PHYSEAL SPARING RECONSTRUCTION OF THE ANTERIOR CRUCIATE LIGAMENT IN SKELETALLY IMMATURE PREPUBESCENT CHILDREN AND ADOLESCENTS

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Background: The management of anterior cruciate ligament injuries in skeletally immature patients is controversial. Conventional adult reconstruction techniques risk potential iatrogenic growth disturbance due to physeal damage. The purpose of this study was to evaluate the results of a physeal sparing, combined intra-articular and extra-articular reconstruction technique in prepubescent skeletally immature children.

Methods: Between 1980 and 2002, forty-four skeletally immature prepubescent children and adolescents who were in Tanner stage 1 or 2 (with a mean chronological age of 10.3 years) underwent physeal sparing, combined intra-articular and extra-articular reconstruction of the anterior cruciate ligament with use of an autogenous iliotibial band graft. Twenty-seven patients had additional meniscal surgery. Functional outcome, graft survival, radiographic outcome, and growth disturbance were evaluated at a mean of 5.3 years after surgery.

Results: Two patients underwent a revision reconstruction for graft failure at 4.7 and 8.3 years postoperatively. In the remaining forty-two patients, the mean International Knee Documentation Committee knee score (and standard deviation) was 96.7 ± 6.0 points, and the mean Lysholm knee score was 95.7 ± 6.7 points. The results of the Lachman examination for anterior cruciate ligament integrity was normal for twenty-three patients, nearly normal for eighteen patients, and abnormal for one patient. The results of the pivot-shift examination were normal for thirty-one patients and nearly normal for eleven patients. Four of the twenty-three patients who underwent concurrent meniscal repair had a repeat arthroscopic meniscal repair or partial meniscectomy. The mean growth in total height from the time of surgery to the final follow-up evaluation was 21.5 cm. No patient had an angular deformity measured radiographically or a discrepancy in the length of the lower extremities measured clinically.

Conclusions: Physeal sparing, combined intra-articular and extra-articular reconstruction of the anterior cruciate ligament with use of an autogenous iliotibial band graft in skeletally immature prepubescent children and adolescents provides excellent functional outcome with a low revision rate and a minimal risk of growth disturbance.

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

Intrarabular injuries of the anterior cruciate ligament in children and adolescents were once thought to be rare, with avulsion fractures of the tibial eminence considered to be the pediatric equivalent of an anterior cruciate ligament injury. However, intrarabular injuries of the anterior cruciate ligament in children and adolescents are being seen with greater frequency and have received increased attention. In clinical series of pediatric patients with acute traumatic hemarthrosis of the knee, anterior cruciate ligament injury has been reported to occur in 10% to 65% of such patients.

Controversy exists with regard to the management of anterior cruciate ligament injuries in patients with open physes. Nonoperative management of complete tears generally has a poor prognosis, with instability leading to further meniscal and chondral injury. Conventional surgical reconstruction tec-
niques risk iatrogenic growth disturbance because of physeal damage to the distal femoral physis or the proximal tibial physis, or both. Surgical techniques to address anterior cruciate ligament insufficiency in skeletally immature patients include primary repair, extra-articular tenodesis, transphyseal reconstruction, partial transphyseal reconstruction, and physeal sparing reconstruction.

The management of these injuries in prepubescent children and adolescents is particularly vexing, given the poor prognosis with nonoperative management, the substantial amount of growth remaining, and the consequences of potential growth disturbance. The purpose of this study was to evaluate the results of a physeal sparing, combined intra-articular and extra-articular reconstruction technique in skeletally immature prepubescent children and adolescents. Our hypothesis was that this technique would yield a good functional outcome with minimal risk of growth disturbance.

Materials and Methods

Institutional review board approval and informed patient consent were obtained for this study. The study design is a retrospective case series. Patients returned for follow-up outcome analysis.

