Systematic Review

Treating Anterior Cruciate Ligament Tears in Skeletally Immature Patients

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Purpose: To systematically review the current evidence for conservative and surgical treatment of anterior cruciate ligament (ACL) tears in skeletally immature patients. **Methods:** A systematic search of PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), and Cochrane Database of Systematic Reviews (CDSR) was performed for surgical and/or conservative treatment of complete ACL tears in immature individuals. Studies with less than 6 months of follow-up were excluded. Study quality was assessed, and data were collected on clinical outcome, growth disturbance, and secondary joint damage. **Results:** We identified 47 studies meeting the inclusion criteria. Conservative treatment was found to result in poor clinical outcomes and a high incidence of secondary defects, including meniscal and cartilage injury. Surgical treatment had only very weak evidence of growth disturbance yet strong evidence of good postoperative stability and function. No specific surgical treatment showed clearly superior outcomes, yet the studies using physeal-sparing techniques had no reported growth disturbances at all. **Conclusions:** The current best evidence suggests that surgical stabilization should be considered the preferred treatment in immature patients with complete ACL tears. Although physeal-sparing techniques are not associated with a risk of growth disturbance, transphyseal reconstruction is an alternative with a beneficial safety profile and a minimal risk of growth disturbance. Conservative treatment commonly leads to meniscal damage and cartilage destruction and should be considered a last resort. **Level of Evidence:** Level IV, systematic review of Level II, III, and IV studies.

The management of anterior cruciate ligament (ACL) injuries in adults attracts a considerable share of interest in ongoing research. However, the management of ACL tears in children is less well studied.[1] A considerable surge in the incidence of such injuries, paired with the substantial spectrum and gravity of secondary damage, underlines the necessity of more, in-depth research in this field.[2-6]

Historically, transphyseal ACL reconstruction has been avoided in skeletally immature patients because drilling across the growth plate carries a risk of future physeal malfunction and resultant growth disturbance and angular deformity.[4,7] Thus traditional care of the skeletally immature patient with an ACL tear has relied on bracing and activity modification until the young athlete is close enough to skeletal maturity to undergo transphyseal reconstruction.[1,8] Recently, surgeons have developed physeal-sparing ACL reconstruction techniques, including transepiphyseal tunnel placement,[9] as well as intra- and extra-articular stabi-

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lization without transosseous tunnels.[10] Clinical results of each of these techniques have been reported individually; however, less is known about how these techniques compare with transphyseal reconstruction or conservative treatment in this patient population.

Our hypothesis was that there would be significant differences in patient outcomes with each different treatment method. A systematic review of the literature to address this hypothesis was performed.

METHODS

This systematic review had 3 objectives. The first was to comprehensively and systematically review the current evidence for operative versus nonoperative treatment of immature patients with ACL tears. The second objective was to systematically assess the outcomes of different types of surgical treatment available to these patients. The third objective was to review the study quality and level of evidence of the current literature for management options of immature ACL injuries.

The systematic review was performed following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) statement.[11,12] The PRISMA statement (http://www.prisma-statement.org), put forward by the CONSORT group (http://www.consort-statement.org), is an evidence-based guideline for conducting and reporting systematic reviews; it was formerly known as the QUOROM (QUality Of Reporting Of Meta-analysis) statement.[13]

Eligibility Criteria

Studies were included if they reported on the clinical outcomes of surgical and/or conservative treatment of complete ACL tears in immature individuals. Immature individuals were defined either as patients with radiologic proof of open physes or those at appropriate Tanner stages (stage IV or below). Chronologic age was not used as an inclusion criterion. Studies with less than 6 months of follow-up were excluded, as were studies of partial ACL tears and tibial spine avulsions.

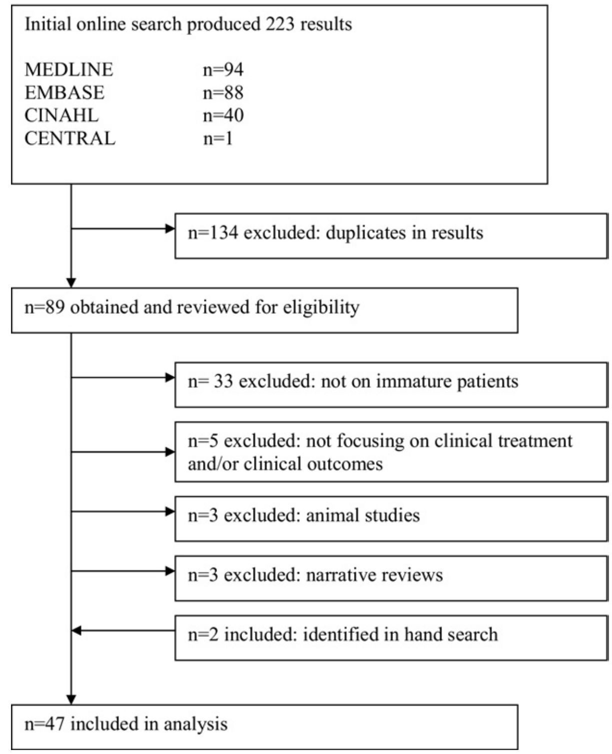

FIGURE 1. Flow of trials during systematic review of literature.

