, considering factors such as the Tanner stage and estimates of remaining growth. (Figure 1) In preadolescent children who have not yet reached a certain level of physical development (Tanner stage ≤2 and a skeletal age of ≤11 years for girls and ≤12 years for boys), the recommended treatment involves physeal-sparing reconstructions. For children who are in a borderline stage of pubescence, but who still have some room for growth (e.g., Tanner stage 3), partial transphyseal reconstruction is recommended. For older children and adolescents who have already undergone significant physical development (a Tanner stage of ≥3 and a skeletal age of ≥12 years in girls and ≥13 years in boys) but still have some growth remaining, transphyseal reconstruction is the recommended treatment (30,31).

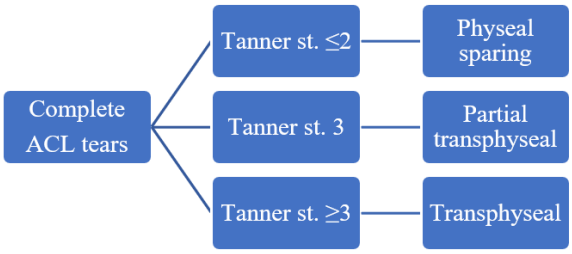
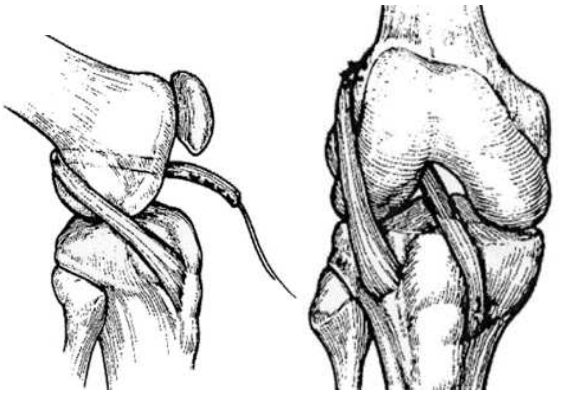


Figure 1. ACL reconstruction in adolescent patients referred to Tanner stage (21).

Physeal Sparing: Extraphyseal Iliotibial Band Autograft Reconstruction suits the smallest infants with the most growth potential because they avoid creating bone tunnels that cross the physis. (Figure 2) Micheli et al. first described the modified MacIntosh combined intra-articular and extra-articular IT band repair, and Kocher et al. further characterized it. The IT band's middle section is collected near its origin and remains connected to Gerdy's tubercle at its end. Then, the transplant is pulled through the back of the knee in a position that goes over the top and is moved underneath the inter meniscal ligament towards the front of the knee and into a groove on the tibia. To secure the transplant, it is sewn onto the intermuscular septum and periosteum on the femur, as well as the tibia's periosteum (32,33). The growing knee appears to have a normal, symmetrical, physiological kinetic and kinematic function after ITB ACLR (34).

Clinical and functional outcomes for ITB autografts, as well as the graft survival rate, are satisfactory. A recent meta-analysis and systematic review including 1,210 patients with ACLR found graft failure occurred after ITB autograft in 4.2% of patients. Mean side-to-side laxity after surgery was 1.41 mm, and 21% of patients had a more than 3 mm discrepancy. In 57% and 85% of cases, the Lachman and pivot-shift tests showed negative results (grade 0), and 95% and 97% were grade 0 or 1. The mean post-operative Lysholm score was 93.3, and 84% of patients had an objective

IKDC grade of A or B. The mean post-operative Tegner score was 6.8. 89% of patients returned to sports, and 61% reached their pre-injury level (21). In the latest study, the physeal sparing strategy outperformed the partial transphyseal and transphyseal techniques in terms of knee laxity (0.22 mm, 1.69 mm, 1.98 mm, respectively), however, the subjective and objective scores did not significantly alter as a result and the specific technique of physeal sparing is not described (extraphyseal or all-epiphyseal) (22).



