The Risk of Transphyseal Drilling in Skeletally Immature Patients With Anterior Cruciate Ligament Injury

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Background: Anterior cruciate ligament reconstruction (ACLR) in skeletally immature patients can result in growth plate injury, which can cause growth disturbances.

Purpose: To evaluate radiological tibial and femoral length and axis growth disturbances as well as clinical outcomes in skeletally immature ACLR patients treated with a transphyseal drilling technique.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 39 pediatric patients with ACL injury and open physes at time of surgery, as diagnosed clinically and with magnetic resonance imaging (MRI), were treated using transphyseal ACLR using hamstring graft. Mean patient age was 11.7 years (range, 9.0-14.0 years). Patients were evaluated with full extremity radiographs measuring leg length discrepancy and malalignment, as well as clinical evaluation with KT-1000 arthrometer measurements and Tegner activity scale and Knee injury and Osteoarthritis Outcome Score (KOOS) outcomes after follow-up of 68 months (range, 29-148 months).

Results: Of the 39 initial patients, 33 were evaluated both clinically and radiographically. We found a mean femoral length shortening of 3.5 mm (P = .01) on the operated leg. Eight patients (24%) had a more than 10-mm shortening of the operated leg, whereas only 1 patient (3%) had a 10-mm shortening of the nonoperated leg. In 27 of 33 patients (82%; P < .001), the anatomic femoral axes of the operated leg were found to be more than 2° of valgus compared with the nonoperated leg. The tibial anatomic axes changed into a less pronounced varus angulation (P = .02). The femoral-tibial anatomic axes were not significantly different when comparing the 2 legs. We did not find any statistical difference in growth arrest comparing patients treated surgically at the ages of 13 to 14 years to patients younger than 13 years. Tegner and KOOS scores were significantly lower among girls compared with boys. Side-to-side KT-1000 arthrometer difference improved from 5.2 mm preoperatively to 1.6 mm at follow-up.

Conclusion: This study shows that transphyseal ACLR in children results in minor length growth disturbances in 24% of patients. The surgically induced distal femoral valgus angulation is counterbalanced by a proximal tibial varus angulation. Growth disturbance after surgery is not associated with a certain pediatric age group. Otherwise, transphyseal ACLR has satisfactory clinical outcomes, with good subjective outcomes, function level, and knee stability.

Keywords: anterior cruciate ligament; open physis; pediatric; transphyseal drilling; knee instability

The incidence of anterior cruciate ligament (ACL) injuries among children is significant and has increased rapidly over the past few years. According to the Danish ACL register, 6% of all ACL reconstructions (ACLRs) are performed in patients younger than 15 years.

The main reason for the existing controversy regarding optimal treatment of children with ACL injury is the concern of surgically induced physeal growth disturbance. Nonoperative treatment may not sufficiently prevent knee instability and can lead to further meniscal and cartilage damage due to recurrent instability episodes. Operative treatment, on the other hand, may cause growth disturbances of the involved leg due to involvement of the physis. However, the literature regarding outcome after surgical treatment of ACL injury in children demonstrates good clinical results comparable to ACLR in adults. In a
meta-analysis of children and adolescents, only 1.9% had leg length discrepancies after transphyseal ACLR. These results were, however, based on clinical judgment or standard radiographs, and the mean patient age was 13 years. Interestingly, in the same study, the use of hamstring grafts was shown to be less prone to provoke growth disturbance than the use of patellar tendon graft.

The purpose of this study was to quantify the degree of growth disturbances in the operated leg compared with the nonoperated leg after transphyseal hamstring ACLR in children using an accurate digital radiographic measurement method.

METHODS

The study was approved by the regional ethics committee (j-36534). In the period from 2001 to 2010, a total of 39 children with ACL lesions diagnosed clinically and on magnetic resonance imaging (MRI) were treated with transphyseal ACLR; hamstring grafts and an Endobutton (Smith & Nephew) were used as the femoral fixation and bicortical screw and washer as the tibial fixation (Figure 1). All patients showed a clear open epiphysis in the distal femur and proximal tibia on preoperative radiographs. Preoperative Tanner staging and bone age radiographs were not done. The patients were evaluated preoperatively and at final follow-up. All patients were skeletally mature at the time of follow-up. Mean age at surgery was 11.7 ± 1.4 years (range, 9-14 years; boys: 11.6 ± 1.3 years, girls: 11.9 ± 1.5 years). The observation time was 68.0 ± 33.9 months (range, 29-148 months). Five patients did not respond to the request for a final follow-up and 1 patient was pregnant, leaving the fully accessible number of patients at 33.

