

ACL Reconstruction in the Skeletally Immature Patient

Mininder S. Kocher, MD, MPH*; Lyle J. Micheli, MD

From Division of Sports Medicine, Department of Orthopaedic Surgery, Children's Hospital, Harvard Medical School, Boston, Massachusetts

‡Address Correspondence and Reprint Requests to Mininder S. Kocher, MD, MPH,
Department of Orthopaedic Surgery, 300 Longwood Avenue, Boston, MA 02115.
(phone: 617-355-7497, fax: 617-730-0459, e-mail:
mininder.kocher@childrens.harvard.edu

Anterior cruciate ligament (ACL) injuries in skeletally immature patients are being seen with increased frequency. Management of these injuries is controversial. Nonreconstructive treatment of complete tears typically results in recurrent functional instability with risk of injury to meniscal and articular cartilage. A variety of reconstructive techniques have been utilized, including physeal sparing, partial transphyseal, and transphyseal methods using various grafts. Conventional adult ACL reconstruction techniques risk potential iatrogenic growth disturbance due to physeal violation. Growth disturbances after ACL reconstruction in skeletally immature patients have been reported.

In this chapter, we discuss our approach to ACL reconstruction in the skeletally immature patient based on physiological age (Figure 1). In prepubescent patients, we perform a physeal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band. In adolescent patients with significant growth remaining, we perform transphyseal ACL reconstruction with autogenous hamstrings tendons with fixation away from the physes. In older adolescent patients approaching skeletal maturity, we perform conventional adult ACL reconstruction with interference screw fixation using either autogenous central third patellar tendon or autogenous hamstrings.

History of the Technique

Intrasubstance ACL injuries in children and adolescents were once considered rare, with tibial eminence avulsion fractures considered the pediatric ACL injury equivalent (1-4). However, intrasubstance ACL injuries in children and adolescents are being seen with increased frequency and have received increased attention. Anterior cruciate ligament injury has been

reported in 10% to 65% of pediatric knees with acute traumatic hemarthroses in series ranging from 35-138 patients (5-10).

Controversy exists regarding the management of anterior cruciate ligament injuries in patients with open physes. Nonoperative management of *partial tears* may be successful in some patients (11). However, nonoperative management of *complete tears* in skeletally immature patients generally has a poor prognosis with recurrent instability leading to further meniscal and chondral injury which has implications in terms of development of degenerative joint disease (12-18). Graf et al, Mizuta et al, and Janarv et al have reported instability symptoms, subsequent meniscal tears, decreased activity level, and need for ACL reconstruction in the majority of skeletally immature patients treated nonoperatively in series of 8, 18, and 23 patients, respectively (13, 14, 17). Similarly, when comparing the results of operative versus nonoperative management of complete ACL injuries in adolescents, McCarroll et al and Pressman et al found that those managed by ACL reconstruction had less instability, higher activity and return to sport levels, and lower rates of subsequent reinjury and meniscal tears (15, 18).

Conventional surgical reconstruction techniques risk potential iatrogenic growth disturbance due to physeal violation. Cases of growth disturbance have been reported in animal models (19-21) and clinical series (22-24). Animal models have demonstrated mixed results regarding growth disturbances from soft tissue grafts across the physes. In a canine model with iliotibial band grafts through 5/32 inch tunnels, Stadelmeier et al found no evidence of growth arrest in the four animals with soft tissue graft across the physis, whereas the four animals with drill holes and no graft demonstrated physeal arrest (25). In a rabbit model using a semitendinosis graft through 2 mm tunnels, Guzzanti et al did have cases of growth disturbance,

however these were not common: 5% shortening (1/21) and 10% distal femoral valgus deformity (2/21) (19). Examining the effect of a tensioned soft-tissue graft across the physis, Edwards et al found a substantial rate of deformity. In a canine model with iliotibial band graft tensioned to 80 N, these investigators found significant increases, compared to the nonoperated control limb, in distal femoral valgus deformity and proximal tibial varus deformity despite no evidence of a bony bar (21). Similarly, Houle et al reported growth disturbance after a tensioned tendon graft in a bone tunnel across the rabbit physis (20).

