Mid-term results of transphyseal anterior cruciate ligament reconstruction in children and adolescents

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1. Introduction

The prevalence of anterior cruciate ligament (ACL) ruptures in children and adolescents is unknown. They are estimated to occur primarily during contact sport activities [1–9]. Among soccer players aged 5 to 18 in the United States, ACL ruptures constitute 30.8% of all symptomatic knee injuries and 6.7% of all injuries [10].

Besides isolated ACL ruptures, additional injuries such as damage to collateral ligaments and associated meniscal tears may occur. The prevalence of such additional injuries is mostly double-digit, ranging up to 100% depending on the study [11–16]. Both conservative and operative treatment options are available for the paediatric population. However, because this patient group is characterized by the presence of an open physis, ACL ruptures provoke some controversy as to optimal treatment strategy, conservative or operative.

This controversy is further exacerbated by the scarcity of data regarding long-term sequellae [17]. Only a few studies have so far examined the long-term results of transphyseal ACL reconstruction in children and adolescents [11,12,14,18–22].

Conservative treatment can be difficult because of noncompliance and may cause secondary meniscal tears due to shearing forces [11,18,19,23]. Moreover, a high rate of degenerative changes may occur, as observed by Mizuta et al. [24] after a mean follow-up of 51 months.

As in adults, a number of surgical techniques are available for repair of ACL ruptures in children and adolescents, including ligament repair, nonanatomic extra-articular tenodesis procedures, physeal-sparing reconstruction and transphyseal fixation using hamstring, bone–patella–bone, quadriceps and fascia lata autografts [17,25–27]. However, a major concern in the treatment of these injuries in children is the integrity of the growth plate. Injury to the growth plate can cause limb malalignment and limb length discrepancy, including both growth arrest and overgrowth [28–30]. Since 65% of the leg length leads from the distal femur and the
proximal tibia, transphyseal reconstruction techniques are regarded with concern in patients with open growth plates [31]. In a recent meta-analysis, transphyseal ACL reconstruction is reported to offer a lower risk of growth disturbances compared to physeal-sparing techniques. Growth disturbances leading to differences in leg length and axis deviation were seen after a median follow-up of 40 months in approximately 1.8% of cases treated operatively with suture repair or graft reconstruction. The mean risk of rerupture was 4.8% [32].

In the present study, we report a series of 15 children and adolescents treated with transphyseal autologous quadriceps tendon graft reconstruction for intraartiglamental ACL ruptures, with a mean follow-up of 4.1 years. The objective is to assess quality of life, function and risk for posttraumatic deformation after transphyseal ACL reconstruction.

2. Patients and methods

Fifteen children and adolescents with open growth plates (12 boys, 3 girls) and normal contralateral knees underwent transphyseal autologous quadriceps tendon graft reconstruction of the ACL to treat traumatic ACL rupture. All children were classified according to Tanner’s criteria [33]. Radiological evaluation with anteroposterior and lateral x-rays revealed clearly open growth plates in both the distal femur and proximal tibia at the time of surgery. Nine of the patients suffered from a right ACL rupture, six from a left ACL rupture. Only six patients had isolated ACL ruptures, the other nine also had meniscal tears. Two meniscus had to be resected, seven meniscus underwent suture repair (all by inside technique using anchors). Patient details are listed in Table 1.

In all 15 patients, the ACL was replaced by a quadriceps tendon graft. Briefly, the middle part (7–9 mm × 8.0 cm) of the autologous unilateral quadriceps tendon was harvested without any bone plug through a small ventral incision under general anesthesia. A transphyseal tunnel. tunnel like that used in adults was then drilled at the centre of the native ACL footprint followed by a femoral tunnel for which the knee was flexed to at least 100°. Both tunnels were drilled transtibially using an Arthrex aiming device (Arthrex Medizinische Instrumente GmbH, Germany). Drilling diameters were determined by the size of the one-stranded quadriceps tendon graft. Each end of the graft was transfixed by two FiberWire sutures (Arthrex Medizinische Instrumente GmbH, Germany). The graft was positioned with the necessary preload and both ends were fixed extra-articularly by 3.5 mm screws with peek washer (Synthes GmbH, Germany) (Figs 1 and 2). The femoral end of the graft was fixed first and then the knee was placed at 30° of flexion for tensioning and fixation of the tibial end of the graft. The total intraosseous graft length was 25 mm for the femur and 25–30 mm for the tibia. No patient required subsequent surgery.

Postoperative care followed a standardized rehabilitation protocol. This included optional initial immobilization followed by a functional knee brace for the first six weeks, a CPM splint (Kinetec S.A., France), physiotherapy or functional rehabilitation [34]. The timing of the postoperative treatment depended on the course and the level of function of the affected knee.

