Published in final edited form as:

Arthroscopy. 2011 May 1; 27(5): 704–716. doi:10.1016/j.arthro.2010.11.062.

Treating Anterior Cruciate Ligament Tears in Skeletally Immature Patients

Patrick Vavken, M.D., M.Sc., F.R.S.P.H.* and Martha M Murray, M.D.

Sports Medicine Research Laboratory, Department of Orthopedic Surgery, Children's Hospital Boston, Harvard Medical School, 300 Longwood Ave, Boston, MA 02115, U.S.A.

Abstract

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, CINAHL, EMBASE, CCTR, and CDSR was performed for surgical and/or conservative treatment of complete ACL tears in immature individuals. Studies with less than six 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 48 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 for 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. While 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.

© 2010 The Arthroscopy Association of North America. Published by Elsevier Inc. All rights reserved.

*corresponding author patrick.vavken@childrens.harvard.edu .

Disclosures: Item 1. Board member/owner/officer/committee appointments:___M.M.M. is a founder of Connective Orthopedics

Item 2. Royalties:___n/a___

Item 3. Speakers bureau/paid presentations:___ n/a ___

Item 4A. Paid consultant or employee:___P.V. is a consultant for Connective Orthopedics___

Item 4B. Unpaid consultant:___ n/a ___

Item 5. Research or institutional support from publishers:___ n/a ___

Item 6. Research or institutional support from companies or suppliers (data generated from such studies must be unrestricted):___This study was supported by NIH NIAMS Grant No. AR 054099. ___

Item 7. Stock or stock options:___M.M.M. is a stockholder in Connective Orthopedics___

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

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 damages, 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), and intra- and extra-articular stabilization 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 three 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 (www.prisma-statement.org), put forward by the CONSORT group (www.consort-statement.org), is a evidence-based guideline for conducting and reporting systematic reviews, and 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 radiological proof of open physes, or those at appropriate Tanner staging (stage IV or below). Chronological 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.

Data Sources

The online databases PubMed, 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 (Figure 1). All searches were unlimited, i.e., 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

Title and abstracts from all search results were screened for eligibility. Studies were excluded if 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 (I to V) using the ranking system published by the *Journal of Bone and Joint Surgery*, American edition (<http://www2.ejbs.org/misc/instrux.dtl>) (14, 15). Data were extracted independently and in duplicate. Duplicate data extractions were compared for difference 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 “Study Description” subsection of the “Results” section.

Data Synthesis

Given the substantial clinical heterogeneity, the 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 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 of patients, and for the highest level of evidence studies (Level II and III), individually. Results are given as mean $\pm$ SD.

RESULTS

Study Selection

Our search produced 247 results in total; 92 publications were obtained and reviewed based on the criteria described above; 2 additional papers were identified by bibliographic cross-reference. Finally, 48 papers reporting on a total of 1,217 patients who were followed-up for

an average 44.7 ± 18.7 months were included in the analysis (2, 4, 7-10, 17-58) (Figure 1). These articles were published between 1986 and 2010 in English, German, and French.

Characteristics of the Included Studies

The average 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 an average 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 5 on extra-articular stabilization, although 3 of these included procedures with both an intra- and an extra-articular component. Twelve studies reported on natural history or had a conservative treatment group in their populations. Table 1 summarizes the characteristics of these studies (Table 1).

Risk of Bias in the Included Studies

The level of evidence for the included papers ranged from Level II to Level IV. There was one 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 longitudinal designs are an adequate design 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), 8 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 reports 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 (average of 50.2%, range 17.4% to 87.6%) during the period of observation. Interestingly, in contrast to the others, one 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 average age for 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 comparison between surgical and conservative treatment (Table 2) (17, 30, 42, 43, 48, 55), and 3 between immediate and delayed ACL reconstruction (Table 3) (8, 33, 57). These studies reported better Lysholm scores ($83 \text{ v } 7$), better subjective outcomes, and fewer secondary pathologies after immediate surgical reconstruction. Thirty-one articles report on ACL stabilization with at

least one transphyseal tunnel in 479 patients of 13.6 ± 0.9 years of age followed for 42.32 ± 18.7 months on average (7, 9, 17, 18, 20-23, 25-30, 33, 34, 36-44, 48, 50-52, 54, 55). In this group of almost 500 subject, 3 angular deformities and 2 limb-length discrepancies (1.3 cm and 2 cm) were observed. Another 10 patients had MRI 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 one transphyseal tunnel (tibia only) versus two tunnels (tibia and femur). No other secondary problems attributable to the reported type of procedures were reported.

Five articles include at least one group of patients undergoing physeal-sparing, intra-articular, 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 average 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 OAK (Orthopädische Arbeitsgruppe Knie) score (98 patients) and IKDC (International Knee Documentation Committee) score (96 patients) are available. The average difference in AP laxity compared with healthy, contra-lateral knees was 1.5 mm.