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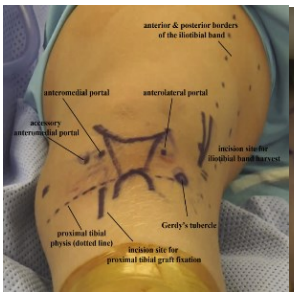

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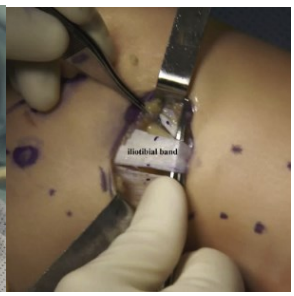

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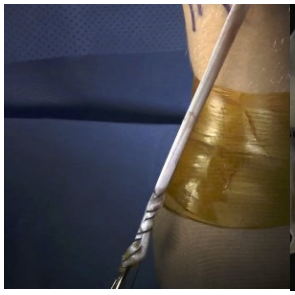

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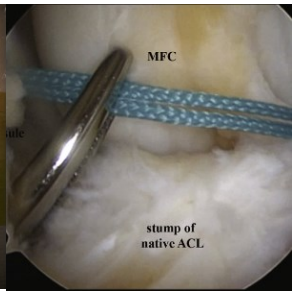

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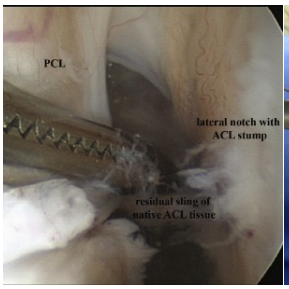


(F)

(G)

(H)

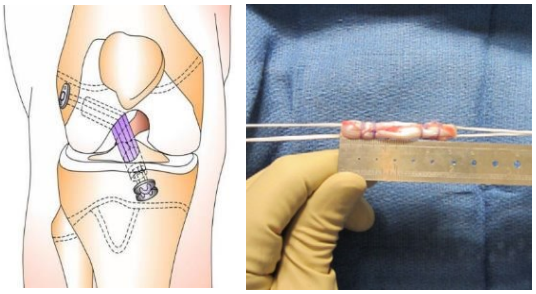
Figure 2. The approach of using an ITB autograft for physeal sparing extraphyseal ACL reconstruction. (A). Illustrations of the technique. (B). The skin incisions were marked before the procedure. (C). The anterior and posterior edges of the iliotibial band are located and incised 2 cm proximal (dotted line) to Gerdy's tubercle to create a 1-cm-wide strip of the band. The anterior and posterior edges of the iliotibial band are located and incised 2 cm proximal (dotted line) to Gerdy's tubercle to create a 1-cm-wide strip of the band. (D). A 15 cm graft should be extracted and the free end should be controlled by using five stitches in each direction. (E). The free end of the graft is brought through the "over-the-top" position and out of the anterolateral incision using a full-length clamp inserted through the anteromedial portal. (F). After passing a clamp from the anteromedial portal under the intermeniscal ligament, the graft is drawn through the joint, under the intermeniscal ligament, and out of the anteromedial epiphyseal groove to be extracted from the tibial incision. (G). The

extra-articular component of the graft is attached to the lateral intermuscular septum and periosteum of the posterolateral femoral condyle using two mattress sutures. (H). Below the proximal tibial physis, the periosteum is incised longitudinally, resulting in the production of periosteal flaps. The graft is then connected to these flaps using a Mason Allen-style stitch (first medial-to-lateral, then anterior-to-posterior) while being pulled taut.

Physeal Sparing All-Epiphyseal Technique Similar advantages to those of the physeal-sparing iliotibial band reconstruction are provided by all-epiphyseal ACLR, with the additional benefit of preserving the ACL's anatomical footprint. The Anderson35, Ganley-Lawrence36, and Cordasco-Green37 are all-epiphyseal ACLR procedures with tunnel drilling and fixation strategies.

