Transphyseal Anterior Cruciate Ligament Reconstruction in the Skeletally Immature
Follow-up to a Minimum of Sixteen Years of Age

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Background: The evidence in favor of early surgical treatment of anterior cruciate ligament (ACL) injuries in children is increasing. However, the controversy regarding the safety of such a procedure in young athletes with wide open physes remains unresolved.

Methods: We reviewed prospectively collected outcome data on consecutive patients who had undergone transphyseal ACL reconstruction at either (1) an age of less than fourteen years and Tanner stage 1 or 2, or (2) an age of less than twelve years and Tanner stage 3. Children who had less than four years of follow-up, who were younger than sixteen years at the time of final follow-up, or who had been at Tanner stage 4 at the time of surgery were excluded. Twenty-eight of the thirty-two included patients had been at Tanner stage 1 or 2 at the time of surgery, and the remaining four had been at Tanner stage 3 but had been younger than twelve years of age. The mean age at the time of the surgery was 11.25 years (range, 9.5 to 14.0 years; median, 12.1 years). The mean duration of follow-up was 72.3 months (range, forty-eight to 129 months; median, seventy-two months).

Results: The mean Lysholm score improved from 71.5 preoperatively to 95.86 postoperatively (p < 0.0001). The mean Tegner activity scale score improved from 4.03 to 7.66 (p < 0.0001), which was comparable with the preinjury score of 8.0. One patient had a mild valgus deformity with no functional disturbance, and none had a limb-length discrepancy. One rerupture occurred, but all other patients had a good or excellent outcome.

Conclusions: This case series indicates good long-term results of ACL reconstruction with use of a transphyseal technique in young children.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

A midsubstance tear of the anterior cruciate ligament (ACL) in children is no longer considered a rare injury. Increasing awareness of the surgical treatment options and higher parental expectations have led to a greater number of these children undergoing ACL reconstruction. There have been many recent publications regarding early reconstruction. This interest is a consequence of the failure of conservative management in preventing instability and meniscal damage resulting in early degenerative changes. However, fear of growth arrest secondary to a procedure involving the physis has led to the use of alternative extra-articular techniques or modified, physis-sparing intra-articular techniques. The modifications to the intra-articular technique require the surgeon to deviate from the familiar transphyseal technique that is commonly used in adults.

Recent animal, radiologic, and clinical studies have shown that a transphyseal technique is safe to use in the presence of open physes. However, the number of patients in the clinical studies was small and follow-up was short. In addition, some series included children who were near or over the age of sixteen years and children who were at Tanner stage 4. The present study of the long-term functional outcome and complications of the transphyseal technique in very young children was designed to take into account the fact that any growth disturbances would depend on the amount of growth remaining. Consequently, all

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of the children included were either less than fourteen years of age or at a Tanner stage of 2 or less.

### Materials and Methods

Eighty-four skeletally immature patients underwent ACL reconstruction between 2000 and 2007. The present case series represents those children in the above group who met the criteria of this study. Any child who was at Tanner stage 4 or had an age of fourteen years or older was excluded. Children at Tanner stage 3 were included only if they had an age of less than twelve years. Children with less than four years of follow-up and those who had an age of less than sixteen years at the time of final follow-up were excluded.

The distribution of chronological age and Tanner stage in the thirty-two included patients is summarized in Table I. The study group contained twenty-eight boys and four girls. The mean age at the time of surgery had been 11.25 years, and the median had been 12.1 years (range, 9.5 to 14.0 years). The right knee was involved in seventeen patients and the left in fifteen.

All patients had been assessed preoperatively in a pediatric knee clinic. Clinical examination included the anterior drawer, Lachman, and pivot-shift tests. Weight-bearing anteroposterior and lateral radiographs of the knee were made. Functional status was assessed with use of the Lysholm knee score and Tegner activity scale questionnaires. All patients underwent magnetic resonance imaging (MRI) to confirm the ACL rupture and to diagnose any meniscal injury. Skeletal maturity was assessed with use of the Tanner scale (see Appendix) once the patient had been anesthetized for the surgery. All surgical procedures were performed by the senior author.

### Operative Technique

After examination of the knee under general anesthesia, an arthroscopy was performed. The stump of the ACL was debrided, and any meniscal injury was treated by repair or excision. Semitendinosus and gracilis tendons were harvested with use of a standard technique, and the two tendons were stitched at each end with use of a whip stitch. The graft was then doubled, and the diameter of the final graft was measured.