Data Sources

The online databases PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), and Cochrane Database of Systematic Reviews (CDSR) were searched for relevant publications. All dates and languages were included. The last search was performed on August 31, 2010.

Search

The search algorithm was "((ACL) OR (anterior cruciate ligament)) AND ((young) OR (child) OR (pediatric) OR (paediatric) OR (immature)) AND ("humans"[MeSH] NOT "animals"[MeSH])" and was replicated using the keywords as MeSH terms as well (Fig 1). All searches were unlimited, that is, considering publications in all languages and regardless of publication date. In addition to the online searches, the bibliographies of the included studies were reviewed by hand to identify further publications.

Study Selection

Titles and abstracts from all search results were screened for eligibility. Studies were excluded if the title and/or abstract clearly refuted eligibility. Full texts were obtained for all studies matching the inclusion criteria and all with unclear eligibility. The obtained full texts were reviewed to confirm eligibility. All study selections were done independently in duplicate and cross referenced. Disagreement was resolved by consensus.

Data Collection Process

All identified studies were categorized by type of treatment (conservative, surgical/intra-articular, surgical/extra-articular) and level of evidence (Levels I to V) by use of the ranking system published in the *Arthroscopy* Instructions for Authors (http://www.elsevier.com/framework_products/promis_misc/623124los.pdf).[14,15] Data were extracted independently and in duplicate. Duplicate data extractions were compared for differences, and disagreement was resolved by consensus.

Data Items

Data were extracted for the endpoints limb-length or angular deformity, clinical outcome (scores), secondary problems, and anteroposterior (AP) laxity to allow for gross comparison between techniques. Levels of evidence were assessed for all included studies.

Risk of Bias in Individual Studies

The risk of bias was assessed through categorization by level of evidence. We decided against using composite scores of study quality because these scores have been shown to be unreliable in some of the included study types, and because there are no scores that allow a valid assessment across different study designs.[16] Studies with particularly high risk of bias are pointed out explicitly in the "Results" section.

Data Synthesis

Given the substantial clinical heterogeneity, poor quality of the evidence from the overall literature, and limited number of studies reporting the same outcome measures, we did not perform a quantitative data synthesis, but we report all data descriptively as a systematic review. To provide a more comprehensive overview of the literature, we included studies from all levels of evidence. As subanalyses, we also analyzed the data for the youngest 15th percentile of patients, as well as for the studies with the highest levels of evidence (Levels II and III), individually. Results are given as mean ± SD.

RESULTS

Study Selection

Our search produced 223 results in total. Eighty-nine publications were obtained and reviewed based on the criteria described previously; two additional articles were identified by bibliographic cross-reference. Finally, 47 articles reporting on a total of 1,256 patients who were followed up for a mean of 44.7 ± 18.7 months were included in the analysis[2,4,7-10,17-58] (Fig 1). These articles were published between 1986 and 2010 in English, German, and French.

Characteristics of Included Studies

The mean age across all studies was 13.3 ± 1.2 years. All but 2 studies reported at least radiologically confirmed open physes as the criterion for immaturity; 16 studies included a Tanner score for description of maturity. Subgrouping by method of determination of skeletal age showed a mean age of 13.2 ± 1.1 years for those studies reporting open physes and 12.9 ± 1.5 years for those reporting Tanner stages (P = .510). A median of 19 patients (range, 1 to 129; interquartile range, 10 to 43) are given per study. Thirty-nine studies reported on intra-articular stabilization and five on extra-articular stabilization, although three of these included procedures with both intra- and extra-articular components. Twelve studies reported on natural history or had a conservative treatment group in their populations. Table 1 summarizes the characteristics of these studies.

Risk of Bias in Included Studies

The level of evidence for the included articles ranged from Level II to Level IV. There was 1 Level II study,[33] 10 Level III studies,[8,17,28,30,33,35,42,43,48,55,57] and 37 Level IV studies (Table 1). Most studies were longitudinal analyses of single cohorts without controls and without randomization; this situation is representative of the studied field.[59] We categorized all studies by level of evidence to underscore the differences in the likelihood of bias of their respective results. However, it should be noted that the objective of this systematic review was to give as comprehensive an analysis as possible of all current evidence and that a longitudinal design is an adequate design by which to study feasibility and long-term outcomes of (surgical) procedures.