The results of extra-physeal stabilization techniques in 106 patients, with an average age of 12.1 ± 1.2 years of age, 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, i.e., modifications of the technique designed by McIntosh and Darby (60). Briefly, 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 this 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, anteriorposterior 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 an average 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 used a somewhat different approach in his study with a semitendinosus and gracilis autograft left in situ at its tibial insertion and passed underneath the anterior horn of the medial meniscus and attached to the femur with staples (24). All of these patients reported satisfying 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 of follow-up (28).

Results for the 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 and II (2, 31, 37, 61-63). Four studies used either intra-articular, physeal-sparing, transosseous stabilization (31, 62) or the modified McIntosh technique (intra- and extra-articular, physeal-sparing, extraosseous reconstruction) (2, 61), and 2 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) after transphyseal reconstruction with a quadrupled hamstring graft, which produced 15 excellent and 1 good result. There were 2 complications, 2 graft re-rupture during a playground accident, and 1 superficial wound infection, but no leg-length discrepancies. One patient developed a 5° valgus deformity 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 an average of 20.3 ± 6.9 cm, but no angular deformities or leg-length discrepancies (defined by Streich and coworkers as ≥ 15 mm side-to-side difference) were observed. Unsurprisingly, the surgical group had significantly better results for laxity and functional scores. Seven (58%) of the 12 patients receiving nonoperative treatment proceeded to undergo surgical stabilization within 2 years after the initial injury.

Results for the Level II and III Studies—Ten studies ranked as Level II and Level III evidence (8, 17, 28, 30, 33, 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 two different surgical treatments ($n=1$). Table 4 summarizes their outcomes in detail. Briefly, in alignment with the overall findings, and the findings for the youngest 15% of patients, the highest level of evidence studies 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, while many patients initially selected for conservative treatment suffer from secondary damages and cross over to surgical stabilization, thus potentially combining the risk profiles of both types of treatments. The specific procedure chosen for surgical stabilization appears to have less clinical impact than the selection of surgical treatment.

Currently, many 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 to result 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 epiphysiodetic effects of fixation devices crossing the tibial physis (27% of angular deformities) (4). Other frequently 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

(average 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 an active patient, deserves critical re-evaluation. A number of studies have followed-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., 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 (55). 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.

Physal-sparing procedures, both intra- and/or extra-articular, have evolved into valuable alternatives (2, 10, 61). Recent studies by Kocher et al. have shown that postoperative results of extra-physal iliotibial band reconstruction are equivalent to transphysal 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 physal sparing ACL reconstruction with autologous fascia lata (n = 12) and transphysal 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 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, but which 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-level evidence. The findings from these subgroups were similar to that 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 in 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 level 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, and under the most stringent criteria used in the current literature.

Two recent, noteworthy publications in *Arthroscopy* deal with the management of immature ACL ruptures (73, 74). Keating et al. 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 <15 years, girls <14 years of age, Tanner stage I to III) (74). They reported no differences in patient-reported outcomes, AP laxity, or leg-length discrepancy or angular deformities between physal-sparing and transphysal 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. 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 (73). 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% 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 and colleagues 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. The authors 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 of all, 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 due in part to the relatively small number of patients as well as the known biologic 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 biggest 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 insure 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 theoretical 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.

