Physeal-sparing reconstruction of anterior cruciate ligament tears in children

RESULTS OF 57 CASES USING PATELLAR TENDON

C. Bonnard, J. Fournier, D. Babusiaux, M. Planchenault, F. Bergerault, B. de Courtivron

From University F. Rabelais, Paediatric Hospital G. de Clocheville-CHU de Tours, Tours, France

This study evaluated the results of a physeal-sparing technique of intra-articular anterior cruciate ligament (ACL) reconstruction in skeletally immature patients, with particular reference to growth disturbance. Between 1992 and 2007, 57 children with a mean age of 12.2 years (6.8 to 14.5) underwent ACL reconstruction using the same technique. At a mean of 5.5 years (2 to 14) after surgery, 56 patients underwent clinical and radiological evaluation. At that time, 49 patients (87.5%) had reached bony maturity and 53 (95%) achieved A or B according to the IKDC 2000 classification. Four patients had stopped participation in sports because of knee symptoms, and three patients (5.4%) had a subsequent recurrent ACL injury. There was no clinical or radiological evidence of growth disturbance after a mean growth in stature of 20.0 cm (3 to 38).

This study demonstrates that ACL reconstruction sparing the physis in children is a safe technique protecting against meniscal tears and giving better results than reconstruction in adults, without causing significant growth disturbance.

Anterior cruciate ligament (ACL) injuries are common in children but there is no consensus on the most effective treatment. Operative treatment is increasingly being recommended in order to prevent subsequent meniscal lesions. However, it is not clear which procedure is the best, particularly when significant growth remains, as few studies have been published and all of them have contained fewer than 50 cases treated with the same technique. The Clocheville technique is physeal-sparing, and has its theoretical advantages and disadvantages. From a stability point of view, the reconstructed ACL lies in an anatomical position on the tibial side, but on the femur its position is isometric but non-anatomical and thus should provide less rotational control. From a growth perspective, epiphyseal fixation on the tibia carries a risk of physeal injury, and the femoral fixation may potentially lead to growth disturbances either by a tethering effect or by injury to the perichondrial ring.

The purpose of this study was to evaluate the results of ACL reconstruction using this technique in skeletally immature children with ACL injuries, with a minimum of two years’ follow-up.

Patients and Methods

The study was a continuous retrospective cohort series, consisting of the first 57 patients to undergo reconstruction of the ACL using the Clocheville technique between 1992 and 2007. Follow-up was obtained for all patients, with 56 available for clinical and radiological follow-up. One patient had a telephone interview and radiological follow-up, and his results were consistent with the rest of the study, but he was excluded because he had no clinical examination.

This is an intra-articular technique that uses the central third of the patellar tendon (periosteum-ligament-periosteum), secured with sutures in a groove in the tibial epiphysis and with an interference screw in an isometric and lateraled position in a metaphyseal tunnel in the femur. The mean diameter of the femoral graft was 7.72 mm (7 to 10). This was recorded in each case as diameter of the femoral tunnel has been shown to be a proportionally significant risk factor for growth disturbance.

A long-leg cast with the knee in 10° flexion was applied for 45 days post-operatively, and the patient then undertook rehabilitation at home for a further 45 days before starting physiotherapy.

There were 43 boys (77%) and 13 girls with a mean age at surgery of 12.2 years (6.8 to 14.5). Six patients were between six and nine years old, 27 were between 10 and 12 years old, and 23 were between 13 and 15 years old. Skeletal age was determined by paediatric radiologists according to the atlas of Greulich and Pyle, the mean skeletal age at the time of...
surgery was 11.5 years (7 to 15) with a corresponding growth potential at the knee of 90 mm for boys and 40 mm for girls according to the Green and Anderson scale.7

The mean interval between injury and surgery was 10.4 months (1 to 65). At the time of ACL reconstruction 16 patients (28.6%) had an associated meniscal injury involving the lateral (11) or the medial meniscus (five). Six lateral meniscus and two medial meniscus injuries were treated with meniscal repair; five lateral meniscus injuries and one medial meniscus injury had no treatment, and two medial meniscus injuries were treated with partial meniscectomy.