Results of Individual Studies

Conservative Management: Twelve articles reported on conservative treatment and natural history,[8,17,19,20,30,33,35,42,43,45,48,55,58] eight of which were Level III studies. [8,17,30,33,35,42,43,48,55] Six of these studies compared conservative treatment with a surgical treatment group.[17,30,42,43,48,55] These re-

TABLE 1. *Characteristics of Included Studies by Level of Evidence*

Authors	Journal	Year	LoE	Age (y)	Tanner/X-Ray	Treatment Group	Control Group	N	Follow-up (m)
Henry et al.[33]	Knee Surg Sports Traumatol Arthrosc	2009	II	—	Open physes, Tanner I-IV	ACLR (QT)	Delayed ACLR	56	27
Streich et al.[55]	Knee Surg Sports Traumatol Arthrosc	2010	III	11	Open physes, Tanner I-II	ACLR (STG)	Nonoperative	31	70
Trentacosta et al.[57]	Am J Sports Med	2009	III	—	?	ACLR	—	62	
Gebhard et al.[28]	Knee Surg Sports Traumatol Arthrosc	2006	III	12.5	Tanner I-III and IV-V	ACLR (4 different graft types)	—	68	32
Woods et al.[8]	Am J Sports Med	2004	III	<16	Open physes	Nonoperative Tx	Healthy Adolescent	129	6.5
Aichroth et al.[17]	J Bone Joint Surg Br	2002	III	13.5	Tanner I-V	ACLR (4HS)	Nonoperative	68	49/72
Pressman et al.[48]	J Pediatr Orthop	1997	III	14.4	?	ACLR (STG BTB)	Nonoperative	42	63.6
Janarv et al.[35]	J Pediatr Orthop	1996	III	13.1	Open physes	Natural History	Nonoperative	28	60
McCarroll et al.[43]	Am J Sports Med	1994	III	—	Open physes, Tanner I-IV	ACLR (BTB)	Nonoperative	60	50.4
Graf et al.[30]	Arthroscopy	1992	III	14.5	Open physes	Intra- and extra-articular reconstructions	Nonoperative	12	
McCarroll et al.[42]	Am J Sports Med	1988	III	—	Open physes, Tanner I-IV	Intra- and extra-articular reconstructions	Nonoperative	40	27
Cohen et al.[25]	Arthroscopy	2009	IV	13.3	Tanner I-IV	ACLR (4HS)	—	26	45
Higuchi et al.[34]	J Pediatr Orthop B	2009	IV	—	?	ACLR	—	10	6
Marx et al.[40]	Sportverletz Sportschaden	2009	IV	13	Open physes	ACLR (4HS)	—	55	38
Bollen et al.[23]	J Bone Joint Surg Br	2008	IV	13	Tanner I, II	ACLR (4HS)	—	5	34.6
Liddle et al.[37]	J Bone Joint Surg Br	2008	IV	12.1	Tanner I, II	ACLR (4HS)	—	17	44
Schneider et al.[51]	Oper Orthop Traumatol	2008	IV	14.7	Tanner IV, V	ACLR (tripled STG)	—	57	25
Arbes et al.[20]	Int Orthop	2007	IV	13.9	Open physes	Various techniques	Nonoperative	20	65
Kocher et al.[36]	J Bone Joint Surg Am	2007	IV	14.7	Tanner III	ACLR (4HS)	—	59	42
McIntosh et al.[44]	Arthroscopy	2006	IV	13.6	Open physes	ACLR (4HS/2HS)	—	16	41.1
Thompson et al.[56]	Orthopedics	2006	IV	<14	Open physes	Single-incision ACLR (STG, AT)	—	30	—
Kocher et al.[61]	J Bone Joint Surg Am	2005	IV	10.3	Tanner I, II	ITB	—	44	63.6
Seon et al.[52]	J Korean Med Sci	2005	IV	14.7	Open physes	ACLR (4HS)	—	11	77.7
Shelbourne et al.[53]	Am J Sports Med	2004	IV	14.8	Tanner III, IV	ACLR (BTB)	—	16	40.8
Sobau and Ellermann.[54]	Unfallchirurg	2004	IV	14.2	Open physes	ACLR (4HS)	—	30	30.8
Anderson.[9]	J Bone Joint Surg Am	2003	IV	13.3	Tanner I-III	ACLR (4HS)	—	12	49.2
Attmanspacher et al.[22]	Unfallchirurg	2003	IV	—	Open physes	ACL repair, ACL refixation, ACLR	—	45	