REFERENCES

1. Mohtadi N, Grant J. Managing anterior cruciate ligament deficiency in the skeletally immature individual: a systematic review of the literature. *Clin J Sport Med*. Nov; 2006 16(6):457–64. [PubMed: 17119358]
2. Micheli, Rask, Gerberg. Anterior cruciate ligament reconstruction in patients who are prepubescent. *Clin Orthop Relat Res*. Jul; 1999 1(364):40–7. [PubMed: 10416390]
3. Shea KG, Pfeiffer R, Wang JH, Curtin M, Apel PJ. Anterior cruciate ligament injury in pediatric and adolescent soccer players: an analysis of insurance data. *J Pediatr Orthop*. Nov-Dec; 2004 24(6):623–8. [PubMed: 15502559]
4. Kocher, Saxon, Hovis, Hawkins. Management and complications of anterior cruciate ligament injuries in skeletally immature patients: survey of the Herodicus Society and The ACL Study Group. *J Pediatr Orthop*. Jul 1; 2002 22(4):452–7. [PubMed: 12131440]
5. Soprano JV. Musculoskeletal injuries in the pediatric and adolescent athlete. *Curr Sports Med Rep*. Dec; 2005 4(6):329–34. [PubMed: 16282035]
6. Vaquero J, Vidal C, Cubillo A. Intra-articular traumatic disorders of the knee in children and adolescents. *Clin Orthop Relat Res*. Mar.2005 (432):97–106. [PubMed: 15738809]
7. Koman, Sanders. Valgus deformity after reconstruction of the anterior cruciate ligament in a skeletally immature patient. A case report. *J Bone Joint Surg Am*. May 1; 1999 81(5):711–5. [PubMed: 10360701]
8. Woods GW, O'Connor DP. Delayed anterior cruciate ligament reconstruction in adolescents with open physes. *The American journal of sports medicine*. Jan 1; 2004 32(1):201–10. [PubMed: 14754745]
9. Anderson. Transepiphyseal replacement of the anterior cruciate ligament in skeletally immature patients. A preliminary report. *J Bone Joint Surg Am*. Jul 1; 2003 85-A(7):1255–63. [PubMed: 12851350]
10. Kocher, Garg, Micheli. Physeal sparing reconstruction of the anterior cruciate ligament in skeletally immature prepubescent children and adolescents. Surgical technique. *J Bone Joint Surg Am*. Sep 1; 2006 88(Suppl 1 Pt 2):283–93. [PubMed: 16951100]
11. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med*. Jul 21.2009 6(7):e1000100. [PubMed: 19621070]
12. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Bmj*. 2009; 339:b2535. [PubMed: 19622551]
13. Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup DF. Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. *Quality of Reporting of Meta-analyses*. *Lancet*. Nov 27; 1999 354(9193):1896–900. [PubMed: 10584742]
14. Wright J. A practical guide to assigning levels of evidence. *J Bone Joint Surg*. 2007; 89-A:1128–30. [PubMed: 17473152]
15. Wright J, Swiontkowski M, Heckman J. Introducing levels of evidence to the journal. *JBJS*. 2003; 85-A:1–3.
16. Emerson J, Burdick E, Hoaglin D, Mosteller F, Chalmers T. An empirical study of the possible relation of treatment differences to quality scores in controlled randomized clinical trials. *Control Clin Trial*. 1990; 11(5):339–52.
17. Aichroth, Patel, Zorrilla. The natural history and treatment of rupture of the anterior cruciate ligament in children and adolescents. A prospective review. *J Bone Joint Surg Br*. Jan 1; 2002 84(1):38–41. [PubMed: 11837830]
18. Andrews, Noyes, Barber-Westin. Anterior cruciate ligament allograft reconstruction in the skeletally immature athlete. *Am J Sports Med*. Jan 1; 1994 22(1):48–54. [PubMed: 8129110]
19. Angel, Hall. Anterior cruciate ligament injury in children and adolescents. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*. Jan 1; 1989 5(3):197–200.

20. Arbes, Resinger, Vecsei, Nau. The functional outcome of total tears of the anterior cruciate ligament (ACL) in the skeletally immature patient. *Int Orthop.* Aug 1; 2007 31(4):471–5. [PubMed: 16947051]
21. Aronowitz, Ganley, Goode, Gregg, Meyer. Anterior cruciate ligament reconstruction in adolescents with open physes. *Am J Sports Med.* Mar 1; 2000 28(2):168–75. [PubMed: 10750992]
22. Attmanspacher, Dittrich, Stedtfeld. Results on treatment of anterior cruciate ligament rupture of immature and adolescents. *Unfallchirurg.* Feb 1; 2003 106(2):136–43. [PubMed: 12624688]
23. Bollen, Pease, Ehrenreich, Church, Skinner, Williams. Changes in the four-strand hamstring graft in anterior cruciate ligament reconstruction in the skeletally-immature knee. *J Bone Joint Surg Br.* Apr 1; 2008 90(4):455–9. [PubMed: 18378919]
24. Brief LP. Anterior cruciate ligament reconstruction without drill holes. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association.* 1991; 7(4):350–7.
25. Cohen M, Ferretti, Quarteiro, Marcondes, Hollanda d, Amaro, et al. Transphyseal anterior cruciate ligament reconstruction in patients with open physes. *Arthroscopy.* Aug 1; 2009 25(8):831–8. [PubMed: 19664501]
26. Edwards, Grana. Anterior cruciate ligament reconstruction in the immature athlete: long-term results of intra-articular reconstruction. *Am J Knee Surg.* 2001; 14(4):232–7. [PubMed: 11703036]
27. Fuchs, Wheatley, Uribe, Hechtman, Zvijac, Schurhoff. Intra-articular anterior cruciate ligament reconstruction using patellar tendon allograft in the skeletally immature patient. *Arthroscopy.* Oct 1; 2002 18(8):824–8. [PubMed: 12368777]
28. Gebhard, Ellermann A, Hoffmann, Jaeger, Friederich. Multicenter-study of operative treatment of intraligamentous tears of the anterior cruciate ligament in children and adolescents. *Knee Surg Sports Traumatol Arthr.* Sep 21; 2006 14(9):797–803.
29. Gorin, Paul, Wilkinson. An anterior cruciate ligament and medial collateral ligament tear in a skeletally immature patient: a new technique to augment primary repair of the medial collateral ligament and an allograft reconstruction of the anterior cruciate ligament. *Arthroscopy.* Dec 1; 2003 19(10):E21–6. [PubMed: 14673466]
30. Graf, Lange, Fujisaki, Landry, Saluja. Anterior cruciate ligament tears in skeletally immature patients: meniscal pathology at presentation and after attempted conservative treatment. *Arthroscopy.* 1992; 8(2):229–33. [PubMed: 1637437]
31. Guzzanti, Falciglia, Stanitski. Physeal-sparing intraarticular anterior cruciate ligament reconstruction in preadolescents. *Am J Sports Med.* Nov 1; 2003 31(6):949–53. [PubMed: 14623662]
32. Guzzanti, Falciglia, Stanitski. Preoperative evaluation and anterior cruciate ligament reconstruction technique for skeletally immature patients in Tanner stages 2 and 3. *Am J Sports Med.* Nov 1; 2003 31(6):941–8. [PubMed: 14623661]
33. Henry, Chotel, Chouteau, Fessy, Berard, Moyen B. Rupture of the anterior cruciate ligament in children: early reconstruction with open physes or delayed reconstruction to skeletal maturity? *Knee Surg Sports Traumatol Arthrosc.* Jul 1; 2009 17(7):748–55. [PubMed: 19252897]
34. Higuchi, Hara, Tsuji, Kubo T. Transepiphyseal reconstruction of the anterior cruciate ligament in skeletally immature athletes: an MRI evaluation for epiphyseal narrowing. *J Pediatr Orthop B.* Jul 18.2009
35. Janarv, Nystrom, Werner S, Hirsch. Anterior cruciate ligament injuries in skeletally immature patients. *J Pediatr Orthop.* Sep 1; 1996 16(5):673–7. [PubMed: 8865058]
36. Kocher, Smith, Zoric, Lee, Micheli. Transphyseal anterior cruciate ligament reconstruction in skeletally immature pubescent adolescents. *J Bone Joint Surg Am.* Dec 1; 2007 89(12):2632–9. [PubMed: 18056495]
37. Liddle, Imbuldeniya, Hunt. Transphyseal reconstruction of the anterior cruciate ligament in prepubescent children. *J Bone Joint Surg Br.* Oct 1; 2008 90(10):1317–22. [PubMed: 18827241]
38. Lipscomb, Anderson AF. Tears of the anterior cruciate ligament in adolescents. *The Journal of bone and joint surgery American volume.* Jan 1; 1986 68(1):19–28. [PubMed: 3941119]