Clinical reports of growth deformity after ACL reconstruction are unusual. Lipscomb and Anderson reported one case of 20 mm shortening in a series of 24 skeletally immature patients reconstructed with transphyseal semitendinosis and gracilis grafts (22). This was associated with staple graft fixation across the physis. Koman and Sanders reported a case of distal femoral valgus deformity requiring osteotomy and contralateral epiphyseodesis after transphyseal reconstruction with a doubled semitendinosis graft (23). This case was also associated with fixation across the distal femoral physis. Kocher et al reported an additional 15 cases of growth disturbances gleaned from a questionnaire of expert experience, including eight cases of distal femoral valgus deformity with an arrest of the lateral distal femoral physis, three cases of tibial recurvatum with an arrest of the tibial tubercle apophysis, two cases of genu valgum without arrest due to a lateral extra-articular tether, and two cases of leg length discrepancy (one shortening and one overgrowth) (24). Associated factors included fixation hardware across the lateral distal femoral physis in three cases, bone plugs of a patellar tendon graft across the distal femoral physis in three cases, large (12 mm) tunnels in two cases, lateral extra-articular tenodesis in two cases, fixation hardware across the tibial tubercle apophysis in

two cases, of the over-the-top femoral position in one case, and suturing near the tibial tubercle apophysis in one case.

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. Primary ligament repair (26, 27) and extra-articular tenodesis alone (13, 15) have had poor results in children and adolescents, similar to adults. Transphyseal reconstructions with tunnels that violate both the distal femoral and proximal tibial physes have been performed with hamstrings autograft, patellar tendon autograft, and allograft tissue (12, 15, 28-37). Partial transphyseal reconstructions violate only one physis with a tunnel through the proximal tibial physis and over-the-top positioning on the femur or a tunnel through the distal femoral physis with an epiphyseal tunnel in the tibia (38-40). A variety of physeal-sparing reconstructions have been described to avoid tunnels across either the distal femoral or proximal tibial physis (7, 41-47).

Indications and Contraindications

All skeletally immature patients are not the same. Some have a tremendous amount of growth remaining, while others are essentially done growing. The consequences of growth disturbance in the former group would be severe, requiring osteotomy and/or limb lengthening. However, the consequences of growth disturbance in the latter group would be minimal. When treating a skeletally immature athlete with an ACL injury, it is important to know their chronological age, their skeletal age, and their physiological age. Skeletal age can be determined from an anteroposterior radiograph of the left hand and wrist per the atlas of Greulich and Pyle (48). Alternatively, skeletal age can be estimated from knee radiographs per the atlas of Pyle and

Hoerr (49). Physiological age is established using the Tanner staging system (Table 1) (50). In the office, the patient can be informally staged by questioning. In the operating room, after the induction of anesthesia, Tanner staging can be confirmed.

The vast majority of anterior cruciate ligament injuries in skeletally immature patients occur in adolescents. The management of these injuries in *preadolescent* children is particularly vexing, given the poor prognosis with nonoperative management, the substantial growth remaining, and the consequences of potential growth disturbance.

Our approach to ACL reconstruction in the skeletally immature patient is based on physiological age (Figure 1). In prepubescent patients, we perform a physal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band. In adolescent patients with significant growth remaining, we perform transphysal ACL reconstruction with autogenous hamstrings tendons with fixation away from the physes. In older adolescent patients approaching skeletal maturity, we perform conventional adult ACL reconstruction with interference screw fixation using either autogenous central third patellar tendon or autogenous hamstrings.

In the prepubescent patient with a complete ACL tear without concurrent chondral or repairable meniscal injury, we first attempt nonreconstructive treatment with a program of rehabilitation, functional bracing, and return to non high-risk activities. Although the results of nonreconstructive treatment are generally poor with subsequent functional instability and risk of injury to meniscal and articular cartilage, surgical reconstruction poses the risk of growth disturbance. Furthermore, some patients are able to cope with their ACL insufficiency or modify their activities, allowing for further growth and aging such that an adolescent-type reconstruction can be performed with transphysal hamstrings tendons in a more anatomic manner.

For those prepubescent patients with concurrent chondral or repairable meniscal injury, or those with functional instability after nonreconstructive treatment, we perform a physeal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band. This procedure is a modification of the combined intra-articular and extra-articular reconstruction described by MacIntosh and Darby (51). Our rationale for utilization of this technique is to provide knee stability and improve function in prepubescent skeletally immature patients with complete intrasubstance ACL injuries while avoiding the risk of iatrogenic growth disturbance by violating the distal femoral and/or proximal tibial physes. In our opinion, the consequences of potential iatrogenic growth disturbance caused by transphyseal reconstruction in these young patients is prohibitive. Recognizing that this reconstruction is nonanatomic, we counsel patients and families that they may require revision reconstruction if they develop recurrent instability, but that this procedure may temporize for further growth such that they may then undergo a more conventional reconstruction with drill holes.