Table 1. *Continued*

Authors	Journal	Year	LoE	Age (y)	Tanner/X-Ray	Treatment Group	Control Group	N	Follow-up (m)
Gorin et al.[29]	Arthroscopy	2003	IV	14	Open physes	ACLR (tibialis posterior)	—	1	6
Guzzanti et al.[32]	Am J Sports Med	2003	IV	11.15	Tanner I	ACLR (STG), physeal sparing	—	8	69.2
Guzzanti et al.[33]	Am J Sports Med	2003	IV	13.6	Tanner II, III	ACLR (STG)	—	14	40.1
Fuchs et al.[27]	Arthroscopy	2002	IV	13.2	Open physes	ACLR (BTB)	—	10	40
Kocher et al.[4]	J Pediatr Orthop	2002	IV	—	Open physes	Various techniques	—		69
Edwards and Grana.[26]	Am J Knee Surg	2001	IV	13.7	?	ACLR (STG BTB)	—	21	34
Aronowitz et al.[21]	Am J Sports Med	2000	IV	13.4	Open physes	ACLR (AT)	—	19	25
Koman and Sanders.[7]	J Bone Joint Surg Am	1999	IV	14.3	Open physes	ACLR (double STG)	—	1	24
Micheli et al.[2]	Clin Orthop Relat Res	1999	IV	11	Open physes	ITB	—	17	66.5
Robert and Bonnard.[62]	Arthroscopy	1999	IV	11.4	Open physes	"Clocheville technique"	—	8	42
Lo et al.[39]	Arthroscopy	1997	IV	12.9	Open physes	ACLR (HS)	—	5	88.8
Matava and Siegel.[41]	Am J Knee Surg	1997	IV	14.7	?	ACLR (HS)	—	8	32
Mizuta et al.[45]	J Bone Joint Surg Br	1995	IV	12.8	Open physes	Natural History	Nonoperative	18	51
Andrews et al.[18]	Am J Sports Med	1994	IV	13.5	Open physes	ACLR (AT)	—	8	58
Parker et al.[47]	Am J Sports Med	1994	IV	—	Open physes	ACLR (HS) physeal sparing	—	6	33.2
Brief et al.[24]	Arthroscopy	1991	IV	—	?	ACLR (STG) physeal sparing	—	9	—
Angel and Hall.[19]	Arthroscopy	1989	IV	14.3	?	Natural History	Nonoperative	27	51
Lipscomb and Anderson.[38]	J Bone Joint Surg Am	1986	IV	13.5	Open physes	ACLR (STG)	—	24	35
Salzmann et al.[50]	Arthroscopy	2009	V	14	?	ACLR (double-bundle STG)	—	1	—
Wester et al.[58]	J Pediatr Orthop	1994	V	12.5	Open physes	ACLR	Nonoperative	2	24

NOTE. All information is reported as given in the publications.

LoE, level of evidence (Levels I to V); ACLR, anterior cruciate ligament reconstruction with graft type in parentheses if reported; QT, quadriceps tendon; STG, semitendinosus-gracilis; 4HS, quadrupled hamstrings; BTB, bone-tendon-bone; 2HS, doubled hamstrings; AT, Achilles tendon; ITB, iliotibial band (physeal-sparing, combined intra-articular and extra-articular reconstruction); HS, hamstrings.

ports provide data for 476 patients followed up for 52.7 ± 11.9 months on average, and they consistently show high proportions of unstable, symptomatic patients with early, severe meniscal degeneration and cartilage defects requiring surgical stabilization (mean, 50.2%; range, 17.4% to 87.6%) during the period of observation. Interestingly, in contrast to the others, 1 study found no increase in secondary injury rates in immature patients with conservative treatment and delayed surgical repair of the ACL deficiency after the physes had closed.[8]

Surgical Procedures: Three types of surgical procedures are presented in the current literature: (1) intra-articular, transphyseal, transosseous reconstruction; (2) intra-articular, physeal-sparing, transosseous reconstruction; and (3) combined intra- and extra-articular, physeal-sparing, extraosseous stabilization.

Thirty-eight studies presented results of intra-articular, transosseous stabilization. The mean age of the patients in this group was 13.2 ± 1.2 years. Nine reports describe physeal-sparing techniques[2,9,10,31,32,35,47,49,53] and two describe physeal-sparing tunnel placement on the femoral, but not the tibial, side. The remainder (n = 27) reported on transphyseal reconstruction. Six studies offered comparisons between surgical and conservative treatment (Table 2)[17,30,42,43,48,55] and three between immediate and delayed ACL reconstruction (Table 3).[8,33,57] These studies reported better Lysholm scores (83 *v* 7), better subjective outcomes, and fewer secondary pathologies after immediate surgical reconstruction. Thirty-one articles report on ACL stabilization with at least 1 transphyseal tunnel in 479 patients with a mean age of 13.6 ± 0.9 years followed up for 42.32 ± 18.7 months on

TABLE 2. *Outcomes of Studies Comparing Surgical Treatment With Nonoperative Treatment*