39. Lo, Kirkley, Fowler, Miniaci. The outcome of operatively treated anterior cruciate ligament disruptions in the skeletally immature child. *Arthroscopy*. Oct 1; 1997 13(5):627–34. [PubMed: 9343653]
40. Marx, Siebold R, Sobau, Saxler, Ellermann A. ACL reconstruction in skeletally immature patients. *Z Orthop Unfall*. Nov 1; 2008 146(6):715–9. [PubMed: 19085718]
41. Matava, Siegel. Arthroscopic reconstruction of the ACL with semitendinosus-gracilis autograft in skeletally immature adolescent patients. *Am J Knee Surg*. 1997; 10(2):60–9. [PubMed: 9131235]
42. McCarroll, Rettig, Shelbourne. Anterior cruciate ligament injuries in the young athlete with open physes. *Am J Sports Med*. Jan 1; 1988 16(1):44–7. [PubMed: 3278634]
43. McCarroll, Shelbourne KD, Porter, Rettig, Murray. Patellar tendon graft reconstruction for midsubstance anterior cruciate ligament rupture in junior high school athletes. An algorithm for management. *The American journal of sports medicine*. Jan 1; 1994 22(4):478–84. [PubMed: 7943512]
44. McIntosh, Dahm, Stuart. Anterior cruciate ligament reconstruction in the skeletally immature patient. *Arthroscopy*. Dec 1; 2006 22(12):1325–30. [PubMed: 17157732]
45. Mizuta, Kubota, Shiraishi, Otsuka, Nagamoto, Takagi. The conservative treatment of complete tears of the anterior cruciate ligament in skeletally immature patients. *J Bone Joint Surg Br*. Nov 1; 1995 77(6):890–4. [PubMed: 7593101]
46. Noble, Heinrich, Guanche. Midsubstance anterior cruciate ligament rupture in a 7-year-old child. Case report. *Am J Knee Surg*. 1995; 8(1):32–4. [PubMed: 7866801]
47. Parker, Drez, Cooper. Anterior cruciate ligament injuries in patients with open physes. *The American journal of sports medicine*. Jan 1; 1994 22(1):44–7. [PubMed: 8129109]
48. Pressman, Letts, Jarvis. Anterior cruciate ligament tears in children: an analysis of operative versus nonoperative treatment. *J Pediatr Orthop*. Jul 1; 1997 17(4):505–11. [PubMed: 9364393]
49. Robert, Bonnard. The possibilities of using the patellar tendon in the treatment of anterior cruciate ligament tears in children. *Arthroscopy*. Jan 1; 1999 15(1):73–6. [PubMed: 10024036]
50. Salzmann, Spang, Imhoff. Double-bundle anterior cruciate ligament reconstruction in a skeletally immature adolescent athlete. *Arthroscopy*. Mar 1; 2009 25(3):321–4. [PubMed: 19245996]
51. Schneider, Kraus, Linhart. Anterior cruciate ligament reconstruction with semitendinosus tendon in children. *Oper Orthop Traumatol*. Oct 1; 2008 20(4-5):409–22. [PubMed: 19169783]
52. Seon, Song, Yoon, Park. Transphyseal reconstruction of the anterior cruciate ligament using hamstring autograft in skeletally immature adolescents. *J Korean Med Sci*. Dec 1; 2005 20(6):1034–8. [PubMed: 16361818]
53. Shelbourne, Gray T, Wiley. Results of transphyseal anterior cruciate ligament reconstruction using patellar tendon autograft in tanner stage 3 or 4 adolescents with clearly open growth plates. *Am J Sports Med*. Jul 1; 2004 32(5):1218–22. [PubMed: 15262645]
54. Sobau, Ellermann A. Anterior cruciate ligament reconstruction with hamstring tendons in the young. *Unfallchirurg*. Aug 1; 2004 107(8):676–9. [PubMed: 15292958]
55. Streich N, Barié A, Gotterbarm T, Keil M, Schmitt H. Transphyseal reconstruction of the anterior cruciate ligament in prepubescent athletes. *Knee Surg Sports Traumatol Arthr*. Feb 4.2010 :1–6.
56. Thompson, Flynn, Wells, Ganley. Single incision arthroscopic ACL reconstruction in skeletally immature patients with direct visualization of the femoral and tibial physes. *Orthopedics*. Jun 1; 2006 29(6):488–92. [PubMed: 16786939]
57. Trentacosta, Vitale, Ahmad. The effects of timing of pediatric knee ligament surgery on short-term academic performance in school-aged athletes. *Am J Sports Med*. Sep 1; 2009 37(9):1684–91. [PubMed: 19460815]
58. Wester, Canale, Dutkowsky, Warner, Beaty. Prediction of angular deformity and leg-length discrepancy after anterior cruciate ligament reconstruction in skeletally immature patients. *J Pediatr Orthop*. Jul 1; 1994 14(4):516–21. [PubMed: 8077439]
59. Vavken P, Culen G, Dorotka R. Clinical applicability of evidence-based orthopedics--a cross-sectional study of the quality of orthopedic evidence. *Z Orthop Unfall*. Jan-Feb; 2008 146(1):21–5. [PubMed: 18324577]
60. MacIntosh D, Darby T. Lateral substitution reconstruction. In *proceedings of universities, colleges, councils and associations*. *J Bone Joint Surg*. 1976; 58B(142):1976.