The Anderson technique35 was described in 2004 and involves using a quadrupled hamstring autograft, epiphyseal bone tunnels created from the outside-in, femoral fixation via a suspensory method, and either a metaphyseal post or epiphyseal suspensory device for tibial fixation. In 2010, the Ganley-Lawrence technique 36 was introduced, which also employs a quadrupled hamstring autograft but uses interference screws inserted in a retrograde manner to fix the femur and tibia, intending to avoid damage to the physis. Another method, the Cordasco-Green modification37, which was also introduced as an all-epiphyseal technique, utilizes cortical suspensory buttons and bone sockets for fixation instead of tunnels. This fixation method is intended to increase contact between the graft and the surrounding bone by eliminating interference fixation. (Figure 3)

The All-epiphyseal ACLR approach can minimize the incidence of the fundamental problem of physeal disruption and any potential concomitant leg-length disparities while still achieving satisfactory post-operative functional results. Post-operative subjective IKDC scores were above 90 points. The return-to-sport rate was 93.2%, and 77.9% of patients returned to the sport at pre-injury level, negative post-operative pivot shift, and Lachman test was 77.8% and 100%, respectively. The overall complication rate was 9.8%, with the most common complication being ACL re-rupture (5.0%). Only 1.5% of patients demonstrated growth disturbances (24). A meta-analysis found that patients who underwent All-epiphyseal reconstruction had significantly lower rates of return to activity, higher incidences of limb length discrepancies, and more incidences of ACL ruptures than patients who underwent extraphyseal restoration. However, this study was limited by the small sample size and poor MCMS score related to the strict inclusion/exclusion criteria (23).



(A) (B)

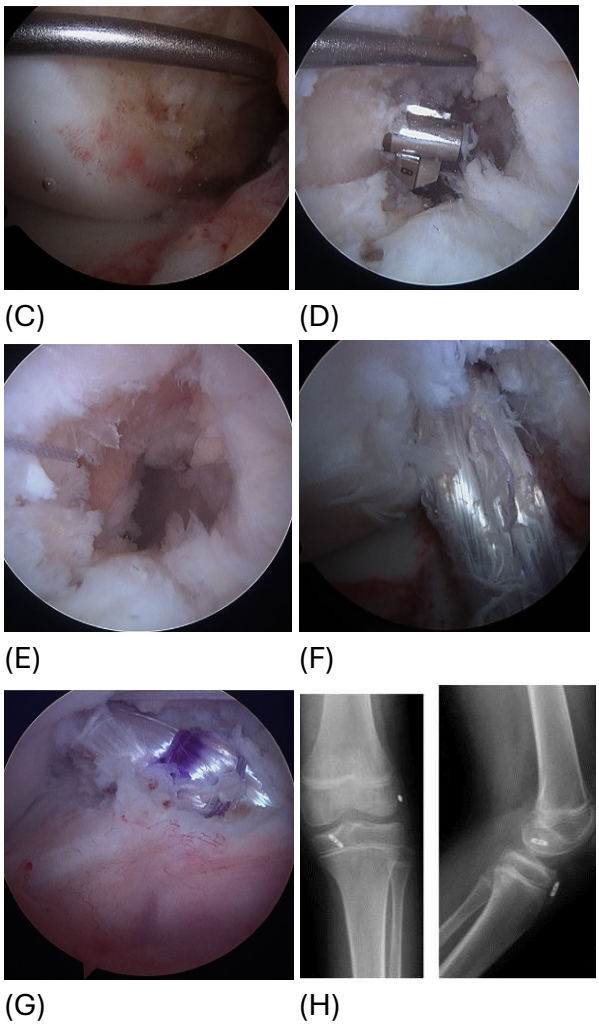


Figure 3. The approach of using a hamstring autograft for physeal sparing all-epiphyseal ACL reconstruction. (A). An illustration of the technique. (B). A quadrupled semitendinosus autograft was used for the graft. (C). While using arthroscopes, the surgeon debrides the femoral footprint. The tunnel will be positioned 2 to 3 mm from the back wall, in the middle of the femoral footprint. (D). Before tunnel drilling, the outside-in femoral guide is placed into the anterolateral portal, and proper positioning is verified using fluoroscopy. The guide pin and reamer are then deployed to create a retrograde tunnel. (E). The anterolateral portal, which features a bone bridge of at least 7 mm, is used to view the fiber wire-marked tunnel for potential graft passage. (F, G). Anterolateral portal views of the intra-articular component of an all-epiphyseal ACL reconstruction. (H). Radiographs of the technique.