For adolescent patients with growth remaining who have a complete ACL tear, we do not advocate initial nonreconstructive treatment since the risk of functional instability with injury to the meniscal and articular cartilage is high, the risk and consequences of growth disturbance from ACL reconstruction are less, and our transphyseal technique is an anatomic reconstruction. In these patients, we perform transphyseal ACL reconstruction with autogenous hamstrings tendons with fixation away from the physes.

For older adolescent patients who are approaching skeletal maturity who have a complete ACL tear, we perform conventional adult ACL reconstruction with interference screw fixation using either autogenous central third patellar tendon or autogenous hamstrings.

In skeletally immature patients as in adult patients, acute ACL reconstruction is not performed within the first three weeks after injury to minimize the risk of arthrofibrosis. Pre-reconstructive rehabilitation is performed to regain range of motion, decrease swelling, and resolve the reflex inhibition of the quadriceps. Anterior cruciate ligament reconstruction may be staged in some cases if there is a displaced, bucket-handle tear of the meniscus that requires extensive repair in order to protect the meniscal repair from the early mobilization prescribed by ACL reconstruction. Skeletally immature patients must be emotionally mature enough to actively participate in the extensive rehabilitation required after ACL reconstruction.

Surgical Technique

In older adolescent patients who are approaching skeletal maturity who have a complete ACL tear, we perform conventional adult ACL reconstruction with interference screw fixation using either autogenous central third patellar tendon or autogenous hamstrings. This is a standard one-incision, arthroscopically assisted technique that is covered elsewhere in the text and will not be further detailed in this chapter.

Prepubescent Patients: Physeal-sparing, Combined Intra/Extra-articular Reconstruction with Autogenous Iliotibial Band

In prepubescent patients, we perform a physeal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band.

The procedure is performed under general anesthesia as an overnight observation procedure. Local anesthesia with sedation may not be reliable in prepubescent children with the potential for a paradoxical effect of sedation. The child is positioned supine on the operating table

with a pneumatic tourniquet about the upper thigh which is used routinely. Examination under anesthesia is performed to confirm ACL insufficiency.

First, the iliotibial band graft is obtained. An incision of approximately 6cm is made obliquely from the lateral joint line to the superior border of the iliotibial band (Figure 3a). Proximally, the iliotibial band is separated from subcutaneous tissue using an periosteal elevator under the skin of the lateral thigh. The anterior and posterior borders of the iliotibial band are incised and the incisions carried proximally under the skin using curved meniscotomes (Figure 3a). The iliotibial band is detached proximally under the skin using a curved meniscotome or an open tendon stripper. Alternatively, a counter-incision can be made at the upper thigh to release the tendon. 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 (Figure 3b). The free proximal end of the iliotibial band is then tubularized with a #5 ethibond whip stitch.

Arthroscopy of the knee is then performed through standard anterolateral viewing and anteromedial working 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. Minimal notchplasty is performed to avoid iatrogenic injury to the perichondrial ring of the distal femoral physis which is in very close proximity to the over-the-top position (52). The free end of the iliotibial band graft is brought through the over-the-top position using a full-length clamp (Figure 3c) or a two-incision rear-entry guide (Figure 2b) and out the anteromedial portal (Figure 2c, Figure 3d).

A second incision of approximately 4.5cm is made over the proximal medial tibia in the region of the pes anserinus insertion. 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 (Figure 3e). A small groove is made in the anteromedial proximal tibial epiphysis under the intermeniscal ligament using 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 (Figure 3f), under the intermeniscal ligament in the anteromedial epiphseal groove, and out the medial tibial incision (Figure 3g). The graft is fixed on the femoral side through the lateral incision with the knee at 90 degrees flexion and 15 degrees external rotation using mattress sutures to the lateral femoral condyle at the insertion of the lateral intermuscular septum to effect an extra-articular reconstruction (Figure 3h). The tibial side is then fixed through the medial incision with the knee flexed 20 degrees 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 tibial medial metaphyseal cortex and the graft is sutured to the periosteum at the rough margins with mattress sutures (Figure 2d).

