Timing for Pediatric ACL Reconstruction in children: When meniscus and cartilage injury exists
Outside-In All Epiphyseal using Hamstrings, Outcomes tell it all

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I. Introduction

- ACL tears in children have been reported with increasing frequency 1-10.
- When a child or adolescent presents with a torn ACL, the physician is faced with a dilemma.
- A non-operative approach may result in meniscal and articular cartilage damage 1, 4-6 and surgery may cause iatrogenic growth disturbance 3, 4, 7-9.
- Management decisions are further complicated by the absence of reliable evidence in the literature. There is a deficiency in our basic science on physeal response to injury and there are methodological limitations in clinical studies.
- Despite this uncertainty, a rational approach to pediatric ACL reconstruction may be based on assessment of the patient’s maturity, treatment options, and physeal response to injury.

II. Normal growth and development

- Central issue is the patient’s maturity.
- The consequences of growth disturbance may be severe in children and insignificant teenagers.
- These consequences may be mitigated by careful evaluation of skeletal and sexual maturity in choosing the safest surgical technique.
- For large populations, chronologic age is an excellent predictor of skeletal maturity; however, patients may show a significant variance from the average.
- Skeletal age may be predicted by radiographs11 and physiologic age by Tanner staging of sexual maturation12.

<table>
<thead>
<tr>
<th>Stage</th>
<th>MALE</th>
<th>FEMALE</th>
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<tbody>
<tr>
<td>Stage I prepubescent</td>
<td>No pubic hair</td>
<td>No breast development</td>
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<tr>
<td>Stage II</td>
<td>Minimal pubic hair</td>
<td>Breast buds</td>
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<td></td>
<td></td>
<td>Minimal pubic hair</td>
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<tr>
<td>Stage III</td>
<td>Pubic hair over penis</td>
<td>Enlargement of breast</td>
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<td></td>
<td>Voice changes</td>
<td>Pubic hair on mons</td>
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<td>Axillary hair</td>
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<tr>
<td>Stage IV</td>
<td>Adult pubic hair</td>
<td>Areola enlargement</td>
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<tr>
<td></td>
<td>Axillary hair</td>
<td>Pubic hair as adult</td>
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<td>Stage V post pubescent</td>
<td>As adult</td>
<td>As adult</td>
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III. Natural History
- The natural history of ACL tears in children and adolescents is generally poor. Patients often experience recurrent instability, meniscal damage and sports-related disability.\textsuperscript{2,5,6,10,15, 26, 27,28}

IV. Risk Factors for Iatrogenic Growth Disturbance
- There is a significant deficiency in the age-specific basic science on physeal response to injury.
- In general, the threshold for growth disturbance is 3-4% of the physeal area.
- Transphyseal reconstruction damages less than 3% of the physis.\textsuperscript{28,29}
- Soft tissue graft through transphyseal drill holes –
  - Guzzanti, et al\textsuperscript{17} found that 2 of 21 tibias in an animal model developed a Valgus deformity and one was shorter
  - Houle, et al\textsuperscript{18} found 8 of 11 growth arrests in an animal model. Larger drill holes caused greater deformity. Soft tissue grafts across the physis offered no protection. Drill holes should not involve more than 1% of the physeal area
  - Babb, et al\textsuperscript{19} found that use of a tendon autograft did not prevent a bony bar.
    - Mensenchymal stem cells, however, prevented growth arrest
  - Stadelmaier, et al\textsuperscript{20}
    - Fascia lata autograft prevents physeal arrest
  - Janarv, et al\textsuperscript{21}
    - Destruction of 7-9% of the physis caused growth disturbance - No growth disturbance in injuries of 4-5% of the physeal area
    - Soft tissue across the physis prevents a bony bar formation
  - Yoo, et al\textsuperscript{29}
    - 5/43 (11.6% of adolescents had a focal bone bridge after transphyseal reconstruction. The authors thought that transphyseal reconstruction was not a benign procedure that could be applied safely to younger children with substantial growth remaining.\textsuperscript{28}
- Graft tension
  - Edwards, et al\textsuperscript{22} tensioned grafts at 80N in an animal model and found growth disturbance
  - The physes are sensitive to compression (Hueter-Volkman principle)
  - Chudik, et al\textsuperscript{23} performed ACL reconstructions using transepiphyseal, transphyseal, and over the top femoral holes. They found that the Transepiphyseal technique was more anatomic and caused less growth disturbance.
- Conclusions
  - Drill hole size is important
    - 3-4% or less of the cross sectional area
    - Drill perpendicular and central rather than peripheral
Soft tissue grafts across the physis offer protection, although the results of animal studies are mixed. The physes are sensitive to compressive forces. Therefore, do not over tension the graft. The tibial physis is probably more vulnerable than the femoral physis.