Functional outcome was assessed according to the International Knee Documentation Committee (IKDC 2000) subjective and objective knee score.8 The objective stability of the knee was measured using the Rolimeter arthrometer (Phusis Corporation, Grenoble, France). The activity level before injury and at follow-up was assessed using the Tegner scale.9 One-legged jumping distance was measured and compared with subjective results. Clinically, growth disturbance was assessed using blocks to level the top of the posterior iliac crests with the patient bending forward, with the knees extended.10 Growth in stature was measured in all cases. Radiological examination of the knee included standing, weight-bearing anteroposterior and lateral radiographs, before surgery and at follow-up. Segmental growth was measured on a full-length standing radiograph prior to surgery (in 42 cases) and at follow-up. Distal femoral growth was assessed by measuring the distance from the femoral tunnel to the growth plate. Proximal tibial growth was assessed by measuring the migration of the Harris growth arrest line when it was visible (in 36 cases).

Radiological evidence of a growth disturbance was evaluated by a different observer (MP) and was assessed according to the integrity of the physes and the symmetry of the ephysesal lines. Six different angles were measured to assess growth disturbance compared to the normal knee (Fig. 1). A preparatory study of inter- and intra-observer variability was made by having seven senior surgeons perform those measurements on 30 anonymous normal knee radiographs and by repeating the measures two months later (Table I). Bone maturity was assessed by fusion of the physes.

**Statistical analysis.** Statistical analysis was performed using Statview software (SAS Institute Inc., Cary, North Carolina). Statistical significance was set at a p-value of ≤ 0.05.

**Results**

The mean follow-up was 5.5 years (2 to 14), with a mean age at follow-up of 17.7 years (13.5 to 26). There were no peri-operative surgical complications, including infection.

All patients completed the objective IKDC score, with 39 in class A, 14 in class B, two in class C, and one in class D. Thus 95% of patients were in class A or B.

The pivot-shift test was performed on 55 patients; 50 knees (91%) were class A, three (5%) class B and two (3%) class C. With the Lachman testing, also performed on 55 patients, 47 (85%) were class A and eight (12%) class B. The mean subjective score was 94.4 (64 to 100). There was a positive correlation between the one-legged jump and the subjective IKDC (Student’s t-test, p < 0.01). We found no correlation with gender, size of graft or delay in repair, but found a negative correlation with age (Student's t-test, p < 0.01): the younger the patient at the time of surgery, the better the result.

Four patients stopped playing sport because of continuing knee symptoms. A total of 15 participated in sports at a lower level than before the initial accident, whereas 35 participated at a level equal to or better than before the accident, and two stopped sport for reasons unrelated to their knee. The mean Tegner activity scale was 6.92 (4 to 9) before injury and 6.75 (4 to 9) at follow-up. The highest level of activity in which the patients could participate on a regular basis according to the IKDC was 4.7 of five (2 to 5).

Assessment of range of movement of the knee showed 12 patients (21%) with limited flexion, four of which were of 5° or less, seven between 5° and 10° and one between 10° and 15° after a new motorcycle injury. Only one patient (1.8%) had a flexion contracture of 5°, and no patient required manipulation under anaesthesia. Further procedures were undertaken for one patient who had a lateral meniscal repair and one who had an untreated lateral meniscus tear.

Growth in stature was a mean of 19.98 cm at follow-up (3 to 38). Correlation of inter-and intra-observer variation

---

**Fig. 1**

Frontal (left) and sagittal (right) radiographs showing the six angles used to detect growth disturbance (K, centre of the knee; HK (frontal) and HK’ (sagittal), central shaft line of the femur; KA (frontal) and KA’ (sagittal), central shaft line of the tibia; HKA, hip-knee-ankle angle; HKF, femur shaft to growth plate angle, TKA, tibial shaft to growth plate angle; HFK, femur shaft to Blumensaat line angle; HK’F’, lateral femur shaft to growth plate angle; T’KA, lateral tibial shaft to growth plate angle).
The measurement of angles on radiographs is given in Table I and the results in Table II. The mean distal growth of the femur was 45 mm (10 to 85, n = 55), and of the proximal tibia 28 mm (0 to 60, n = 36). Radiological measurement of bone length (n = 55) found a mean side-to-side difference of -0.4 mm (-10 to +9) for the femur after a mean longitudinal growth of 66 mm (15 to 120, n = 42) and +0.2 mm (-7 to +8) for the tibia after a mean growth of 45 mm (0 to 109, n = 42). Clinical assessment found the operated limb to be shorter by a mean of 0.4 mm (-5 mm to +15). Mean malalignment was 0.7° (-4° to +4°). Neither varus nor valgus exceeded 4° in any patient. Skeletal maturity was reached by 49 patients (87.5%).

