Journal of Pediatric Orthopaedics
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Management and Complications of Anterior Cruciate Ligament Injuries in Skeletally Immature Patients: Survey of The Herodicus Society and The ACL Study Group

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Summary: Expert opinion regarding experience with the management and complications of pediatric anterior cruciate ligament (ACL) injuries was studied by surveying members of The Herodicus Society and The ACL Study Group. There was large practice variation in initial management and ACL reconstruction technique. There were 15 reported cases of growth disturbance: 8 cases of distal femoral valgus deformity with arrest of the lateral distal femoral physis, 3 cases of tibial recurvatum with arrest of the tibial tubercle apophysis, 2 cases of genu valgum without arrest, and 2 cases of leg length discrepancy. Associated factors included fixation hardware across the lateral distal femoral physis in 3 cases, bone plugs of a patellar tendon graft across the distal femoral physis in 3 cases, large (12 mm) tunnels in 2 cases, fixation hardware across the tibial tubercle apophysis in 3 cases, lateral extra-articular tenodesis in 2 cases, and over-the-top femoral position in 1 case. Based on this experience, we recommend a guarded approach to ACL reconstruction in the skeletally immature patient with careful attention to technique and follow-up. **Key Words:** Anterior Cruciate Ligament—Children—Complications—Knee.

Once thought to be rare, midsubstance anterior cruciate ligament (ACL) injury in children and adolescents has received increasing attention recently (1–4,12,14,17–27,30,32,35–37). Although the true incidence and prevalence of injury in the pediatric age group is unknown, ACL injury has been reported in 10% to 65% of pediatric knees with acute hemarthroses in reported series ranging from 35–138 patients (9,15,31,34).

With respect to pediatric ACL injuries, controversy exists regarding initial management, indications for operative management, the effect of age and maturity on management, and the risk of growth disturbance from operative management. In addition, there is large practice variation in operative technique for ACL injuries in skeletally immature patients.

The purpose of this study was to survey the members of The Herodicus Society and The ACL Study Group regarding experience with the management and complications of pediatric ACL injuries.

MATERIALS AND METHODS

A questionnaire was constructed to assess experience with pediatric ACL injuries (Fig. 1). Questions were asked regarding number of skeletally immature patients with ACL injuries seen, number of ACL reconstructions performed in skeletally immature patients, age of patients, initial treatment of a complete midsubstance tears in an 8-year-old child and a 13-year-old child, ACL reconstruction technique on the tibial and femoral sides, graft source for ACL reconstruction, and complications from pediatric ACL reconstruction such as growth deformity.

One hundred eighty-seven questionnaires were sent to clinicians who were members of The Herodicus Society or The ACL Study Group, whose membership consists of international experts in sports medicine and ACL injuries, respectively. Two authors are members of these groups: The Herodicus Society (RJH), The ACL Study Group (RJH, MSK). A repeat questionnaire was sent to nonresponders 4 months after the initial mailing. The overall response rate was 75% (140/187).

Data were summarized and standard descriptive statistics were performed.

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DOI: 10.1097/01.BPO.0000018989.02445.F8

Herodicus Society/ ACL Study Group questionnaire

1. Have you treated a skeletally-immature patient with a midsubstance ACL injury during the last year?
   _____ Yes If yes, how many? _____
   _____ No

2. Have you performed an ACL reconstruction on an skeletally-immature Knee?
   _____ Yes If yes, how many? _____
   _____ No

3. What is the age of the youngest child on whom you have performed ACL reconstruction?

4. What is your recommended initial treatment in an 8-year-old child with complete, acute ACL disruption?
   _____ Nonoperative
   _____ Acute ACL reconstruction
   _____ Delay surgery until skeletally mature.

5. What is your recommended initial treatment in an 13-year-old child with complete, acute ACL disruption?
   _____ Nonoperative
   _____ Acute ACL reconstruction
   _____ Delay surgery until skeletally mature.

6. What is your technique for ACL reconstruction in a skeletally-immature patient?
   Tibial side: _____ transphyseal tibial tunnel
   _____ all epiphysis tunnel
   _____ no tunnel on tibial side
   Femoral side: _____ endoscopic
   _____ transphyseal femoral tunnel
   _____ two-incision tranphyseal femoral tunnel
   _____ over-the-top femur fixation
   Choice of graft:
   _____ Autograft bone-patellar tendon-bone
   _____ Autograft Hamstring
   _____ Hamstring attached distally
   _____ Allograft
   _____ Other

7. Have you ever seen a growth arrest or deformity from ACL reconstruction in a skeletally-immature patient?
   _____ Yes
   _____ No

   If yes, was deformity…
   _____ on femoral side
   _____ on tibial side
   _____ both

Describe deformity (shortening, angular deformity):

_____

_____

Please describe associated factors, i.e., interference screw or staple across physis.