Between 1980 and 2002, fifty skeletally immature prepubescent patients underwent physeal sparing, combined intra-articular and extra-articular reconstruction of the anterior cruciate ligament with use of an autogenous iliotibial band graft performed by two surgeons (M.S.K. and L.J.M.). Six patients were unable to be located for follow-up, but forty-four (88%) had complete follow-up. Thus, the study population included forty-four patients (forty-four knees) who had reconstruction of the anterior cruciate ligament. The six patients lost to follow-up were similar to the study population in terms of age, gender, mechanism of injury, and associated injuries.

The study population included twenty-eight boys (64%) and sixteen girls (36%). The mean chronological age at the time of surgery was 10.3 years (range, 6.0 to 14.0 years). According to age-group, three patients were three to six years old, twenty-four were seven to ten years old, and seventeen were eleven to fourteen years old. A 3.6-year-old boy underwent anterior cruciate ligament reconstruction because of symptomatic knee instability due to congenital absence of the anterior cruciate ligament associated with proximal femoral focal deficiency. Skeletal age was determined by pediatric radiologists on an anteroposterior radiograph of the left hand and wrist with use of the atlas of Greulich and Pyle. Despite the potential increased variance in the determination of skeletal age in young children, we believed that it was necessary to assess skeletal age to allow for comparisons with other studies. The mean skeletal age at the time of surgery was 10.1 years (range, 5.3 to 14.0 years). Biological age was determined according to the method of Tanner and Whitehouse (see Appendix). The Tanner stage was assessed by the patients and families on a questionnaire completed preoperatively and was confirmed by the surgeon at the time of surgery after the patient was placed under general anesthesia. Thirty-one patients were in Tanner stage 1, and thirteen patients were in Tanner stage 2. No patient in this study was in Tanner stage 3 or 4.

The mechanisms of injury included accidents that occurred during soccer (eight patients), football (seven), basketball (five), gymnastics (four), bicycling (four), free play (three), jumping on a trampoline (three), and during a dance, wrestling, lacrosse, field hockey, baseball, martial arts, and a fall from stairs (one patient each). The mean time-interval from the injury to surgery was 11.1 months (range, three to forty months). Five patients had undergone arthroscopic surgery prior to anterior cruciate ligament reconstruction for a partial lateral meniscectomy (two patients), lateral meniscal repair (one patient), and diagnostic arthroscopy (two patients). Three patients did not have a specific injury, but they had congenital absence of the anterior cruciate ligament associated with proximal femoral focal deficiency (two patients) or with fibular hemimelia (one patient). Two of those patients underwent anterior cruciate ligament reconstruction after limb-lengthening procedures, and one patient underwent reconstruction prior to limb-lengthening.

Patients were managed surgically if they had an associated meniscal injury requiring repair or if they had had failure of prior nonreconstructive management consisting of rehabilitation and functional bracing with recurrent episodes of instability and limited function. The duration of nonoperative management prior to reconstruction and the compliance with nonoperative management were not reliably recorded. Twenty-seven patients had an associated meniscal injury at the time of anterior cruciate ligament reconstruction involving the lateral meniscus (twenty-three patients) or the medial meniscus (four patients). Meniscal injury was treated with meniscal repair in twenty-three patients and with partial meniscectomy in four patients.

Functional outcome was assessed with use of questionnaires completed by the patients to determine the International Knee Documentation Committee (IKDC) subjective knee score and the Lysholm knee score. The IKDC subjective knee form is a validated region-specific outcome measure that consists of eighteen questions in the domains of symptoms, function during activities of daily living and sports, current function of the knee, and participation in work and/or sports. An overall score of 0 to 100 points is calculated. The Lysholm knee scale is a condition-specific outcome measure that contains eight domains: limp, locking, pain, stair-climbing, support, instability, swelling, and squatting. An overall score of 0 to 100 points is calculated, with 95 to 100 points indicating an excellent result; 84 to 94 points, a good result; 65 to 83 points, a fair result; and <65 points, a poor result. The objective examination included a comprehensive physical evaluation of the knee, with stability assessed with use of the Lachman and pivot-shift examinations as graded according to the IKDC criteria by two of the authors (M.S.K. and L.J.M.). Radiographic examination of the knee included weight-bearing anteroposterior, notch, lateral, and Merchant radiographs. Radiographic evidence of a growth disturbance
was evaluated by a single observer and was assessed according to the integrity of the physes and the symmetry of the Harris lines. A radiographically important angular growth disturbance was considered to be any anatomic varus and/or valgus change of >5° from the findings on the preoperative radio-