V. Treatment Options

- Non-operative. Despite poor results, many surgeons still advocate a non-operative approach to avoid iatrogenic bone growth disturbance.
- Extra-articular procedures. Others have recommended a primary repair or extra-articular procedures. Unfortunately, the results of these procedures have been no more successful in children than adults.
- Modified physeal sparing procedures
  - Parker, et al used hamstrings through the tibial groove and over the top. Kocher, et al used an iliotibial band over the top and through the knee. If the over the top position is used, avoid rasping, which may damage the perichondral ring of LaCroix.
  - Anatomic ACL reconstruction is the standard of care now. Why should children be treated differently?
- Transepiphyseal Reconstruction
  - Anderson in a preliminary report demonstrated the efficacy of this intra-articular procedure using quadruple hamstring tendons.
- Transphyseal Reconstruction
  - Higuchi, et al and Yoo, et al in MRI studies, found that damage to the physis during a transphyseal reconstruction was less than 3% of the physeal area. Even so, all of the patients had narrowing, or early closure, of the physis. Nawabi, et al report 5.4% damage to the area of the tibial physician. In the study by Yoo, et al, 11% developed a focal bone bridge. They questioned the safety transphyseal reconstructions in younger patients who had more growth remaining.

VI. Treatment Recommendations

- There is a great disparity in the literature on treatment of ACL tears in the pediatric age group. Consequently, it is difficult to determine the current “best treatment”. Until we have better information from multi-center studies, our bias is to use a modified anatomic, intra-articular procedure based on the patient’s physiologic and skeletal age.
- High risk pre-pubescent patients in Tanner Stages I and II of development, including males less than 12 and females less than 11, may be treated with an outside-in transepiphyseal ACL replacement or an ALL inside-ALL epiphyseal procedure.
- The advantages of an outside-in transepiphyseal technique are that the procedure is anatomic and relatively simple to perform. The theoretical disadvantages are that the drilling may damage the fibular collateral ligament or popliteal tendon insertion and there may be tethering of the tibial physis.
- The advantages of the ALL inside-ALL epiphyseal procedure include that it is anatomic, this procedure avoids damage to the fibular collateral ligament or popliteal insertions and there is no tethering of the tibial physis. The disadvantages are that the procedure is technically difficult, there is potential for graft tunnel length mismatch, and there may be a short tibial tunnel.

- Conclusions
  For behavioral or other reasons, the natural history of ACL tears in children is poor. The risks of nonoperative treatment are greater than the risks of surgery. Consequently, the treatment of choice is reconstruction in this age group. Significant leg length discrepancy or angular deformity, although rare, has been reported. Additional research is needed to determine safe drill hole size and graft tension. Increased scientific rigor provided by multi-center research will clarify the contradictions in literature and help to determine the current “best treatment” for these patients. Until we have this information, our bias is to modify the procedure based on the patient’s physiologic and skeletal age, which determines severity should growth disturbance occur. High risk pre-pubescent Tanner Stages I and II patients may be treated with efficacy and relative safety using an anatomic ALL-epiphyseal ACL reconstruction. Intermediate risk Tanner stage III patients may be treated with transphyseal reconstruction.