		Type of Treatment (n*)		Clinical Scores			Laxity		Growth Deformities		Other Outcomes (n)		
Authors	LoE	Tx	Co	Score	Tx	Co	Tx	Co	Tx	Co	Outcome	Tx	Co
Streich et al.[55] (2010)	3	ACLR (16)	Nonoperative (12)	IKDC	95	87†	1.8 (1.4)	4.3 (2.9)†	0	0	Giving way	0	12
				Lysholm	93	84†					Extension deficit	1	1
Aichroth et al.[17] (2002)	3	ACLR (45)	Nonoperative (23)	Tegner	—	4.2	—	—	0	0	Meniscal tears at time 0	17	14
				Lysholm	21 A; 15 B; 11 C, D	53.4					Osteochondral fractures	—	3
Pressman and Letts[48] (1997)	3	ACLR (23) and repair (6)	Nonoperative (13)	Lysholm	ACLR better (P = ?)‡		—	—	—	—	Lachman	ACLR better ($P < .005$)	
				Zarins and Rowe	ACLR better ($P < .001$)						Pivot shift	ACLR better ($P < .009$)	
McCarroll et al.[43] (1994)	3	ACLR (22)	Nonoperative (38)		—	—	51 $<$3 mm		0	0	Giving way	—	37
											Meniscal tears	—	27
Graf et al.[30] (1992)	3	ACLR (4)§	Nonoperative (8)		—	—	—	—	0	0	Return to sports	4	8
											Giving way	0	8
											Meniscal tears	2	7
McCarroll et al.[42] (1988)	3	ACLR (24)§	Nonoperative (16)		—	—	1.7	—	0	0	Return to sports	24	7
											Giving way	4	16

LoE, level of evidence (Levels I to V); Tx, treatment group; Co, control group; ACLR, anterior cruciate ligament reconstruction, transphyseal unless otherwise specified; IKDC, International Knee Documentation Committee.
*Number of patients available for analysis.
†Reported as statistically significant; exact *P* value not given.
‡*P* value not given.
§Intra-articular and extra-articular reconstruction.

TABLE 3. *Outcomes of Studies Comparing Different Surgical Treatments*

		Type of Treatment (n*)		Clinical Scores†			Growth Deformities		Other Outcomes		
Authors	LoE	Tx	Co	Score	Tx	Co	Tx	Co	Outcome	Tx	Co
Woods and O'Connor[8] (2004)	3	Immature, nonoperative treatment (13)	Mature, immediate and delayed ACLR (116)		—	—	—	—	Meniscal injury	46%	44%
									Cartilage injury	8%	8%
Trentacosta et al.[57] (2009)	3	Immediate ACLR (23)	Delayed ACLR (39)	IKDC	58	85.9	—	—	Immediate return to school	3.8%	62.3%
				Lysholm	92.8	90.1			Failed an examination	36.4%	0%
Gebhard et al.[28] (2006)	3	Transphyseal ACLR (28)	Physeal-sparing (12)		—	—	0	0	Meniscal tears	55%	17%

LoE, level of evidence (Levels I to V); Tx, treatment group; Co, control group; IKDC, International Knee Documentation Committee; ACLR, anterior cruciate ligament reconstruction.
*Number of patients available for analysis.
†At latest follow-up.

average.[7,9,17,18,20-23,25-30,33,34,36-44,48,50-52,54,55] In this group of almost 500 subjects, 3 angular deformities and 2 limb-length discrepancies (1.3 cm and 2 cm) were observed. Another 10 patients had magnetic resonance imaging results consistent with physeal narrowing but without angular or limb-length deformities. Across these studies, the Lysholm scores for the surgically treated patients ranged from 83 (at 63 months) to 98 (at 78 months). There was no significant difference in results with the use of 1 transphyseal tunnel (tibia only) versus 2 tunnels (tibia and femur). No other secondary problems attributable to the reported type of procedure were reported.

Five articles include at least 1 group of patients undergoing intra-articular, physeal-sparing, transosseous stabilization, which is usually done by placing tunnels proximally to the tibial physis and distal from the femoral physis.[31,32,47,49,53] The mean age of this group was 12.7 ± 1.8 years. No limb-length or angular deformities were seen in this group. Unfortunately, these authors did not use the Lysholm score, but data on the Orthopädische Arbeitsgruppe Knie score (98 points) and International Knee Documentation Committee score (96 points) are available. The mean difference in AP laxity compared with healthy, contralateral knees was 1.5 mm.