Three patients (5.4%) had subsequent recurrent ACL tears. One woman had a secondary rupture and underwent an adult reconstruction procedure eight years after the initial surgery. She was IKDC class A before the second tear and at bony maturity. Another male patient underwent revision using an adult technique. He was IKDC class D for this study. The final patient suffered a partial tear nine months after surgery and was treated with a long-leg cast for six weeks. He was objectively IKDC class B at three years' follow-up. In the entire cohort, sport was resumed at a mean of 11 months (6 to 18) after surgery. The patient for whom we had no clinical exam and one phone interview, and who was therefore excluded, had no growth disturbance and a subjective IKDC score of 99.

### Table I. Intra- and interobserver study for six angles measured around a normal knee

<table>
<thead>
<tr>
<th>Measures</th>
<th>HKA*</th>
<th>HKF†</th>
<th>TKA‡</th>
<th>HK’F’§</th>
<th>HKF’¶</th>
<th>T’KA**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordance intra-observer (%)</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>88</td>
<td>95</td>
</tr>
<tr>
<td>Interval intra-observer (*)</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Difference maximum intra-observer (*)</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>12</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Concordance interobserver (%)</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Interval interobserver (*)</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Difference maximum interobserver (*)</td>
<td>11</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>19</td>
<td>25</td>
</tr>
</tbody>
</table>

* HKA, hip-knee-ankle angle  
† HKF, femur shaft to growth plate angle  
‡ TKA, tibial shaft to growth plate angle  
§ HK’F’, lateral femur shaft to growth plate angle  
¶ HKF’, femoral shaft to Blumensaat line angle  
** T’KA, lateral tibial shaft to growth plate angle

### Table II. Radiological comparison between operated and contralateral normal knee

<table>
<thead>
<tr>
<th>Angle</th>
<th>HKA*</th>
<th>HKF†</th>
<th>TKA‡</th>
<th>HK’F’§</th>
<th>HKF’¶</th>
<th>T’KA**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean difference between knees (°)</td>
<td>0.71</td>
<td>0.67</td>
<td>-0.07</td>
<td>-0.18</td>
<td>-4.37</td>
<td>-0.11</td>
</tr>
<tr>
<td>Range (°)</td>
<td>-2 to 4</td>
<td>-2 to 5</td>
<td>-6 to 4</td>
<td>-10 to 13</td>
<td>-19 to 8</td>
<td>-5 to 7</td>
</tr>
</tbody>
</table>

* HKA, hip-knee-ankle angle  
† HKF, femur shaft to growth plate angle  
‡ TKA, tibial shaft to growth plate angle  
§ HK’F’, lateral femur shaft to growth plate angle  
¶ HKF’, femoral shaft to Blumensaat line angle  
** T’KA, lateral tibial shaft to growth plate angle

### Discussion

This study shows that the technique is safe and gives satisfactory results. More than 90% of our patients had excellent or good results in terms of objective and subjective assessment of stability, with no malalignment and no significant growth disturbance. All had a minimum of two years follow-up and 49 (87.5%) had reached skeletal maturity. Our patients obtained a mean subjective IKDC score of 94, which compares favourably with the study by Slobegean, Mulputi and Reilly,11 which reported a mean score of 89 for normal adolescent knees. Graft positioning in our experience was easy, and as the cohort includes the first patients treated, the effect of the learning curve is included in the results. Theoretical concerns raised by the epiphyseal fixation of the graft on the tibial side have not been realised; no patient treated with this technique has so far shown significant malalignment or growth disturbance on the tibial side. Concerns have also been raised about the quality of the fixation of the graft on the tibial side, but as all patients were immobilised in a long-leg cast, no loss of fixation was observed. As might be expected in children, the use of a cast did not result in significant loss of movement or muscle wasting, and acted as an effective safeguard against premature resumption of activity. The non-anatomical fixation above the femoral physis should theoretically give less rotational control, but our results show good rotational control in more than 90% of cases. In the few cases where an arthroscopy was performed at a later stage it
appeared that the transplant had a tendency to fix itself over time to the normal point of insertion. Although one case of femoral varus requiring osteotomy has been described by Robert and Casin, and linked to a technical error, to our knowledge this is the only case of significant malalignment linked with the use of this technique, although their femoral tunnel was not in a frontal plane. No tethering effect was observed (Figs 2 to 4).