Postoperatively, the patient is maintained touch-down weight bearing for six weeks. Range of motion is limited from 0 to 90 degrees for the first two weeks, followed by progressive full range of motion. A continuous passive motion (CPM) from 0 to 90 degrees and cryotherapy are used for two weeks post-operatively. A protective post-operative brace is used for six weeks postoperatively.

Adolescent Patients with Growth Remaining: Transphyseal Reconstruction with Autogenous Hamstrings with Metaphseal Fixation

In adolescents with growth remaining, we perform transphyseal ACL reconstruction with autogenous hamstrings tendons with metaphyseal fixation away from the physes. This is a fairly standard one-incision, arthroscopically assisted technique utilizing a four-stranded gracilis/semitendinosis graft with endobutton fixation on the femur. On the tibial side, the graft is either fixed with a soft-tissue interference screw if there is adequate tunnel distance (at least 30mm) below the physis to ensure metaphyseal placement of the screw or with a post and spiked washer.

The procedure is performed under general anesthesia as an overnight observation procedure. Local anesthesia with sedation may be performed in the emotionally mature adolescent child. The patient is positioned supine on the operating table with a pneumatic tourniquet about the upper thigh which is not used routinely. Examination under anesthesia is performed to confirm ACL insufficiency.

First, the hamstrings tendons are harvested. If the diagnosis is in doubt, arthroscopy can be performed first to confirm ACL tear. A 4 cm incision is made over the palpable pes anserinus tendons on the medial side of the upper tibia (Fig 4a). Dissection is carried through skin to the sartorius fascia. Care is taken to protect superficial sensory nerves. The sartorius tendon is incised longitudinally and the gracilis and semitendinosis tendons are identified. The tendons are dissected free distally and their free ends whip-stitched with #2 or #5 ethibond suture. They are dissected proximally using sharp and blunt dissection. Fibrous bands to the medial head of gastrocnemius should be sought and released. A closed tendon stripper is used to dissect the tendons free proximally. Alternatively, the tendons can be left attached distally, and an open tendon stripper used to release the tendons proximally. The tendons are taken to the back table, where excess muscle is removed and the remaining ends are whip-stitched with #2 or #5

ethibond suture. The tendons are folded over a closed loop endobutton. The graft diameter is sized and the graft is placed under tension.

Arthroscopy of the knee is then performed through standard anterolateral viewing and anteromedial working 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 is identified. Minimal notchplasty is performed to avoid iatrogenic injury to the perichondrial ring of the distal femoral physis which is in very close proximity to the over-the-top position (52).

A tibial tunnel guide (set at 55 degrees) is used through the anteromedial portal (Fig 4b). A guide wire is drilled through the hamstrings harvest incision into the posterior aspect of the ACL tibial footprint. The guidewire entry point on the tibia should be kept medial to avoid injury to the tibial tubercle apophysis. The guidewire is reamed with the appropriate diameter reamer. Excess soft tissue at the tibial tunnel is excised to avoid arthrofibrosis. The transtibial over-the-top guide of the appropriate offset to ensure a 1mm or 2mm back wall is used to pass the femoral guide pin (Fig 4c). The femoral guide pin is overdrilled with the endobutton reamer. Both are removed in order to use the depth gauge to measure the femoral tunnel length. The guide pin is replaced and brought through the distal lateral thigh. The femur is reamed to the appropriate depth (femoral tunnel length – endobutton length + 6-7mm to flip the endobutton).

The #5 ethibond sutures on the endobutton are placed in slot of the guidewire and pulled through the tibial tunnel, through the femoral tunnel, and out the lateral thigh. These are then pulled to bring the endobutton and graft through the tibial tunnel and into the femoral tunnel. One set of sutures is used to “lead” the endobutton, while the other set of sutures is used to “follow.” Once the graft is fully seated in the femoral tunnel, the “follow” sutures are pulled to

flip the endobutton (Fig 4d). The flip can be palpated in the thigh and tension is applied to the graft to endure no graft slippage. The knee is then extended to ensure no graft impingement. The knee is then cycled approximately ten times with tension applied to the graft. The graft is fixed on the tibial side with the knee in 20-30 degrees of flexion, tension applied to the graft, and a posterior force placed on the tibia. On the tibial side, the graft is either fixed with a soft-tissue interference screw if there is adequate tunnel distance (at least 30mm) below the physis to ensure metaphyseal placement of the screw or with a post and spiked washer. Fluoroscopy can be used to ensure that the fixation is away from the physes. Post-operative radiographs are shown in Figure 5.