61. Kocher MS, Garg S, Micheli LJ. Physeal sparing reconstruction of the anterior cruciate ligament in skeletally immature prepubescent children and adolescents. *J Bone Joint Surg Am.* Nov; 2005 87(11):2371–9. [PubMed: 16264110]
62. Robert H, Bonnard C. The possibilities of using the patellar tendon in the treatment of anterior cruciate ligament tears in children. *Arthroscopy.* Jan-Feb; 1999 15(1):73–6. [PubMed: 10024036]
63. Streich NA, Barie A, Gotterbarm T, Keil M, Schmitt H. Transphyseal reconstruction of the anterior cruciate ligament in prepubescent athletes. *Knee Surg Sports Traumatol Arthrosc.* Feb 4.2010
64. McCarroll JR, Rettig AC, Shelbourne KD. Anterior cruciate ligament injuries in the young athlete with open physes. *Am J Sports Med.* Jan-Feb; 1988 16(1):44–7. [PubMed: 3278634]
65. Shea KG, Apel PJ, Pfeiffer RP. Anterior cruciate ligament injury in paediatric and adolescent patients: a review of basic science and clinical research. *Sports Med.* 2003; 33(6):455–71. [PubMed: 12744718]
66. Shea KG, Apel PJ, Pfeiffer RP, Traugher PD. The anatomy of the proximal tibia in pediatric and adolescent patients: implications for ACL reconstruction and prevention of physeal arrest. *Knee Surg Sports Traumatol Arthrosc.* Apr; 2007 15(4):320–7. [PubMed: 16909299]
67. Houle JB, Letts M, Yang J. Effects of a tensioned tendon graft in a bone tunnel across the rabbit physis. *Clin Orthop Relat Res.* Oct.2001 (391):275–81. [PubMed: 11603681]
68. Edwards TB, Greene CC, Baratta RV, Zieske A, Willis RB. The effect of placing a tensioned graft across open growth plates. A gross and histologic analysis. *J Bone Joint Surg Am.* May; 2001 83-A(5):725–34. [PubMed: 11379743]
69. Seil R, Pape D, Kohn D. The risk of growth changes during transphyseal drilling in sheep with open physes. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association.* Jul 1; 2008 24(7):824–33.
70. Stadelmaier DM, Arnoczky SP, Dodds J, Ross H. The effect of drilling and soft tissue grafting across open growth plates. A histologic study. *Am J Sports Med.* Jul-Aug; 1995 23(4):431–5. [PubMed: 7573652]
71. Chudik S, Beasley L, Potter H, Wickiewicz T, Warren R, Rodeo S. The influence of femoral technique for graft placement on anterior cruciate ligament reconstruction using a skeletally immature canine model with a rapidly growing physis. *Arthroscopy.* Dec; 2007 23(12):1309–19. e1. [PubMed: 18063175]
72. Meller R, Kendoff D, Hankemeier S, Jagodzinski M, Grotz M, Knobloch K, et al. Hindlimb growth after a transphyseal reconstruction of the anterior cruciate ligament: a study in skeletally immature sheep with wide-open physes. *Am J Sports Med.* Dec; 2008 36(12):2437–43. [PubMed: 18815236]
73. Frosch KH, Stengel D, Brodhun T, Stietenron I, Holsten D, Jung C, et al. Outcomes and risks of operative treatment of rupture of the anterior cruciate ligament in children and adolescents. *Arthroscopy.* Nov; 2010 26(11):1539–50. [PubMed: 21035009]
74. Kaeding CC, Flanigan D, Donaldson C. Surgical techniques and outcomes after anterior cruciate ligament reconstruction in preadolescent patients. *Arthroscopy.* Nov; 2010 26(11):1530–8. [PubMed: 20888170]
75. Vavken P, Dorotka R. A systematic review of conflicting meta-analyses in orthopaedic surgery. *Clin Orthop Relat Res.* Oct; 2009 467(10):2723–35. [PubMed: 19252958]
76. Egger, M.; Smith, GD.; Altman, DG. *Meta-analysis in context.* 2nd Ed.. BMJ Publishing Group; London: 2005. Systematic reviews in health care.