To test for growth disturbances, leg length discrepancy and extremity alignment were measured with ortheradiograms. To evaluate the clinical results of transphyseal reconstruction, each of the 15 patients was asked to complete the SF–12 questionnaire, a 12-item downsized subset of the SF-36 health survey [35,36]. Two components were assessed, the physical health component summary (SF-12 PCS) and the mental health component summary (SF-12 MCS) [37]. All patients underwent physical examinations, including x-ray. To facilitate accuracy of comparison, results of the physical examination and x-rays were converted to the IKDC 2000 Knee Examination Form [38]. This instrument evaluates the following aspects: knee effusion, passive motion deficits, ligament stability, compartment findings, harvest side pathology, x-ray findings and a functional test. Results are graded from A (normal) to D (severely abnormal), each patient’s worst grade determining that patient’s final assessment [39]. The Lysholm–Gillquist score was used to register symptoms of knee instability, which besides pain has the greatest impact on daily living [40]. Leg length and extremity alignment were determined by means of ortheradiograms.

This study was performed according to the guidelines of the Ethics Committee of the University of Bern, Switzerland, and informed consent was obtained from all 15 patients.

3. Results

The mean age of the study group was 12.8 ± 2.6 years, range 6.2–15.8 years. Six children were evaluated to be at Tanner stage 2, 7 at Tanner stage 3 and 2 at Tanner stage 4 of physical development at the time of surgery (Table 1). Average graft diameter was 8.2 ± 0.7 mm while average anteroposterior laxity measured with the KT-1000 was 5.9 ± 1.2 mm. Average follow-up was 4.1 ± 2.2 years (range 1.9–9.7 years). None of the patients experienced a rerupture. Functional tests were normal in 10 patients.

4. IKDC 2000, Lysholm–Gillquist score, SF-12 (PCS + MCS)

On clinical examination, applying the IKDC 2000, one knee was assessed as IKDC grade A, thirteen as IKDC grade B and only two as IKDC grade C due to harvest side pathology and ligament instability. Overall, 13 patients had either grade A or B scores at the final follow-up. The mean Lysholm–Gillquist score was 94.0 (range 68–100). The

### Table 1

<table>
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<tr>
<th>Patient</th>
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<th>Age at follow-up (years)</th>
<th>Years since surgery</th>
<th>Side of injury</th>
<th>Additional injury</th>
<th>KT 1000 Post op (mm)</th>
<th>KT 1000 healthy (mm)</th>
<th>Graft Diameter (mm)</th>
<th>SF-12 PCS</th>
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mean SF-12 PCS was 54.0 ± 4.8 (range 37.3–57.6), and the mean SF-12
MCS was 59.1 ± 3.7 (range 51.8–63.4).

5. Radiological evaluation

Orthoradiograms demonstrated normal lower extremity alignment
in 14 children (Fig. 3); one child developed a valgus knee. All patients
had a normal gait pattern. Radiologically measured leg length varied
slightly between injured and healthy legs, the previously ruptured
ACL leg being 98% to 101% as long as the healthy leg. The absolute
range was from −20 mm to +9 mm, with 13/15 children ranging
between −10 mm to +9 mm compared to the healthy side. Two
children did not show any leg length discrepancy. The mean leg length
of the affected side compared to the healthy side was −2.9 ± 8.6 mm
(99.7 ± 0.9%). Results are summarized in Table 1. X-ray analysis at the
last follow-up demonstrated no signs of osteoarthritis.

6. Discussion

The transphyseal reconstruction of the anterior cruciate ligament in
im mature patients demonstrated good radiological and functional mid-
term results. Only one child with mild valgus deformity was detected at
the final follow-up.

Among the available operative strategies are ligament repair,
nonanatomic extra-articular tenodesis procedures, physeal-sparing
reconstruction and transphyseal techniques [17,25–27,41]. The last
ones are burdened, however, by concerns over growth disturbances.
Although recent literature data support their safety, specific technical
modifications should be followed to avoid damaging the physis. These
modifications refer to the size, type and tensioning of applied grafts
[42–44], the technique of drilling [42,45], the localization, the diameter
and the slope of the tunnels crossing the physis [42,43,46,47].

In the present study, all patients were operated on using a transtibial
technique. Kocher et al. [29] report that growth disturbances predomi-
nantly occur at the femoral physis. Although the femoral tunnel can
now be safely drilled through the anteromedial portal, at that time we
believed that a transtibial technique would provide adequate stability
as well as a more vertical and centrally located femoral tunnel, thus
causing less damage at the growth plate [27]. For all patients, a quadri-
ceps tendon autograft without any bone plug was applied. Quadriceps
tendon has been widely applied in the ACL reconstruction of skeletally
immature patients. The graft provides strong biomechanical character-
istics, comparable to a patella tendon autograft [48–50]. Additionally,
preserving the hamstrings at this age is important not only for their
function as knee rotators but also for future reconstructions [51]. Since
some concerns have been raised on the use of bone plugs in children’s
ACL reconstruction, a pure tendinous graft was applied maintaining
the biomechanical characteristics and avoiding the donor site morbidity
of a bone plug [27,52].