Postoperatively, the patient is maintained touch-down weight bearing for two weeks. Range of motion is limited from 0 to 90 degrees for the first two weeks, followed by progressive full range of motion. A continuous passive motion (CPM) from 0 to 90 degrees and cryotherapy are used for two weeks post-operatively. A protective post-operative brace is used for six weeks postoperatively.

Technical Alternatives and Pitfalls

Transphyseal reconstruction, partial transphyseal reconstruction, and physeal sparing reconstruction techniques have been described to address ACL insufficiency in skeletally immature patients.

In prepubescent patients, physeal sparing techniques have been described that utilize hamstrings tendons under the intermeniscal ligament and over-the-top on the femur, through all-epiphyseal femoral and tibial tunnels, and with a femoral epiphyseal staple (7, 41-47).

In adolescent patients with growth remaining, transphyseal reconstructions have been performed with hamstrings autograft, patellar tendon autograft, and allograft tissue (12, 15, 28-37). In addition, partial transphyseal reconstructions have been described with a tunnel through the proximal tibial physis and over-the-top positioning on the femur or a tunnel through the distal femoral physis with an epiphyseal tunnel in the tibia (38-40, 53).

Pitfalls to avoid with the physeal-sparing iliotibial band reconstruction in prepubescents include harvesting a short graft insufficient to reach the medial tibial incision, difficulty passing the graft through the posterior joint capsule, and difficulty passing the graft under the intermeniscal ligament.

Pitfalls to avoid with the transphyseal hamstrings reconstruction in adolescents with growth remaining include amputation of the hamstring grafts, poor tunnel placement, and graft impingement.

Based on the 15 cases of growth disturbance after ACL reconstruction in skeletally immature patients that we reported, we recommend careful attention to technical details during ACL reconstruction in skeletally immature patients, particularly the avoidance of fixation hardware across the lateral distal femoral epiphyseal plate (24). Care should also be taken to avoid injury to the vulnerable tibial tubercle apophysis. Given the cases of growth disturbances associated with transphyseal placement of patellar tendon graft bone blocks, we recommend the use of soft tissue grafts. Large tunnels should likely be avoided as likelihood of arrest is associated with greater violation of epiphyseal plate cross-sectional area. The two cases of genu valgum without arrest associated with lateral extra-articular tenodesis raise additional concerns about the effect of tension on physeal growth. Finally, care should be taken to avoid dissection

or notching around the posterolateral aspect of the physis during over-the-top nonphyseal femoral placement to avoid potential injury to the perichondrial ring and subsequent deformity.

Rehabilitation

Rehabilitation after ACL reconstruction in skeletally immature patients is essential to ensure a good outcome, allow return to sports, and avoid reinjury. Rehabilitation in prepubescent children can be challenging. A therapist who is used to working with children and can make therapy interesting and fun is very helpful. Compliance with therapy and restrictions should be carefully monitored.

After physeal-sparing iliotibial band reconstruction in prepubescent patients, we restrict full weight-bearing for 6 weeks to allow graft healing. After transphyseal hamstring reconstruction in adolescents with growth remaining, we restrict full weight-bearing for 2 weeks. A CPM machine is used for two weeks post-operatively. A post-operative brace is used for 6 weeks post-operatively.

Progressive rehabilitation consists of range-of motion exercises, patellar mobilization, electrical stimulation, pool therapy if available, proprioception exercises, and closed chain strengthening, during the three months post-operatively, followed by straight-line jogging, plyometric exercises, sport cord exercises, and sport specific exercises.

Return to full activity, including cutting sports is usually allowed at six months post-operatively. A functional knee brace is used routinely during cutting and pivoting activities for the first two years after return to sports.

Outcomes and Future Directions

We have reviewed the results of physeal-sparing iliotibial band reconstruction in prepubescent patients in a preliminary series of 8 patients (47).