Figure 1.
The flow of trials during the systematic review of the literature.

Characteristics of the included studies by Level of Evidence. **Table 1** summarizes the characteristics of the included studies. All information is reported as given in the publications. Level of evidence (LoE, I-V).

Table 1

Authors	Journal	Year	LoE	age (y)	Tanner/XR	Tx group*	Co group	N	fu (m)
Henry et al.	Knee Surg Sports Traumatol Arthrosc	2009	II	-	open physes, Tanner I-IV	ACLR (QT)	delayed ACLR	56	27
Streich et al.	Knee Surg Sports Traumatol Arthrosc	2010	III	11	open physes, Tanner I-II	ACLR (STG)	non operative Tx	31	70
Trentacosta et al.	Am J Sports Med	2009	III	-	?	ACLR	-	62	
Gebhard et al.	Knee Surg Sports Traumatol Arthr	2006	III	12.5	1-3 and 4-5	ACLR (4 different graft types)	-	68	32
Woods et al.	Am J Sports Med	2004	III	<16	open physes	non operative Tx	healthy adol	129	6.5
Aichroth et al.	J Bone Joint Surg Br	2002	III	13.5	1-5	ACLR (4HS)	non operative Tx	68	49/72
Pressman et al.	J Pediatr Orthop	1997	III	14.4	?	ACLR (STG BTB)	non operative Tx	42	63.6
Janarv et al.	J Pediatr Orthop	1996	III	13.1	open physes	natural Hx	non operative Tx	28	60
McCarroll et al.	Am J Sports Med	1994	III	-	open physes, Tanner I-IV	ACLR (BTB)	non operative Tx	60	50.4
Graf et al.	Arthroscopy	1992	III	14.5	open physes	intra- and extraarticular reconstructions	non operative Tx	12	
McCarroll et al.	Am J Sports Med	1988	III	-	open physes, Tanner I-IV	intra- and extraarticular reconstructions	non operative Tx	40	27
Cohen et al.	Arthroscopy	2009	IV	13.3	1-4	ACLR (4HS)	-	26	45
Higuchi et al.	J Pediatr Orthop B	2009	IV	-	?	ACLR	-	10	6
Marx et al.	Sportverletz Sportschaden	2009	IV	13	open physes	ACLR (4HS)	-	55	38
Bollen et al.	J Bone Joint Surg Br	2008	IV	13	Tanner I,II	ACLR (4HS)	-	5	34.6
Liddle et al.	J Bone Joint Surg Br	2008	IV	12.1	Tanner I,II	ACLR (4HS)	-	17	44
Schneider et al.	Oper Orthop Traumatol	2008	IV	14.7	4,5	ACLR (tripled STG)	-	57	25