With regard to evaluating remaining growth, we believe that assessing bone age according to the atlas of Greulich and Pyle is preferable to using Tanner staging, as has been used in other studies. Skeletal maturity is only loosely related to the Tanner stage and it is never used to predict remaining growth. It should not, in our opinion, be used to evaluate growth potential in children. Despite the inaccuracies in determining skeletal maturity in young children, we believe that an assessment was necessary in order to make comparisons with other studies. We agree with Iversen et al that the subjective IKDC score and Tegner activity scale may not be ideal assessments for children, as they were designed for assessment of the degenerative knee. We believe that the emphasis should be on objective tests such as the one-legged jump, which is a simple and accurate method of evaluating knee function. It correlates well with the subjective IKDC score and is easily reproducible.

Our study showed that the accuracy of the measurements of angles made on plain anteroposterior radiographs but significantly less so on lateral views, presumably owing to the lack of distinct landmarks from which to take measurements. A summary of the results of ACL reconstruction in children is shown in Table III; this includes two multicentre studies, which combined different techniques. The overall results were good, with a minimum of 84% or 87% good or excellent results in a relatively large number of cases. Studies using transphyseal techniques report good results, ranging from 75% of IKDC class A or B to mean Lysholm scores of 97%, with only a few cases of growth disturbance. Similarly, the partial transphyseal technique appears safe and effective, with seven out of eight good or excellent results for Andrews, Noyes and Barber-Westin and four out of five cases of IKDC class A for Lo et al. However, these are small series, as
is often the case in studies on ACL tears in children. Extraphyseal studies also showed good results, but the average IKDC was as high as 97 in the most recent series. Lastly, transphyseal techniques such as ours have given good results in small series, with knee scores ≥ 95%. All of these series reveal a relatively low occurrence of growth disturbance, but it is possible that this is under-reported. A survey by the Herodicus Society found a rate of growth disturbance of 11% in children who had ACL reconstructive surgery, with most cases linked to technical errors and injudicious drilling and fixation. Compared to these studies, our study shows good results in a relatively large sample. It is the largest study of an immature population using a single technique, although the lack of a comparison group does not allow us to conclude that this technique is superior to other forms of treatments.

In a recently published study Higuchi et al evaluated transphyseal reconstruction in adolescents and showed a narrowing of growth plates around transphyseal drilling and grafting sites. This did not result in any growth disturbances, but as in many other studies, their patients were close to skeletal maturity. It is possible that in a younger cohort such physeal narrowing would result in growth disturbance.

Table III. Summary of different studies of ACL reconstruction in children. All are retrospective