More recently, we have reviewed the minimum two-year results in 44 prepubescent patients. Between 1980 to 2002, 44 skeletally immature preadolescent children who were Tanner stage 1 or 2 (mean chronological age: 10.3 years old; range: 3.6-14.0 years old) underwent physeal sparing combined intra-articular and extra-articular anterior cruciate ligament reconstruction using autogenous iliotibial band. Twenty-four patients had additional meniscal surgery. Functional outcome, graft survival, radiographic outcome, and growth disturbance were evaluated at a mean of 5.3 years (range: 2.0-15.1 years) after surgery. Two patients underwent revision anterior cruciate ligament reconstruction for graft failure at 4.7 and 8.3 years after initial surgery (revision rate: 4.5%). In the remaining 42 patients, the mean International Knee Documentation (IKDC) subjective knee score was 96.7 ± 6.0 (range: 88.5-100) and the mean Lysholm knee score was 95.7 ± 6.7 (range: 74-100). Per IKDC criteria, Lachman examination was normal in twenty-three patients, nearly normal in eighteen patients, and abnormal in one patient. Pivot-shift examination was normal in thirty-one patients and nearly normal in eleven patients. Four patients who underwent concurrent meniscus repair had repeat arthroscopic meniscal repair or partial menisectomy. Mean growth in total height from the time of surgery to final follow-up was 21.5 cm (range: 9.5 to 118.5 cm). There were no cases of significant angular deformity measured radiographically or leg length discrepancy measured clinically. Thus, physeal sparing combined intra-articular and extra-articular anterior cruciate ligament reconstruction using iliotibial band in preadolescent skeletally immature patients appears to provide for excellent functional outcome with a low revision rate and a minimal risk of growth disturbance.

Figure Legends

Figure 1: Algorithm for management of complete ACL injuries in skeletally immature patients.

Figure 2: Physeal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band for prepubescents. 2a: The iliotibial band graft is harvested free proximally and left attached to Gerdy's tubercle distally. 2b: The graft is brought through the knee in the over-the-top position posteriorly. 2c: The graft is brought through the knee and under the intermeniscal ligament anteriorly. 2d: Resulting intra-articular and extra-articular reconstruction.

Figure 3: Physeal-sparing, combined intra-articular and extra-articular reconstruction utilizing autogenous iliotibial band for prepubescents. 3a: The graft is harvested through the lateral incision. 3b: The graft is left attached to Gerdy's tubercle distally. 3c & 3d: The graft is brought through the knee in the over-the-top position using a full length clamp. 3e: The graft is brought under the intermeniscal ligament. A groove can be made in the epiphysis in this region with a rasp. 3f: Intra-articular reconstruction component. 3g: The graft is brought out the medial tibial incision and fixed here to a trough in the periosteum. 3h: Extra-articular reconstruction component.

Figure 4: Transphyseal reconstruction with autogenous hamstrings for adolescents with growth remaining. 4a: The gracilis and semitendinosus tendons are harvested through an incision over the proximal medial tibia. 4b: The tibial guide is used to drill the tibial tunnel. 4c: The transtibial over-the-top offset guide is used to drill the femoral tunnel. 4d: Hamstrings graft after fixation.

Figure 5: Transphyseal reconstruction with autogenous hamstrings for adolescents with growth remaining. Post-operative anteroposterior (a) and lateral (b) radiographs.

Table 1: Tanner Staging Classification of Secondary Sexual Characteristics

Tanner Stage		Male	Female
Stage 1 (Prepubertal)	Growth	5-6 cm/yr	5-6 cm/yr
	Development	Testes <4ml or <2.5cm No pubic hair	No breast development No pubic hair
Stage 2	Growth	5-6 cm/yr	7-8 cm/yr
	Development	Testes 4ml or 2.5-3.2cm Minimal pubic hair at base of penis	Breast buds Minimal pubic hair on labia
Stage 3	Growth	7-8 cm/yr	8 cm/yr
	Development	Testes 12ml or 3.6cm Pubic hair over pubis Voice changes Muscle mass increases	Elevation of breast; areolae enlarge Pubic hair of mons pubis Axillary hair Acne
Stage 4	Growth	10 cm/yr	7 cm/yr
	Development	Testes 4.1-4.5cm Pubic hair as adult Axillary hair Acne	Areolae enlarge Pubic hair as adult
Stage 5	Growth	No growth	No growth
	Development	Testes as adult Pubic hair as adult Facial hair as adult Mature physique	Adult breast contour Pubic hair as adult
Other		Peak Height Velocity: 13.5 years	Adrenarche: 6-8 years Menarche 12.7 years Peak Height Velocity: 11.5 years

Suggested Readings:

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