The results of extraphyseal stabilization techniques in 106 patients, with a mean age of 12.1 ± 1.2 years, were presented in 6 reports.[2,10,24,28,30,42] Strictly speaking, these were all combined intra- and extra-articular, physeal-sparing, extraosseous reconstructions, that is, modifications of the technique designed by MacIntosh and Darby.[60] In brief, the iliotibial band was incised, tubularized, and brought to the over-the-top position by wrapping it around, and suturing it to, the lateral femoral condyle. At that position, it was inserted into the knee through the posterior knee capsule. From there, the iliotibial band was brought to the front of the tibial ACL footprint, led through a groove made underneath the intermeniscal ligament, and attached to the tibial cortex with staples or sutured to the periosteum. This configuration created extra-articular, AP stabilization between Gerdy's tubercle and the lateral femoral condyle, as well as an intra-articular stabilizer against AP translation and rotation. No growth deformities were seen in these patients at a mean follow-up of 47.3 ± 20.7 months. Lysholm scores at the latest follow-up were in the range of 94.3 to 97.4, with no instabilities. Brief[24] used a somewhat different approach in his study with a semitendinosus and gracilis autograft left in situ at its tibial insertion, passed underneath the anterior horn of the medial meniscus, and attached to the femur with staples. All of these patients reported satisfactory results, but none returned to sports without a brace. One study included both extraphyseal stabilization and transphyseal reconstruction and reported no difference in functional outcomes at 32 months' follow-up.[28]

Results for Youngest 15th Percentile: Six studies present data on the youngest 15% of patients, ranging from 10.3 to 12.1 years of age at Tanner stage I or II.[2,31,37,61-63] Four studies used either intra-articular, physeal-sparing, transosseous stabilization[31,62] or the modified MacIntosh technique (intra- and extra-articular, physeal-sparing, extraosseous reconstruction),[2,61] and two studies used intra-articular transphyseal reconstruction.[37,63] Liddle et al.[37] followed up on 17 prepubescent (Tanner I and II) patients aged 12.1 years (range, 9.5 to 14.0) for 44 months (range, 25 to 100 months) after transphyseal reconstruction with a quadrupled hamstring graft, which produced 15 excellent results and 1 good result. There were 2 complications, 2 graft reruptures during a playground accident, and 1 superficial wound infection, but no leg-length discrepancies. In 1 patient a 5° valgus deformity developed without functional disturbance according to these authors. Streich et al.[63] treated 12 patients nonoperatively and 16 surgically with semitendinosus and gracilis grafts (median age, 11 years; range, 9 to 12 years) and followed them up for 70 months. At the final follow-up, the patients had grown by a mean of 20.3 ± 6.9 cm, but no angular deformities or leg-length discrepancies (defined by Streich et al. as side-to-side difference ≥15 mm) were observed. Unsurprisingly, the surgical group had significantly better results for laxity and functional scores. Of the 12 patients receiving nonoperative treatment, 7 (58%) proceeded to undergo surgical stabilization within 2 years after the initial injury.

Results for Level II and III Studies: Ten studies ranked as Level II and Level III evidence.[8,17,28,30,33,42,43,48,57,64] These studies compared surgical with conservative, nonsurgical treatments (n = 6), immediate with delayed surgical treatment (n = 2), and surgical treatment in mature with immature patients (n = 1) or 2 different surgical treatments (n = 1). Table 4 summarizes their outcomes in detail. In brief, in alignment with the overall findings, as well as the findings for the youngest 15% of patients, the studies with the highest level of evidence unanimously report significantly better results in clinical scores and knee laxity after surgical ACL reconstruction when compared with conservative treatment. At the same time, there was no difference in the risk of growth disturbances. The studies that looked specifically at the timing of surgical repair support immediate treatment over delays.

DISCUSSION

Summary of Evidence

This systematic review of conservative versus surgical treatment provides evidence that surgical treatment of the immature, torn ACL produces superior clinical outcomes in stability and in the prevention of secondary injury. Few risks are associated with surgical stabilization, whereas secondary damage will occur in many patients initially selected for conservative treatment, who will then cross over to surgical stabilization, thus potentially combining the risk profiles of both types of treatment. The specific procedure chosen for surgical stabilization appears to have less clinical impact than the selection of surgical treatment.

Currently, many investigators consider nonsurgical treatment to be the most appropriate initial approach to the torn ACL in immature patients until they reach skeletal maturity.[1,8] The rationale of this approach is to allow the physes to close before a surgical intervention, primarily because it is feared that transphyseal tunnel placement would cause sufficient growth plate damage, resulting in limb-length differences or angular deformities due to the formation of bony bridges along the tunnel across the growth plate.[4,7] The exact mechanisms and risk factors for such deformities have been the subject of a number of animal studies suggesting that the risks of growth disturbance can be minimized by adherence to several basic principles. Factors associated with increased risk of physeal malfunction in animals include posterior tunnel placement,[65,66] a high ratio of tunnel diameter to physeal surface area,[31,32,67] excessive graft tensioning,[68] incomplete tunnel filling by the graft,[69,70] and graft fixation across the physis.[71] If these factors are considered, transphyseal reconstruction can be performed in immature ovine knees without subsequent growth disturbance.[72] In human patients the vast majority of growth disturbances and angular deformities have been associated with graft fixation devices or bone plugs leading to bony bars across the lateral distal femoral physis (54% of angular deformities) or epiphysiodesis effects of fixation devices crossing the tibial physis (27% of angular deformities).[4] Other noteworthy reasons for deformities included tunnel placement and tunnel diameter.[4]