At final follow-up, a clinical outcome evaluation was performed using a subjective evaluation: the Knee injury and Osteoarthritis Outcome Score (KOOS). The functional level was evaluated using the Tegner activity scale, and objective knee stability was evaluated using side-to-side KT-1000 arthrometer measurements. Furthermore, patients were evaluated using full-extremity radiographs assessing leg length discrepancy and angular malalignment.

Surgical Technique

In all 33 patients, ACLR was performed using 4-stranded hamstring autografts and an Endobutton as femoral fixation. For tibial fixation, the graft ends were locked under a spiked washer (Arthrotek) secured with a bicortical screw (Arthrotek) placed distally to the tibial epiphysis. The tibial tunnel was placed close to the tibial tuberosity, and the femoral tunnel was drilled transtibially to achieve a steep graft orientation. The diameters of the drilled tunnels were the same as for the graft within 0.5-mm increments (Figure 1).

Radiological Evaluation

The postoperative radiological examinations were performed using the MultiDiagnost Eleva 3D-RX system (Philips Medical Systems) with an optional application designed for measurement of lower limb geometry. A run of radiographic images used for leg measurements was obtained using the normal acquisition protocol with the patient in the standing position with their back against the tabletop and full body weight on the leg displayed. The image dataset was transferred to a ViewForum R6.3 workstation (Philips Medical Systems) with the “Leg Measurement Package” installed. The algorithm for leg composite image reconstruction is specifically designed for a series of images of the lower limb skeleton taking specific features of these images into account. The package reconstructs a single composite image from a run of radiographic images made for this purpose. The composite image was used for length of femur and tibia and angle measurements around the knee (Figure 2). The angle and length measurements are performed by defining specific anatomic landmarks in the composite image. Thereafter, the software program automatically calculates the measurements.

All radiological measurements were performed by a senior radiologist (L.R.). There was no previous relevant validating of the MultiDiagnost Eleva system, so we performed an inter- and intraobserver study on 10 radiographs from the study patients. Intra- and interobserver variation were assessed by interclass correlation analysis. Three individual observers (P.F., M.L., T.N.) measured all radiological parameters from 10 study patients for interobserver variation analysis. Measurements were repeated after 2 weeks for intraobserver variation analysis. Measurement variations were calculated by interclass correlation coefficient (ICC) statistics for both length and angulation parameters.
Interobserver ICC for length and angular measurements was 1.00 for both. The intraobserver ICC for length and angular measurements was 0.98 and 0.95, respectively. We found these precision data satisfactory for our radiological analysis. We defined a leg length discrepancy of more than 10 mm as clinically relevant.

Statistical Analysis

Radiographic outcome was analyzed using the Student paired \( t \) test and the chi-square test. The patient-reported outcome scores and the KT-1000 arthrometer measurements comparing preoperative with final follow-up were evaluated using the Student \( t \) test. Analyses were made comparing age groups and sex. \( P < .05 \) was considered statistically significant. Tests were 1-sided and were not adjusted for multiple comparisons.

RESULTS

Clinical Outcome

The effect of ACLR on KOOS and Tegner scores is outlined in Table 1. All KOOS subscores, in particular the Sport and the Quality of Life (QoL) subscores, improved significantly. This finding is supported by a significant improvement in activity level as measured with Tegner score improvement from 2.8 (boys, 5.0; girls, 2.2) to 6.1 (boys, 7.0; girls, 6.2). Postoperative Tegner and KOOS scores were significantly lower among girls compared with boys. KT-1000 arthrometer measurements improved from 5.2 mm preoperatively to 1.6 mm at follow-up. There was 1 patient with a more than 4-mm side-to-side laxity.