Leg length discrepancies greater than 20 mm are reported to impact
on patients’ gait pattern [53–58]. In this study, the absolute leg length
varied between −9 mm and +9 mm compared to the healthy limb;
the range in 13 children was −10 mm to +9 mm. None of our patients
presented with an abnormal gait pattern at follow-up examination and

Fig. 1. AP x-ray of a patient with an open physis, demonstrating placement and fixation of
the quadriceps tendon graft.

Fig. 2. Lateral x-ray of the same patient, demonstrating placement and fixation of the
quadriceps tendon graft.
none had complaints concerning leg length. The leg length discrepancies noted here accord with those reported by other study groups [13,20]. Only one of our patients demonstrated a growth disturbance. He developed a progressive valgus deformity of the distal femur due to harmed posterolateral epiphyseal plate leading to an early localized growth stop (Fig. 4). Radiograms revealed that the drill hole was not centrally located and was crossing the growth plate obliquely, affecting a larger cross-sectional area. However, only a few authors in the past have reported on growth disturbances [57–59].

While all of our patients had a normal gait pattern and were able to stand on the repaired leg alone without qualm, only one knee could be considered normal (grade A) according to IKDC 2000. Instead, 13 knees were graded as nearly normal, two as abnormal, one due to ligament instability (reflected in a Lysholm–Gillquist score of 68) and the other due to abnormal harvest side pathology (abnormal IKDC 2000 score). In contrast, Aichroth et al. [12] identified 52% of repaired knees as IKDC 2000 grade A (normal) and 20% as IKDC 2000 grade B, a higher rate of unobjectionable outcomes. In a meta-analysis on ACL ruptures treated by suture repair of graft, Frosch et al. [32] described a normal or nearly normal knee in 84.2% of patients. Conspicuously, only one of the knees in the present study had a normal ligament finding; the mean Lysholm–Gillquist score for all 15 knees was 94 ± 10.0 (range 68–100). This reflects the presence of at least some laxity, either objective or subjective, in the majority of our young patients. Children exhibit a higher physiological knee laxity than adults. The study of Falciglia et al. shows an inverse relationship
between Tanner stage and KT 2000 laxity measures. The authors reported a progressive decrease of sagittal laxity at the onset of Tanner stage 2. Laxity was significantly greater in adolescents, with signs of joint physiologic hyperflexibility [60]. In a recent study on skeletally immature patients undergoing ACL reconstruction, Streich et al. reported a median Lysholm–Gillquist score of 93 points [20]. Frosh et al. [32] found a mean Lysholm–Gillquist score of 96.3. Accordingly, our results tally well with previously published data. Although rerupture is reported to occur in approximately 4.2% of patients after ACL reconstruction [32], this complication was not observed in our patients. This finding may be due to the limited size of our cohort and thus of only vague validity.

Osteoarthritis is known to occur occasionally 10 to 20 years after ACL rupture, the prevalence varying widely depending on the study [61,62]. At the time of the last follow-up, none of our 15 patients exhibited radiological signs of osteoarthritis.

Injuries like ACL rupture can negatively influence quality of life due to, e.g., a persistent feeling of knee instability. We measured the health-related quality of life of our young patients applying the SF-12 PCS and SF-12 MCS scales, which are standardized to population norms and approved in the United States and many European countries. The mean value of the questionnaires is set at 50 and the standard deviation is 10 [37]. The data of this study demonstrate that subjective health-related quality of life after transphyseal ACL reconstruction thus resembled that of the normal population.

Despite the IKDC 2000 results, none of our patients complained of any discomfort. Sequelae such as secondary meniscal tears or significant growth disturbances were not observed. The follow-up, however, was less than 10 years, not decades. Future studies will have to analyze whether secondary maladies occur in middle or old age, after transphyseal reconstruction while the growth plate is still open.

Despite our efforts to ensure the reliability of this study, it does have certain limitations. The number of patients of this study group is limited. Moreover, no baseline pre-operative data could be retrieved to compare with the post-operative findings.

7. Conclusions

The present findings show that the transphyseal reconstruction of the anterior cruciate ligament shows satisfactory mid-term results in the immature patient.

8. Conflict of interest statement

All authors confirm that there are no conflicts of interest.

References