graphs. Clinically, growth disturbance was assessed with use of blocks to level the top of the iliac crests with the patient standing with the knees extended and with measurement of the true lower-extremity length from the anterior superior iliac spine to the medial malleolus. A clinically important
limb-length discrepancy was considered to be >2 cm, as measured with either method.

**Surgical Technique**
The surgical technique consists of arthroscopically assisted, physeal sparing, combined intra-articular and extra-articular reconstruction of the anterior cruciate ligament with use of an autogenous iliotibial band graft. This procedure is a modification of the combined intra-articular and extra-articular reconstruction described by MacIntosh and Darby\(^4\). Modifications include application in skeletally immature patients, arthroscopic assistance, graft fixation, and accelerated rehabilitation.

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*Fig. 1-C* The iliotibial band graft is brought through the knee with use of a full-length clamp placed from the anteromedial portal through the over-the-top position into the lateral incision.

*Fig. 1-D* The graft is then brought through the over-the-top position. *Fig. 1-E* A clamp is placed from the proximal medial incision in the leg under the intermeniscal ligament, and a groove is made in the anteromedial tibial epiphysis with use of a rasp.
The graft is brought through the knee in the over-the-top position and under the intermeniscal ligament.

The procedure is performed with the patient under general anesthesia as an overnight observation procedure. The child is positioned supine on the operating table with a pneumatic tourniquet about the proximal aspect of the thigh, which is used routinely. With the patient under anesthesia, he or she is examined to confirm anterior cruciate ligament insufficiency. An incision of approximately 6 cm is made obliquely from the lateral joint line to the superior border of the iliotibial band (Fig. 1-A). Proximally, the iliotibial band is separated from the subcutaneous tissue with use of a periosteal elevator under the skin of the lateral part of the thigh. The anterior and posterior borders of the iliotibial band are incised, and the incisions are carried proximally under the skin with use of a curved meniscotome. The iliotibial band is detached proximally under the skin with use of a curved meniscotome or an open tendon stripper. The iliotibial band is left attached distally at Gerdy's tubercle. Dissection is performed distally to separate the iliotibial band from the joint capsule and from the lateral patellar retinaculum (Fig. 1-B). The free proximal end of the iliotibial band is then tubularized with use of a whipstitch with a number-5 Ethibond suture (Ethicon, Johnson and Johnson, Somerville, New Jersey). Arthroscopy of the knee is then performed through standard anterolateral and anteromedial portals. Management of meniscal injury or chondral injury is performed, if present. The anterior cruciate ligament remnant is excised. The over-the-top position on the femur and the over-the-front position under the intermeniscal ligament are identified. A minimal notchplasty is performed to avoid iatrogenic injury to the perichondrial ring of the distal femoral physis, which is in close proximity to the over-the-top position. The free end of the iliotibial band graft is brought through the over-the-top position with use of a full-length clamp (Figs. 1-C and 1-D) or a two-incision rear-entry guide and out the anteromedial portal. A second incision of approximately 4.5 cm is made over the proximal medial aspect of the
tibia in the region of the pes anserinus. Dissection is carried through the subcutaneous tissue to the periosteum. A curved clamp is placed from this incision into the joint under the intermeniscal ligament (Fig. 1-E). A small groove is made in the anteromedial aspect of the proximal tibial epiphysial under the intermeniscal ligament with use of a curved rat-tail rasp to bring the tibial graft placement more posterior. The free end of the graft is then brought through the joint (Fig. 1-F), under the intermeniscal ligament in the anteromedial epiphyseal groove, and out the medial tibial incision (Fig. 1-G). The graft is fixed on the femoral side through the lateral incision with the knee at 90° of flexion and 15° of external rotation with use of mattress sutures to the lateral femoral condyle at the insertion of the lateral intermuscular septum to effect an extra- articular reconstruction. The tibial side is then fixed through the medial incision with the knee flexed 20° and tension applied to the graft. A periosteal incision is made distal to the proximal tibial physis as checked with fluoroscopic imaging. A trough is made in the proximal medial tibial metaphyseal cortex, and the graft is sutured to the periosteum at the rough margins with mattress sutures (Fig. 1-H).