Partial Transphyseal ACL Reconstruction were introduced in 1986, which involved fixing the femoral graft using an over-the-top physeal-sparing method and creating a transphyseal tibial tunnel.38 To minimize damage to the distal femoral physis in skeletally immature patients and avoid the technical difficulty of creating an intra-epiphyseal tunnel in the proximal tibia, a partial transphyseal technique was introduced where the femoral tunnel is placed in the distal femoral epiphysis and the tibial tunnel is positioned transphyseally medial to the tibial tubercle. This approach is particularly suitable for patients with more than three years of growth remaining, as it allows them to avoid femoral physis injury while drilling a small, vertical tibial tunnel with minimal impact on the tibial physis. Theoretically, it is less likely to cause damage to the growth plates while adhering to the principles of an anatomic ACLR, although there is currently limited clinical evidence available to support this (25).

DISCUSSION

The functional results of partial transphyseal ACLR are good, and it has low graft failure and reoperation rates. In a case series of 24 patients, the Partial transphyseal procedure has a 16.7% overall incidence of post-operative growth disturbance, but the incidence of growth disturbance was 66.7% for those patients with >5 years of growth remains. The mean

score in the sample of patients who completed the Pedi-IKDC questionnaire was 94.8 ± 5.3 (25)

Transphyseal Reconstruction In younger athletes, ACL tears are common and typically occur in adolescents with little growth remaining, usually less than a year. For most skeletally immature children, a transphyseal ACL reconstruction can be an effective treatment option as long as careful patient selection and attention to technical details are followed. Although growth arrest or disturbances may be observed in patients with significant growth left (>4 cm), the effect is usually temporary and does not cause clinically significant leg length discrepancies (39). In transphyseal techniques, it is important to create a femoral drill tunnel that is as steep as possible to protect Ranvier's zone, which is typically achieved by transtibial drilling (40). These bone tunnels are commonly referred to as non-anatomical since they are typically placed outside the femoral insertion zone of the original ACL, which may lead to less rotational stability compared to an anatomical tunnel position (41–43)

A study involving a group of 100 adolescents who underwent ACL reconstruction using living parental hamstring tendon allograft has yielded promising results. The cohort demonstrated excellent clinical stability, with a 12% ACL graft rupture rate and a 9% contralateral ACL injury rate. Among those who didn't suffer from further ACL injuries, 82% returned to competitive sports, 52% had a normal IKDC ligament evaluation and 48% were almost normal. The median side-to-side difference in manual maximum testing using the KT1000 was 2 mm, ranging from -1 to 5. Almost half of the subjects (49%) showed a radiographic PTS of 12 degrees or more (26).

According to a systematic review of 22 retrospective or prospective case series, transphyseal ACLR had an overall failure/rupture rate of 11.0%. The contralateral ACL rupture rate was 9.7%, and there was no statistically significant difference in failure rates between independent and transtibial drilling techniques (27).

A recent cohort study that followed patients for an average of 3 years reported no significant differences in patient outcomes based on the type of graft used. The average scores for patient satisfaction, SANE, and Lysholm scores for the entire group were 9.3, 91, and 95, respectively, while the mean post-operative Tegner activity score was 6.9. Although there were no physical problems observed in either group, those who received a hamstring tendon autograft had a higher incidence of graft rupture (21% vs. 4%) (28). Patients with substantial growth remaining should avoid undergoing bone-patellar tendon-bone (BPTB) autograft reconstructions as it can result in early physeal arrest with bone plug healing around the physis (30). In patients who undergo transphyseal ACLR, radiographically evident limb deformities occurred at a rate of 17%, but these were clinically apparent in only 5% of patients. The probability of developing a deformity

might be elevated when tunnels intersect physes near cortical margins (29).

CONCLUSIONS

Orthopedic surgeons need to pay close attention since ACL injuries are becoming more common in skeletally immature patients. To determine the best ACLR approach, it is crucial to evaluate the skeletal age in addition to chronologic age. Current literature supports early operative treatment to restore knee stability and prevent progressive meniscal and/or chondral damage. The reconstruction techniques were adjusted to each patient's potential for growth, the facilities' capabilities, and the surgeons' skills. High-growth potential patients should still undergo surgery using a technique with the slightest manipulation of growth cartilage. Future research with a large sample and higher quality of evidence might be needed to find the best treatment for ACL tears in adolescence.

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