The tibial tunnel was drilled with use of an ACUFEX PRO-TRAC tibial guide (Smith & Nephew, Andover, Massachusetts) through the incision made for harvesting the graft. A guidewire was then introduced through the tibial tunnel and across the femur with use of a standard femoral offset guide (Smith & Nephew). The medial arthroscopy portal was not used because of concern about exiting in the region of the perichondral ring, which would cause greater damage to the growth plate. The length of the femoral tunnel was measured, and an appropriate ENDOBUTTON loop (Smith & Nephew) was selected. The graft was threaded through the loop. The tunnels were drilled very slowly, approximately one-quarter of a turn at a time, to minimize the thermal damage to the growth plate. The tunnels were thoroughly cleared of bone fragments. The mean tunnel diameter was 8 mm (range, 7 to 9 mm). The graft was then passed through the tunnels and the ENDOBUTTON was seated appropriately. With the knee in 20° of flexion, the graft was secured distally with use of a spiked washer and screw (Smith & Nephew) placed transversely across the tibia and distal to the growth plate (Fig. 1). The stability of the knee was confirmed, and the graft was inspected for impingement in extension. The notch was cleared of soft tissue; no osseous notchplasty was required.

![Fig. 1](image-url)

**TABLE I Distribution of Patient Age and Tanner Stage**

<table>
<thead>
<tr>
<th>Chronological Age</th>
<th>Tanner Stage 1</th>
<th>Total</th>
<th>Tanner Stage 2</th>
<th>Total</th>
<th>Tanner Stage 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys</td>
<td>Girls</td>
<td></td>
<td>Boys</td>
<td>Girls</td>
<td></td>
</tr>
<tr>
<td>Younger than 12 yr</td>
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<td>2</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>12 or 13 yr</td>
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<td>0</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>16</td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

*Patients in Tanner stage 3 who were at least 12 years of age and patients in Tanner stage 4 were excluded.*
The patient was mobilized with full weight-bearing on the first day after the operation. A brace was not used routinely. Anteroposterior and lateral radiographs of the knee were obtained to confirm the position of the tunnels and the fixation. All patients were treated with a standard rehabilitation that initially focused on knee extension.

All patients were followed on a regular basis, with formal assessment at six months, one year, and annually thereafter. Clinical testing of ligament laxity, limb length measurement, and assessment of deformity were performed. We chose to rely only on clinical evaluation to prevent unnecessary exposure of the child to radiation unless there was a clinical indication for radiography. The limb length was measured clinically by the senior author from the anterior superior iliac spine to the medial malleolus with use of a tape measure marked in 1-mm increments. A discrepancy between the length of the limb and that of the contralateral limb was recorded if present; a difference of >1 cm was considered notable. Functional outcome was assessed objectively with use of the Lysholm score, Tegner activity scale, and International Knee Documentation Committee (IKDC) evaluation form. We used the Aircast Rolimeter (DJO Global, Vista, California) for objective assessment of anteroposterior laxity, as we found the KT1000 arthrometer (MEDmetric, San Diego, California) to be large for these children. Any surgical complications were recorded. Standing anteroposterior and lateral radiographs of the knee were made during follow-up to identify physeal injury or deformity, and preoperative radiographs were reviewed. Any clinical deformity was monitored at intervals with use of computed tomography (CT) scout films and long-leg radiographs; this was required in only one child in the present series who was noted clinically to have a valgus knee deformity (Fig. 2-A).

Statistical Methods
Data were analyzed with use of GraphPad Prism for Windows (version 12.0). The Wilcoxon signed-rank test was used to compare preoperative and postoperative data; a p value of <0.05 was considered significant.

Source of Funding
No external funding was received for this study.

Results
The mean duration of follow-up of the thirty-two patients was 72.3 months (range, forty-eight to 129 months; median, seventy-two months). Twenty-five (78%) of these patients had attained skeletal maturity at the time of final follow-up.

The mode of injury involved football in nine patients, rugby in ten, and skiing in seven. A motor-vehicle accident, a fall, and netball, basketball, squash, and trampoline injuries each accounted for one of the remaining cases. Twenty-eight of the thirty-two patients were at Tanner stage 1 or 2. The remaining four were at Tanner stage 3 but were less than twelve years of age.