Postoperatively, the patient is maintained with touch- down weight-bearing for six weeks. Immediate mobilization is performed, from 0° to 90° for the first two weeks, followed by progression to a full range of motion. Continuous passive mo- tion from 0° to 90° is used for the first two weeks postoperatively to initiate motion and overcome the anxiety associated with postoperative movement in these young children. A protective hinged knee brace is used for six weeks postoperatively with motion limits of 0° to 90° for the first two weeks. Progressive rehabilitation consists of range-of-motion exercises, patellar mobilization, electrical stimulation, pool therapy (if available), proprioception exercises, and closed-chain strengthening exercises during the first three months postoperatively followed by straight-line jogging, plyometric exercises, sport cord exercises, and sport-specific exercises. Return to full activity, including sports that involve cutting, is usually allowed at six months postoperatively. A custom-made functional knee brace is used routinely during cutting and pivoting activities for the first two years after the return to sports. Compliance with bracing was not formally assessed.

Results

The mean postoperative duration of follow-up was 5.3 years (range, 2.0 to 15.1 years). The mean duration of the operation was 101 minutes (range, sixty to 140 minutes), and the mean tourniquet time was seventy-two minutes (range, forty- three to 109 minutes). There were no surgical complications, such as infection, failure of graft harvest, or arthrofibrosis. Two patients (4.9%) underwent a revision anterior cruciate ligament reconstruction for graft failure at 4.7 and 8.3 years postoperatively. Both patients had a re-injury and were participating in cutting and pivoting sports. Both had midsubstance rupture of the iliotibial band graft. The grafts appeared well incorporated at the femoral and tibial insertions. Four patients who underwent concurrent meniscal repair during anterior cruciate ligament reconstruction had repeat arthroscopic meniscal repair or partial meniscectomy.

For the remaining forty-two patients without revision anterior cruciate ligament repair, the mean IKDC subjective knee score (and standard deviation) was 96.7 ± 6.0 points (range, 88.5 to 100 points) and the mean Lysholm knee score was 95.7 ± 6.7 points (range, 74 to 100 points). All patients, other than the three patients with congenital limb deficiencies, had returned to cutting or pivoting sports. According to the IKDC criteria, the findings of the Lachman examination were normal for twenty-three patients, nearly normal for eighteen patients, and abnormal for one patient. The results of the pivot-shift examination were normal for thirty-one patients and nearly normal for eleven patients. The mean growth in total height from the time of surgery to the final follow-up examination was 21.5 cm (range, 9.5 to 118.5 cm). It should be noted that total height is a combination of trunk and lower extremity lengths. No patient had a substantial angular deformity measured radiographically. No patient had a substantial limb-length discrepancy measured clinically.