Authors	Journal	Year	LoE	age (y)	Tanner/XR	Tx group*	Co group	N	fu (m)
Arbes et al.	Int Orthop	2007	IV	13.9	open physyes	var. Sx	non operative Tx	20	65
Kocher et al.	J Bone Joint Surg Am	2007	IV	14.7	Tanner III	ACLR (4HS)	-	59	42
McIntosh et al.	Arthroscopy	2006	IV	13.6	open physyes	ACLR (4HS/2HS)	-	16	41.1
Thompson et al.	Orthopedics	2006	IV	<14	open physyes	single incision ACLR (STG, AT)	-	30	-
Kocher et al.	J Bone Joint Surg Am	2005	IV	10.3	Tanner I,II	ITB	-	44	63.6
Seon et al.	J Korean Med Sci	2005	IV	14.7	open physyes	ACLR (4HS)	-	11	77.7
Shelbourne et al.	Am J Sports Med	2004	IV	14.8	Tanner III, IV	ACLR (BTB)	-	16	40.8
Sobau and Ellermann.	Unfallchirurg	2004	IV	14.2	open physyes	ACLR (4HS)	-	30	30.8
Anderson.	J Bone Joint Surg Am	2003	IV	13.3	1-3	ACLR (4HS)	-	12	49.2
Atmanspacher et al.	Unfallchirurg	2003	IV	-	open physyes	ACL repair, ACL refix, ACLR	-	45	
Gorin et al.	Arthroscopy	2003	IV	14	open physyes	ACLR (Tib. Posterior)	-	1	6
Guzzanti et al.	Am J Sports Med	2003	IV	11.15	1	ACLR (STG), physcal sparing	-	8	69.2
Guzzanti et al.	Am J Sports Med	2003	IV	13.6	2-3	ACLR (STG)	-	14	40.1
Fuchs et al.	Arthroscopy	2002	IV	13.2	open physyes	ACLR (BTB)	-	10	40
Kocher et al.	J Pediatr Orthop	2002	IV	-	open physyes	var. Sx	-	69	
Edwards and Grana.	Am J Knee Surg	2001	IV	13.7	?	ACLR (STG BTB)	-	21	34
Aronowitz et al.	Am J Sports Med	2000	IV	13.4	open physyes	ACLR (AT)	-	19	25
Koman and Sanders.	J Bone Joint Surg Am	1999	IV	14.3	open physyes	ACLR (double STG)	-	1	24
Micheli et al.	Clin Orthop Relat Res	1999	IV	11	open physyes	ITB	-	17	66.5
Robert and Bonnard.	Arthroscopy	1999	IV	11.4	open physyes	"Clocheville technique"	-	8	42

Authors	Journal	Year	LoE	age (y)	Tanner/XR	Tx group*	Co group	N	fu (m)
Lo et al.	Arthroscopy	1997	IV	12.9	open physes	ACLR (HS)	-	5	88.8
Mataava and Siegel	Am J Knee Surg	1997	IV	14.7	?	ACLR (HS)	-	8	32
Mizuta et al.	J Bone Joint Surg Br	1995	IV	12.8	open physes	natural Hx	non operative Tx	18	51
Andrews et al.	Am J Sports Med	1994	IV	13.5	open physes	ACLR (AT)	-	8	58
Parker et al.	Am J Sports Med	1994	IV	-	open physes	ACLR (HS) physesal sparing	-	6	33.2
Brief et al.	Arthroscopy	1991	IV	-	?	ACLR (STG) physesal sparing	-	9	-
Angel and Hall.	Arthroscopy	1989	IV	14.3	?	natural Hx	non operative Tx	27	51
Lipscomb and Anderson.	J Bone Joint Surg Am	1986	IV	13.5	open physes	ACLR (STG)	-	24	35
Salzmann et al.	Arthroscopy	2009	V	14	?	ACLR (double bundle STG)	-	1	-
Wester et al.	J Pediatr Orthop	1994	V	12.5	open physes	ACLR	non operative Tx	2	24

* ITB = iliotibial band (physesal sparing, combined intra-articular and extra-articular reconstruction) ACLR = ACL reconstruction with graft type in parentheses if reported (STG = Semitendinosus-Gracilis, HS = Hamstrings, 4HS = quadrupled HS, 2 HS = doubled HS, BTB = bone-tendon-bone, AT = Achilles Tendon, QT = quadriceps tendon).

Table 2

Outcomes in the studies comparing surgical treatment with nonoperative treatment

Authors	LoE	Type of treatment (N [§])		Clinical scores [‡]		Laxity [§]		Growth deformities		Other outcomes (n)	
		Tx	Co	Tx	Co	Tx	Co	Tx	Co	Tx	Co
Streich et al. (2010)	3	ACLR (16)	Non-op. (12)	IKDC	87 *	1.8 (1.4)	4.3 (2.9) *	0	0	giving-way	0
Aichroth et al. (2002)	3	ACLR (45)	Non-op. (23)	Lysholm	93	84 *				extension deficit	1
				Tegner	-	4.2	-	0	0	meniscal tears at time zero	17
				Lysholm	21 A; 15 B; 11 C,D	53.4				osteochochondral fractures	-
Pressman et al. (1997)	3	ACLR (23) and repair (6)	Non-op. (13)	Lysholm	ACLR better (p=?)	-	-	-	-	Lachman	ACLR better (p<0.005)
				Zarins&Rowe	ACLR better (p<0.001)					pivot-shift	ACLR better (p<0.009)
McCarroll et al. (1994)	3	ACLR (22)	Non-op. (38)				51 less than 3mm	0	0	giving-way	-
										meniscal tears	-
Graf et al. (1992)	3	ACLR (4) [†]	Non-op. (8)					0	0	return-to-sports	4
										giving-way	0
McCarroll et al. (1988)	3	ACLR (24) [†]	Non-op. (16)							meniscal tears	2
								1.7	-	return-to-sports	24
										giving-way	4

[§] number of patients available for analysis.