On the other hand, it has been reported repeatedly and consistently that conservative treatment leads to recurrent instability and results in increased intra-articular damage, specifically meniscal damage and cartilage degeneration.[30,35,45] Hence it is not surprising that most patients treated conservatively eventually press for ACL reconstruction (mean, 50.2%; range, 17.4% to 87.6%), some even when still at a young age.[30,35,45] In light of these facts, conservative treatment might be an option for a few, very carefully selected, highly compliant patients with low demands and no other pathologies,[8] but the notion that nonsurgical treatment is the most suitable approach for all immature cases, especially in active patients, deserves critical re-evaluation. A number of studies have fol-

TABLE 4. *Characteristics of and Outcomes From Level II and III Studies*

			Type of Treatment (n*)		Clinical Scores at Latest Follow-Up			Laxity [Mean Side-to-Side (SD)]		LLD, Angular Deformities		Other Reported Outcomes†		
Authors	Year	LoE	Tx	Control		Tx	Control	Tx	Control	Tx	Co	Outcome	Tx	Control
Streich et al.[55]	2010	III	ACLR (16)	Nonoperative (12)	IKDC	95	87‡	1.8 (1.4)	4.3 (2.9)‡	0	0	Giving way	0	12
					Lysholm	93	84‡					Extension deficit	1	1
Aichroth et al.[17]	2002	III	ACLR (45)	Nonoperative (23)	Tegner	—	4.2	—	—	0	0	Meniscal tears at time 0	17	14
					Lysholm	21 A, 15 B, 11 C and D	53.4					Osteochondral fractures		3
Pressman et al.[48]	1997	III	ACLR (23) and repair (6)	Nonoperative (13)	Lysholm	ACLR better (P = ?)‖		—	—			Lachman	ACLR better ($P < .005$)	
					Zarins and Rowe	ACLR better ($P < .001$)						Pivot shift	ACLR better ($P < .009$)	
McCarroll et al.[43]	1994	III	ACLR (22)	Nonoperative (38)				51 less than 3 mm		0	0	Giving way		37
												Meniscal tears		27
Graf et al.[30]	1992	III	ACLR (4)¶	Nonoperative (8)		—	—	—	—	0	0	Return to sports	4	8
												Giving way	0	8
												New meniscal tears	2	7
McCarroll et al.[42]	1988	III	ACLR (24)¶	Nonoperative (16)		—	—	1.7	—	0	0	Return to sports	24	7
												Giving way	4 (mild)	16
Henry et al.[33]	2009	II	Immediate ACLR (29)	Delayed ACLR (27)	IKDC	94.6	82.4‡	1.93 (1.2)	1.76 (2)	0	0	Meniscal tears	12 (41%)	19 (70%)
Woods et al.[8]	2004	III	Immature patients with nonoperative treatment (13)	Skeletally mature patients with immediate and delayed (6, 26, >26 wk) treatment (116)		—	—					Meniscal injury	46%	44%
												Cartilage injury	8%	8%
Trentacosta et al.[57]	2009	III	Immediate ACLR (23)	Delayed ACLR (39)	IKDC	58	85.9					Immediate return to school	3.8%	62.3%
					Lysholm	92.8	90.1					Failed an examination	36.4%	0%
Gebhard et al.[28]	2006	III	Transphyseal ACLR (28)	Physeal-sparing ACLR (12)		—	—	—	—	0	0	Meniscal tears	55%	17%

LLD, leg-length discrepancy; IKDC, International Knee Documentation Committee; ACLR, anterior cruciate ligament reconstruction.
*Available for analysis.
†Number or percentage, as given in original publication.
‡Reported as statistically significant; exact P value not given.
‖P value not given.
¶Intra-articular and extra-articular reconstruction.

lowed up on immature patients after ACL reconstruction using various techniques. What stands out from these studies is that surgical treatment of the immature, torn ACL produces convincing, beneficial results, at least in the short and intermediate term. Streich et al.,[55] in the most recent of the included studies, allocated only those patients with concomitant injury to surgical treatment and compared them with nonoperatively treated patients with isolated ACL ruptures without evidence of other injuries. Yet, interestingly, even this hand-selected group of conservatively treated patients, with unequivocally better initial conditions, performed significantly worse than their surgically treated counterparts with complex and extensive injuries, suggesting that any ACL rupture, even if isolated and without concomitant injuries, would benefit from surgical treatment.