Twelve patients had associated meniscal tears, which involved the lateral meniscus only in six patients, the medial meniscus only in five, and both menisci in one. Three of these twelve patients had minor tears that were repaired at the same time as

Figs. 2-A and 2-B The child who developed a valgus deformity. Fig. 2-A Clinical photograph at the one-year follow-up showing the deformity. Fig. 2-B Computed tomography scanogram at the time of final follow-up at age sixteen.
the ACL reconstruction, and three had tears that were repaired at a different time. The remaining six patients were treated with partial meniscectomy and ACL reconstruction. The mean time from injury to ACL reconstruction in the thirty-two patients was 7.9 months (range, six weeks to thirty-nine months).

Outcomes
Twenty-three (72%) of the thirty-two patients described the outcome as excellent, and the remaining nine (28%) reported a good outcome. The mean Lysholm score improved from 71.5 preoperatively to 95.86 postoperatively (p < 0.0001). The mean Tegner activity scale score improved from 4.03 after injury to 7.66 (p < 0.0001), which was comparable to the preinjury score of 8.0.

Two patients reported occasional giving-way but still rated the result as good. One failure of the graft fixation occurred; this patient had Ehlers-Danlos syndrome and had undergone reconstruction at the age of 10.5 years. She returned to her previous level of activity after surgery, then fell again in the playground and sustained a rerupture nine months following surgery. She subsequently ruptured the ACL in her other knee, and that reconstruction (which was performed elsewhere) also failed. She elected to modify her activities and has been able to avoid any episodes of instability. Another patient was noted clinically to have a valgus deformity at twelve months of follow-up (Fig. 2-A). This was evaluated on long-leg radiographs, which showed 6.2° of valgus on the operatively treated side compared with 0.5° on the contralateral side. The patient remained asymptomatic clinically but was followed until his sixteenth birthday. Long-leg radiographs at that time showed 7.1° of valgus on the operatively treated side and 0.9° of valgus on the contralateral side. The limb-length measurements on the final scanograms confirmed the above measurements and showed a shortening of 1.6 mm on the operatively treated side (Fig. 2-B).

One patient developed an abscess at the stitch over the tibial screw site; the abscess resolved with drainage and antibiotics. One patient had persistent numbness around the harvest site. The hamstrings in three patients were only sufficient for a three-strand graft. All patients showed elongation of the graft with growth (Fig. 3). All operatively treated knees had a range of motion equal to that of the contralateral knee.

No patient had an obvious physeal bar or deformity suggestive of a growth arrest on follow-up radiographs. No patient had obvious radiographic signs of degenerative joint disease.

Anteroposterior laxity was measured during maximum manual anterior displacement at 30° of flexion. The mean side-to-side difference was <3 mm in thirty patients and 4 to 5 mm in the remaining two patients. The IKDC grade was A in twenty-six patients, B in five, and C in the one patient with failure of the graft.

Discussion
There is increasing support for early reconstruction of the ACL in young children. If reconstruction is not performed, persistent laxity results in high incidences of meniscal injury and degenerative changes. A good argument can be made for operating on these children sooner rather than later to prevent secondary damage. However, should ACL reconstruction in children with open physes be performed with use of a different technique than that in children with closed physes, and if so, why?

Direct repair of the torn ligament does not work. Concerns about the potential damage to growth plates during reconstruction have resulted in alternative reconstruction techniques being used in children to spare the growth plates. These include extra-articular, “over-the-top” (over the top of the tibia or the femur or both), and epiphyseal-only techniques. The results of these techniques are encouraging but follow-up has been short, sample sizes have been small, and the studies have often included children who were sixteen years of age and children who were at a Tanner stage of 4 or beyond. These procedures are challenging and often unfamiliar, leading to a high chance of error. The reconstruction may not be anatomical and isometric. Anterior placement of the graft over the front of the tibia may lead to impingement, anterior knee pain, limited extension, and graft failure. A femoral over-the-top position results in an average of 10 mm of graft elongation in extension.

A recent MRI study by Sasaki et al. has shown that the distal femoral and proximal tibial physes are 100% open (in terms of cross-sectional area) at eleven years of age and 95% open at twelve years, but 94% closed at fifteen years. The concern regarding potential growth arrest resulting from a standard transphyseal procedure in children younger than twelve years of age is therefore justified. Various authors have stressed the importance of a number of technical considerations when a transphyseal technique is used in such children. The tibial tuberosity must be avoided to prevent genu recurvatum. Damage


Appendix

A table outlining the Tanner stages is available with the online version of this article as a data supplement at jbsj.org.

References