Discussion

There is controversy regarding the management of anterior cruciate ligament injuries in patients with open physes. Nonoperative management, consisting of rehabilitation, brac-
ing, and activity restriction, is often recommended in order to
temporize for later conventional reconstruction near
skeletal maturity. Nonoperative management of partial tears
may be successful in patients with a lower-grade partial tear,
in younger children, and in patients with a tear that predomi-
nantly involves the anteromedial bundle. However, nonopera-
tive management of complete tears generally has a poor
prognosis, with recurrent instability leading to further men-
sical and chondral injury. Graf et al., Janarv et al., and
Mizuta et al. reported instability symptoms, subsequent men-
sical tears, a decreased activity level, and a need for anterior
cruciate ligament reconstruction in skeletally immature pa-
tients treated nonoperatively. Similarly, when comparing
the results of operative and nonoperative management of com-
plete anterior cruciate ligament injuries in adolescents,
McCarroll et al. and Pressman et al. found that those managed
with anterior cruciate ligament reconstruction had less insta-
Bility, higher levels of activity and return to sports, and lower
rates of subsequent reinjury and meniscal tears. These sub-
sequent meniscal and chondral injuries have important implica-
tions in terms of the long-term prognosis for the knee and the
risk of degenerative joint disease. In addition, compliance
with activity restriction is often problematic in the pediatric
athlete and is unappealing to the patient’s family.

Conventional surgical reconstruction techniques risk
potential iatrogenic growth disturbance due to physeal dam-
age. Cases of growth disturbance have been reported in animal
models. Animal models have demonstrated mixed results
regarding growth disturbances from soft-tissue grafts across
the physe. In a canine model with iliotibial band grafts
through 0.16-in (4-mm) tunnels, Stadelmaier et al. found no
evidence of growth arrest in four animals with a soft-tissue
graft across the physe, whereas four animals with drill-holes
and no graft demonstrated physeal arrest. In a rabbit model
with use of a semitendinosus graft through 2-mm tunnels,
Guzzanti et al. noted cases of growth disturbance; however,
they were not common. Examining the effect of a tensioned
soft-tissue graft across the physe, Edwards et al. found a sub-
stantial rate of deformity. In a canine model with an iliotibial
band graft tensioned to 80 N, those investigators found in-
creases, compared with the nonoperatively treated control
limb, in distal femoral valgus deformity and proximal tibial
varus deformity despite no evidence of an osseous bar. Simi-
larly, Houle et al. reported growth disturbance after use of a
tensioned tendon graft in a bone tunnel across the rabbit
physe. However, the tension applied to the graft in the stud-
ies by Edwards et al. and Houle et al. may have been corre-
spondingly excessive for their animal models, thus resulting in
growth disturbance.

Clinical reports of growth deformity after anterior cruci-
te ligament reconstruction are unusual. In a series of
twenty-four skeletally immature patients who had reconstruc-
tion with transphyseal semitendinosis and gracilis grafts,
Lipscomb and Anderson described one patient who had 20 mm
of shortening. This was associated with staple fixation of a
graft across the physe. Koman and Sanders reported the case
of a patient who had a distal femoral valgus deformity requir-
ing an osteotomy and contralateral epiphyseodesis after trans-
physeal reconstruction with a doubled semitendinosus graft.
This deformity was also associated with fixation across the
distal femoral physe. In a study based on a survey of experts in
the management of anterior cruciate ligament injuries in pe-
diatric patients, Kocher et al. reported the cases of an addi-
tional fifteen patients who had growth disturbances, including
eight patients who had a distal femoral valgus deformity with
an arrest of the lateral distal femoral physe; three patients who
had tibial recurvatum with an arrest of the tibial tubercle apop-
physis; two patients who had genu valgum, without arrest, due
to a lateral extra-articular tether; and two patients who had a
leg-length discrepancy (one who had shortening and one who
had overgrowth). Associated factors included fixation hard-
ware across the lateral distal femoral physe in three patients,
bone plugs of a patellar tendon graft across the distal femoral
physe in three patients, large (12-mm) tunnels in two pa-
tients, lateral extra-articular tenodesis in two patients, fixation
hardware across the tibial tubercle apophysis in two patients,
and suturing near the tibial tubercle apophysis in one patient.