Radiographic Outcome

We found a mean femoral shortening of 3.5 mm \( (P < .01) \) for the operated leg. The tibial length was not significantly

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**TABLE 1**

Pre- and Postoperative Subjective and Objective Knee Scores\(^a\)

| KOOS subscore                  | Preoperative | Follow-up  |
|-------------------------------|--------------|------------|
| Symptoms                      | 69.1 ± 14.6  | 76.8 ± 15.1|
| Pain                          | 67.2 ± 19.3  | 85.7 ± 14.4|
| Activities of daily living    | 73.8 ± 23.0  | 91.0 ± 11.7|
| Sports/recreation              | 38.7 ± 29.1  | 69.2 ± 26.8|
| Quality of life               | 35.4 ± 19.6  | 67.9 ± 23.9|
| Tegner score                  | 2.8 ± 2.7    | 6.1 ± 2.0  |
| KT-1000 arthrometer measurement, mm | 5.2 ± 2.9   | 1.6 ± 1.6  |

\(^a\)Data are reported as mean ± SD. Significant improvement was seen on all measures from preoperative to final follow-up \( (P < .05) \).

KOOS, Knee injury and Osteoarthritis Outcome Score.
TABLE 2
Radiological Length and Angulation Measures of Operated Compared With Nonoperated Leg\textsuperscript{a}

|                | Operated Leg | Nonoperated Leg | P Value |
|----------------|--------------|-----------------|---------|
| Leg length, mm | 816 ± 58     | 818 ± 57        | <.01\textsuperscript{b} |
| Femoral length, mm | 399 ± 28    | 402 ± 28        | <.01\textsuperscript{b} |
| Tibial length, mm | 373 ± 27     | 374 ± 28        | .11     |
| Femoral-tibial mechanical axis, deg | 0.9 ± 2.8 | 0.3 ± 2.3 | .09 |
| Femoral transcondylar tangent, deg | 100.1 ± 2.1 | 98.5 ± 1.7 | <.01\textsuperscript{b} |
| Tibial transcondylar tangent, deg | 87.2 ± 2.6 | 88.2 ± 2.2 | <.01\textsuperscript{b} |

\textsuperscript{a}Data are reported as mean ± SD.
\textsuperscript{b}Significant difference between operated and nonoperated leg (P < .05, paired Student t test).

TABLE 3
Leg Length Discrepancy Between Operated and Nonoperated Leg\textsuperscript{a}

|                | Nonoperated Leg | Operated Leg | P Value |
|----------------|-----------------|--------------|---------|
| Leg length discrepancy |               |              |         |
| ≥10 mm         | 1               | 8            |         |
| <10 mm         | 32              | 25           | .01\textsuperscript{b} |

\textsuperscript{a}n, number of patients with a difference in leg length of ≥10 mm. Leg length discrepancy was measured as mechanical axis length.
\textsuperscript{b}Chi-square test used for comparison.

Our study demonstrates that transphyseal-placed soft tissue grafts without intraosseous-placed fixation implants affect both length and angular growth around the knee. This is in contrast to earlier publications, where no growth disturbances were seen.\textsuperscript{8,16,17,22,23} This could be explained by different diagnostic measures, as several previous studies have based their evaluation of limb alignment on clinical measurements, plain radiograph evaluation, small patient groups, or greater age of the studied patients. However, Koch et al\textsuperscript{20} found growth disturbances after pediatric ACLR in 2 of 12 patients. In contrast to our results, they found an overgrowth in the operated limb. In a recent study by Calvo et al,\textsuperscript{6} no radiological changes were seen in 27 patients 10 years postoperatively. The mean patient age in this group was greater (13 years) than in our patient group, which could explain why no changes could be registered. Furthermore, a different diagnostic tool used in our study with computerized measurements of length and angle measurement of legs could explain the difference between the studies.

Comparing patients younger than 12 years at the time of surgery with patients aged 12 to 14 years, there was no significant difference in leg length inequality or femoral-tibial axis (Table 4). Similarly, when patients with graft sizes 7 mm or less (n = 14) were compared with patients with graft diameters greater than 7 mm (n = 19), no significant differences were found.

In 27 of 33 patients (82%) (P < .001), the anatomic femoral axis of the operated leg was found to be 2° or more valgus compared with the nonoperated leg. Tibial transcondylar angle changed into significant varus angulation (P < .01). The overall femoral-tibial anatomic axes were not significantly different comparing the legs (Table 5).
because of decreased growth rate.\textsuperscript{2,7} This could not be confirmed in our study.