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Mean age (yrs) (range)</th>
<th>Number</th>
<th>Lost</th>
<th>Re-rupture</th>
<th>Meniscal tear</th>
<th>Secondary meniscal repair</th>
<th>Transplant* Result</th>
<th>Growth disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current study</strong></td>
<td>12.2 (6 to 14)</td>
<td>56</td>
<td>2</td>
<td>2</td>
<td>11</td>
<td>5.51</td>
<td>2 PT</td>
<td>95 IKDC A or B</td>
</tr>
<tr>
<td><strong>Transphyseal technique</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macintosh et al</td>
<td>13.5</td>
<td>16</td>
<td>2</td>
<td>3.41</td>
<td>11</td>
<td>4 Ham</td>
<td>Mean Lysholm 98.9, 1</td>
<td></td>
</tr>
<tr>
<td>Lipscomb and Anderson</td>
<td>15.0 (12 to 15)</td>
<td>24</td>
<td>0</td>
<td>2.91</td>
<td>1</td>
<td>7 Ham or PT</td>
<td>75 good result</td>
<td></td>
</tr>
<tr>
<td>Gaulrapp and Haus</td>
<td>13.8 (3 to 16)</td>
<td>44</td>
<td>0</td>
<td>6.5</td>
<td>0</td>
<td>4 Ham</td>
<td>77% good result</td>
<td></td>
</tr>
<tr>
<td>McCarron et al</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aichroth et al</td>
<td>14.0 (11 to 15)</td>
<td>15</td>
<td>0</td>
<td>2.08</td>
<td>1</td>
<td>7 TA</td>
<td>Lysholm average 97</td>
<td></td>
</tr>
<tr>
<td>Higuchi et al</td>
<td>13.0 (11 to 15)</td>
<td>47</td>
<td>3</td>
<td>14</td>
<td>7</td>
<td>4 Ham</td>
<td>77% good result</td>
<td></td>
</tr>
<tr>
<td>Liddle et al</td>
<td>14.5 (13 to 16)</td>
<td>10</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>4 Ham</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kocher et al</td>
<td>12.0 (9 to 14)</td>
<td>17</td>
<td>0</td>
<td>3.66</td>
<td>1</td>
<td>7 Ham</td>
<td>IKDC A or B for further intervention</td>
<td></td>
</tr>
<tr>
<td><strong>Partial transphyseal</strong></td>
<td>13.0 (10 to 15)</td>
<td>8</td>
<td>0</td>
<td>4.83</td>
<td>0</td>
<td>6 FL or TA</td>
<td>6 excellent, 1 good, 1 fair</td>
<td></td>
</tr>
<tr>
<td>Andrews et al</td>
<td>12.9 (8 to 14)</td>
<td>5</td>
<td>0</td>
<td>7.4</td>
<td>0</td>
<td>4 FL or TA</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Extraphyseal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brief</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>8 patients satisfied</td>
<td>4 out of 5 return to sport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parker et al</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>2.7</td>
<td>0</td>
<td>4 Ham</td>
<td>Satisfactory for all 1</td>
<td></td>
</tr>
<tr>
<td>Nakhostine et al</td>
<td>14.0 (12 to 15)</td>
<td>5</td>
<td>0</td>
<td>4.4</td>
<td>0</td>
<td>4 FL</td>
<td>Average IKDC 97%, 41 Lachman normal</td>
<td></td>
</tr>
<tr>
<td>Kocher et al</td>
<td>10.0 (3 to 14)</td>
<td>50</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>4 FL</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transepiphyseal technique</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guzanti et al</td>
<td>11.0</td>
<td>8</td>
<td>3</td>
<td>5.75</td>
<td>0</td>
<td>4 Ham</td>
<td>Average knee score OA of 97 post-operative growth 21</td>
<td></td>
</tr>
<tr>
<td>Anderson</td>
<td>13.3</td>
<td>12</td>
<td>0</td>
<td>4.1</td>
<td>4</td>
<td>4 Ham</td>
<td>IKDC 96.5, growth 16.5 cm</td>
<td></td>
</tr>
<tr>
<td><strong>Multicentre studies covering different techniques</strong></td>
<td>12.3 (6 to 15)</td>
<td>119</td>
<td>17</td>
<td>34</td>
<td>3.5</td>
<td>1</td>
<td>84% IKDC A or B</td>
<td>1</td>
</tr>
<tr>
<td>Gebhard et al</td>
<td>12.5</td>
<td>68</td>
<td>6</td>
<td>2.66</td>
<td>1</td>
<td>87% IKDC normal or nearly normal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* PT, patellar tendon; 4 Ham, quadruple hamstring; Ham, hamstring; BPT, bone-patellar-tendon; TA, tendo Achillis; FL, fascia lata
† IKDC, International Knee Documentation Committee
‡ OAK, Orthopädische Arbeitsgruppe Knie score
In this paper we report the results of a physeal-sparing, intra-articular reconstruction technique using a periosteum-patellar tendon-bone graft in 56 skeletally immature children with no cases lost to follow-up. At a mean of five years’ this technique provided good functional outcomes with a low revision rate comparable with other studies, and with no growth disturbances.

Further opinion

A further opinion by Mr D. Hunt is available with the electronic version of this article on our website at www.jbjs.org.uk/education/further-opinions

Listen live

Listen to the abstract of this article at www.jbjs.org.uk/interactive/audio

The authors would like to thank Dr K. Wood for reviewing this paper before submission.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References