Surgical techniques to address anterior cruciate liga-
ment insufficiency in skeletally immature patients include
primary repair, extra-articular tenodesis, transphyseal recon-
struction, partial transphyseal reconstruction, and physeal
sparing reconstruction. Primary ligament repair and extra-
articular tenodesis alone in children and adolescents have
had poor results, similar to the outcomes seen in adults.
Transphyseal reconstructions with tunnels that violate both
the distal femoral and proximal tibial physe have been per-
formed with hamstrings autograft, patellar tendon autograft,
and allograft tissue. Partial transphyseal reconstruc-
tions damage only one physe with a tunnel through the prox-
imal tibial physe and over-the-top positioning on the femur
or with a tunnel through the distal femoral physe with an
epiphysyeal tunnel in the tibia. A variety of physeal spar-
ing reconstructions to avoid tunnels across either the distal
femoral physe or the proximal tibial physe have been
described.

The management of anterior cruciate ligament injuries
in pubescent children and adolescents is particularly vex-
ing, given the large amount of growth remaining. Most clin-
cal series of skeletally immature patients with anterior cruci-
te ligament injuries have involved adolescent patients, not pre-
pubescent patients. The consequences of growth disturbance
in the pubescent age-group are substantial, requiring ma-
jor limb reconstruction with osteotomy and/or limb-length-
ening. However, anterior cruciate ligament insufficiency must
be adequately corrected with reconstructive techniques in or-
der to avoid subsequent meniscal and chondral injuries, which
also have substantial consequences. Case reports or small clin-
ical series of patients in this age-group managed with physeal
sparing techniques to provide a stable knee while avoiding vi-
olation of the physe have been described. DeLee and Curtis
used a portion of the patellar tendon without drill-holes.
Briefly, and Parker et al. used hamstrings tendons, left at-
Physial Sparring Reconstruction of the ACL in Skeletally Immature Prepubescent Children and Adolescents

Fig. 2
A STIR (short tau inversion-recovery) sagittal magnetic resonance imaging scan of an iliotibial band graft at 3.4 years after reconstruction.

tached distally, that were brought through the knee under the intermeniscal ligament on the tibial side and the over-the-top position on the femoral side. More recently, physial sparing reconstruction techniques with use of hamstrings tendon in prepubescent patients were described by Guzzanti et al.10, who used an epiphysical tibial tunnel with distal femoral epiphysial fixation, and by Anderson11, who used epiphysical tibial and femoral tunnels.

In the present study, we report the results of a physial sparing, combined intra-articular and extra-articular reconstruction technique with use of an autogenous iliotibial band graft in prepubescent, skeletally immature children (Fig. 2). In forty-four children who were followed for a mean of 5.3 years, this technique provided excellent functional outcome with a low revision rate and no growth disturbance. Our rationale for the utilization of this technique is to provide knee stability and improve function while avoiding the risk of iatrogenic growth disturbance in prepubescent, skeletally immature patients with complete intrasubstance injuries of the anterior cruciate ligament who have repairable meniscal tears or who have had failure of nonoperative treatment. This series included three prepubescent patients with congenital insufficiency of the anterior cruciate ligament associated with longitudinal deficiency of the lower extremities. Our indications for reconstruction of the anterior cruciate ligament in a child with congenital deficiency of a limb are symptomatic instability that substantially limits function and is uncontrollable by bracing. In older, skeletally immature adolescents (Tanner stage 3 and 4) with an anterior cruciate ligament injury, we perform transphysial reconstruction with a quadrupled hamstrings tendon graft with fixation away from the physes. However, in our opinion, the consequences of potential iatrogenic growth disturbance caused by transphysial reconstruction in prepubescent children are prohibitive and, therefore, we perform the physial sparing reconstruction. This procedure is nonanatomic as the graft is in the over-the-top position on the femur and under the intermeniscal ligament on the tibia. Although nonanatomic, it provided for a stable knee with excellent function in children who returned to sports that involved cutting and pivoting. We counsel parents that this may be a temporizing procedure for later conventional reconstruction near skeletal maturity; however, this technique has functioned as the definitive reconstruction for most of our patients.

Appendix

A table showing the Tanner staging system is available with the electronic versions of this article, on our website at jbj.s.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM).

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The authors did not receive grants or outside funding in support of their research or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

doi:10.2106/JBJS.D.02802

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