Physeal-sparing procedures, both intra-articular and extra-articular, have evolved into valuable alternatives.[2,10,61] Recent studies by Kocher et al.[10,61] have shown that postoperative results of extraphyseal iliotibial band reconstruction are equivalent to transphyseal ACL reconstruction. Although this treatment was initially planned to be a temporizing procedure, it has functioned as a definitive reconstruction for a number of patients.[10,61] Similarly, a comparative study of physeal-sparing ACL reconstruction with autologous fascia lata (n = 12) and transphyseal ACL reconstruction (hamstring, bone–patellar tendon–bone, and quadriceps tendon; n = 12 each) showed no differences in terms of functional outcome or the occurrence of growth disturbances.[28] Lastly, transepiphyseal graft placement with tunnels placed in the tibial and femoral epiphyses has shown good outcomes in 8 patients at 4 ± 2 years postoperatively.[9] However, to date, there is no evidence available on the effects of drilling close and parallel to the growth plate, which not only has a risk of directly injuring the physes but also of thermal damage from friction heat that cannot be seen at the time of the procedure and might manifest later.[54,73]

In addition to the overall systematic review, which had a liberal inclusion policy, we also separately analyzed the youngest patients and studies with the highest levels of evidence. The findings from these subgroups were similar to those of the overall cohort of studies. Even for the youngest patients, there was no significant increased risk of growth deformities with surgical treatment, but there were significantly better outcomes for knee stability and function 70 months after surgical treatment compared with conservative treatment. Equivalent results were seen for Level II and III studies, which constitute the highest levels of evidence available. In summary, the findings in these subgroups suggest that our overall interpretation of surgical treatment being more effective and no more complication prone than conservative treatment is accurate and valid, even for the youngest patients in this collective, under the most stringent criteria used in this literature.

Two recent, noteworthy reports in *Arthroscopy* deal with the management of immature ACL ruptures.[73,74] Kaeding et al.[74] published a systematic review of 13 studies (192 patients; median age, 13 years; follow-up, 45.6 months) of varied surgical treatments for ACL injuries in preadolescent patients (boys aged <15 years and girls aged <14 years, Tanner stage I to III). They reported no differences in patient-reported outcomes, AP laxity, or leg-length discrepancy or angular deformities between physeal-sparing and transphyseal reconstruction for any of the surgical treatments, which is in alignment with our findings. These authors point out that they could not accrue sufficient data on Tanner I patients to reach a valid conclusion. However, in our study, by inclusion of non–English-language publications, we were able to produce some data on Tanner I and II patients that support the use of surgical reconstruction in the management of ACL tears even in those younger patients. In a second article, Frosch et al.[73] presented results from a meta-analysis of 55 original studies (935 patients; median age, 13 years, median follow-up, 40 months) on surgical treatment options for immature ACL tears. This study showed that the risk of leg-length discrepancy or angular deformity after surgical treatment of an ACL tear in a skeletally immature individual was 1.8% (95% confidence interval [CI], 0% to 3.9%). The risk of rerupture in the same population was 3.8% (95% CI, 2.6% to 5.2%). However, this study included no comparison of surgical treatment with conservative treatment (Table 2). Interestingly, Frosch et al. found evidence for a significantly higher risk of angular deformity after physeal-sparing, transosseous reconstruction compared with transphyseal, transosseous reconstruction, with a risk ratio of 0.34 (95% CI, 0.14 to 0.81) in favor of transphyseal reconstruction. They argue that this difference in risk might stem from detrimental effects of drilling parallel to the growth plate or from a pressure/obstacle effect of the implant on the expanding growth plate.[73]

Limitations

Our study has potential shortcomings. First, the bulk of the literature in this field is situated at the base of the pyramid of levels of evidence and is most likely subject to some level of confounding and/or bias. We used levels of evidence to categorize the included studies but decided against the use of composite quality scores because of the variations in study designs in this group of studies.[16]

Lack of statistical power was a feature of several of the studies. This was likely partly because of the relatively small number of patients as well as the known biological variability inherent in clinical outcome studies. Thus relative effectiveness of several surgical techniques may be difficult to assess in each individual study. The systematic review was helpful in comparing techniques because cohorts and case series are appropriate tools to investigate long-term outcomes. It is also possible that some studies were not published in this controversial area, thus causing publication bias.

Finally, the greatest limitation of this study is the definition of skeletal immaturity. Tanner stages, physeal closure, and other parameters of skeletal age have been used in addition to chronologic age, but there is no universal method across the current literature, which complicates direct comparison of patient populations. However, our findings show convincing consistency for outcome differences across different age groups, suggesting that our collective was homogenous enough to ensure valid conclusions.

CONCLUSIONS

The results of our systematic review of the current evidence for management of immature ACL tears suggest that early surgical treatment results in more favorable outcomes than conservative management. Thus, surgical stabilization should be considered as the first line of treatment for immature patients with ACL tears. The existing literature suggests that transphyseal reconstruction can be safely done in this population if a few rules are considered, and there are physeal-sparing procedures that provide excellent results with less theoretic risk to the growth plate. Conservative or delayed surgical treatment, which carries an increased risk of secondary joint injury, should be reserved for very compliant patients with both low demands and no other pathologies.

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