[‡] at latest follow-up.

[§] side to side as mean with (SD), if given.

[†] intra-articular and extra-articular reconstruction. LoE = Levels of Evidence (I-V). Tx = Treatment group. Co = control group. ACLR = ACL reconstruction, transphyseal unless otherwise specified.

* = reported as statistically significant,

*** p-value not given

Table 3

Outcomes in the studies comparing different surgical treatments

Authors	LoE	Type of treatment (N [§])		Clinical scores [‡]		Growth deformities		Other outcomes	
		Tx	Co	Tx	Co	Tx	Co	Tx	Co
Woods et al. (2004)	3	Immature, non operative treatment (13)	Mature, immediate & delayed ACLR (116)	-	-	-	-	meniscal injury	46%
Trentacosta et al. (2009)	3	Immediate ACLR (23)	Delayed ACLR (39)	IKDC 58	IKDC 85.9	-	-	cartilage injury	8%
				Lysholm 92.8	Lysholm 90.1			immediate return to school	62.3%
Gebhard et al. (2006)	3	transphyseal ACLR (28)	physeal-sparing (12)	-	-	0	0	failed an exam	36.4%
								meniscal tears	55%
									17%

[§] number of patients available for analysis.

[‡] at latest follow-up. LoE = Levels of Evidence (I-V). Tx = Treatment group, Co = control group.

Table 4

Characteristics of and outcomes from Level II and III studies

Authors	Year	LoE	Type of treatment (N [§])		Clinical scores at latest follow-up		laxity (mean side-to-side (SD))		LLD, angular deformities		other reported outcomes [#]	
			Tx	Control	Tx	Control	Tx	Control	Tx	Co	Tx	Control
Streich et al.	2010	III	ACLR (16)	Non operative (12)	IKDC	95	87 *	1.8 (1.4)	4.3 (2.9) *	0	0	giving-way 0 12
Aichroth et al.	2002	III	ACLR (45)	Non operative (23)	Lysholm	93	84 *					extension deficit 1 1
					Tegner	-	4.2	-	-	0	0	meniscal tears at time zero 17 14
Pressman et al.	1997	III	ACLR (23) and repair (6)	Non operative (13)	Lysholm	21 A, 15 B, 11 C and D	53.4					osteocondral fractures 3
					Lysholm	ACLR better (p=?)**		-	-			lachman ACLR better (p<0.005)
McCarroll et al.	1994	III	ACLR (22)	Non operative (38)	Zarins& Rowe	ACLR better (p<0.001)						pivot-shift ACLR better (p<0.009)
								51 less than 3mm	0	0		giving-way 37
Graf et al.	1992	III	ACLR (4) [†]	Non operative (8)		-	-	-	-	0	0	meniscal tears 27
												return-to sports 4 8
McCarroll et al.	1988	III	ACLR (24) [‡]	Non operative (16)		-	-	1.7	-	0	0	giving-way 0 8
												new meniscal tears 2 7
Henry et al.	2009	II	Immediate ACLR (29)	Delayed ACLR (27)	IKDC	94.6	82.4 *	1.93 (1.2)	1.76 (2)	0	0	return-to sports 24 7
												giving-way 4 (mild) 16
Woods et al.	2004	III	immature patients w/ non operative	skeletal mature patients with immediate and delayed (>26wks)		-	-					meniscal tears 12 (41%) 19 (70%)
												meniscal injury 46% 44%
												cartilage injury 8% 8%

Authors	Year	LoE	Type of treatment (N ^{\$})		Clinical scores at latest follow-up		laxity (mean side-to-side (SD))		LLD, angular deformities		other reported outcomes [#]	
			Tx	Control	Tx	Control	Tx	Control	Tx	Co	Tx	Cont rol
treatment (13) treatment (116)												
Trentacosta et al.	2009	III	Immediate ACLR (23)	Delayed ACLR (39)	IKDC	58	85.9				immediate return to school	62.3 %
Gebhard et al.	2006	III	transphyscal ACLR (28)	physcal-sparing ACLR (12)	Lysholm	92.8	90.1				failed an exam	0%
					-	-	-	0	0	meniscal tears	55%	17%

^{\$} available for analysis,

[†] intra-articular and extra-articular reconstruction.

[#] number or percentage, as given in original