We did not find graft size to be of importance for later growth disturbances. This could be explained by a possible correlation between the diameter of the graft and knee size.

In our study, the distal femur was affected more than the proximal tibia after ACLR. This is likely explained by the fact that the contribution of the total limb growth is 37\% for the distal femur and only 28\% for the proximal tibial physis.\textsuperscript{33} We saw a significant number of femoral valgus deformities, which may be caused by restricted growth in the lateral part of the epiphyseal plate induced by drilling or graft placement. There were also a significant number of tibial varus malformations in the operated leg, probably due to the medially placed tunnel. This growth arresting phenomenon was demonstrated in an animal study in 1950, when Haas\textsuperscript{14} found that placement of pins across the epiphyseal plate caused restriction of bone growth. The same growth arrest has been seen when using epiphyseal-placed biodegradable implants.\textsuperscript{27}

The significant femoral valgus deformity was partly counterbalanced by the less significant tibial varus deformity, leading to a nonsignificant increased number of patients with valgus of the femur-tibia axis (Figure 3). The significance of these changes in the biomechanics around the knee is not clear and has not yet been described in the literature. Patients in our study responded well to surgical reconstruction based on functional and subjective outcome scores. One can speculate whether patients with hanged knee kinematics are more prone to later knee injury or overuse injuries. This needs further study.

The patients included in this study underwent surgery several years ago. Therefore, ACLR was performed using the transtibial technique, which was standard at that time. Within the past few years, use of the anteromedial portal for femoral drilling has been advocated to place a more anatomic femoral tunnel.\textsuperscript{28} This in turn will lead to a more oblique femoral tunnel, resulting in a more peripherally located drill tunnel through the distal femoral epiphysis. In animal studies, peripherally placed tunnels have shown to cause more growth disturbance compared with more centrally placed tunnels.\textsuperscript{32} Furthermore, a more oblique course of the femoral tunnel compared with the steeper tunnel will lead to a more ovular and thereby larger effect on the physis, which could compromise growth even more. Consequently, one could fear that the growth disturbances seen in our study would be increased in skeletally immature patients operated on using a more anatomic reconstruction.\textsuperscript{18} This calls for further study.

Epiphyseal-sparing ACLR techniques have now been developed and gained interest. There are many different techniques described.\textsuperscript{1,4,10,21} These techniques should theoretically reduce the growth disturbances seen in this study. In a meta-analysis, Frosch et al\textsuperscript{9} reported a greater incidence of growth disturbances in studies with physeal-sparing techniques compared with studies where transphyseal reconstructions were used.

Limitations

In this study, we only analyzed malformation registered as leg length discrepancy and varus-valgus direction. We did not measure any growth disturbance in the sagittal plane. The tunnels, as seen in the sagittal plane, are also placed asymmetrically in the anterior part of the tibial growth plate and the posterior part of the femoral growth plate. Therefore, one could expect an impact on growth in the sagittal plane.

In theory, one cannot exclude the impact of the trauma itself. Posttraumatic MRI often shows bone bruise changes around the knee extend up to the epiphysis. We did not obtain preoperative long-leg films so it is unclear whether the discrepancies we saw occurred prior to surgery. The malformation around the knee seen in this study could have been influenced by the initial trauma. Studies of ACL patients who did not receive surgery are needed to clarify this issue.

Five of the original 39 patients did not respond to the invitation to participate in this study (13\%). This is concerning, as the results of the nonresponding patients could have changed those of this study. The drilling angle with respect to the epiphyseal line was not documented in this study. The drilling angle could differ among patients and thereby the area of the affected growth plate. This could result in different growth disturbances among patients.
CONCLUSION

This study shows that transphyseal ACLR in children results in minor length growth disturbances in 24% of patients. The surgically induced distal femoral valgus angulation is counterbalanced by a proximal tibial varus angulation. Age was not found to be associated with growth disturbance after surgery. Transphyseal ACLR has satisfactory clinical outcomes, with good subjective outcomes, function level, and knee stability despite the growth changes induced by transphyseal drilling.

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