_____

_____

Additional Comments:

_____

THANK YOU!

FIG. 1. Herodicus Society/ACL Study Group questionnaire.

RESULTS

1. Have you treated a skeletally immature patient with an ACL injury during the last year? How many?

88% (122/139) responded yes and 12% (17/139) responded no. One respondent did not answer. The mean number of skeletally immature patients with ACL tears seen in the last year was 5.8 (range: 0 to 30).

2. Have you performed ACL reconstruction on a skeletally-immature knee?

78% (108/139) responded yes and 22% (30/139) responded no. One respondent did not answer.

3. What is the age of the youngest child on whom you have performed ACL reconstruction?

The mean age of the youngest child on whom responders had performed ACL reconstruction was 11.5 years old (range: 2 to 16 years old).

4. What is your recommended initial treatment in an 8-year-old child with complete, acute ACL disruption?

58% (82/141) selected initial nonoperative management, 16% (22/141) selected initial operative management, and 26% (37/141) selected delaying reconstruction until skeletally mature. One respondent selected two responses.

5. What is your recommended initial treatment in a 13-year-old child with complete, acute ACL disruption?

51% (75/146) selected initial nonoperative management, 34% (50/146) selected initial operative management, and 14% (21/146) selected delaying reconstruction until skeletally mature. Six respondents selected two responses.

6. What is your technique for ACL reconstruction in a skeletally immature patient?

Tibial side

79% (104/132) perform a transphyseal technique, 15% (20/132) perform a nontransphyseal technique with an epiphyseal tunnel, and 6% (8/132) perform a nontransphyseal technique with no tunnels. Eight respondents did not answer.

Femoral side

58% (86/148) perform an endoscopic transphyseal technique, 10% (14/148) perform a two-incision transphyseal technique, and 32% (48/148) perform a nontransphyseal technique with over-the-top positioning. Eight respondents selected two responses.

Graft choice

57% (81/142) selected free autogenous hamstrings graft, 13% (19/142) selected autogenous hamstrings graft with an intact distal insertion, 20% (29/142) selected autogenous bone-patellar tendon-bone graft, 1% (2/142) selected allograft, and 8% (11/142) selected "other." Two respondents selected two responses.

Additional factors

24% of respondents wrote in that their technique of ACL reconstruction in a skeletally-immature patient is dependent on additional factors, including chronological age, skeletal age, Tanner stage (33), or pubertal status.

7. Have you ever seen a growth arrest or deformity from ACL reconstruction in a skeletally immature patient?

11% (15/140) of respondents had seen a growth disturbance from ACL reconstruction in a skeletally immature patient.

Where was the growth disturbance?

Of the 15 reported cases of growth disturbance, 80% (12/15) were on the femoral side and 20% (3/15) were on the tibial side.

What were the growth disturbances and associated factors?

There were three cases of distal femoral valgus deformity with a bony bar associated with implants (interference screw, staple, and transfixion pin) across the lateral aspect of the distal femoral physis. There were three cases of distal femoral valgus deformity with a bony bar associated with the bone plug of a patellar tendon graft across the lateral aspect of the distal femoral physis. There was one case of distal femoral valgus deformity with a bony bar associated with a large (12 mm) femoral tunnel and bone-patellar-tendon-bone graft. There was one case of distal femoral valgus deformity with a bony bar associated with over-the-top graft placement. There were two cases of genu valgum without a bony bar associated with lateral extra-articular tenodesis procedures.

There were two cases of leg-length discrepancy. One case involved a 2.5 cm shortening and valgus deformity of the distal femur associated with a 12 mm bone-patellar tendon-bone graft requiring contralateral epiphysiodesis. The other case involved an overgrowth of 3cm after transphyseal reconstruction with a 6-mm hamstrings graft in an 11-year-old girl requiring ipsilateral epiphysiodesis.

There were three cases of genu recurvatum resulting from closure of the tibial tubercle apophysis associated with a staple across the apophysis ($n = 2$) or suturing to the tibial periosteum ($n = 1$).

DISCUSSION

The utility of questionnaire data is limited as it is anecdotal, uncontrolled, and lacks information regarding the population at risk for prevalence determination. Nevertheless, surveys of expert opinion can reveal valuable information regarding practice patterns and can allow for accumulation of infrequent, but important, occurrences such as complications.

Midsubstance ACL injuries in children and adolescents were traditionally thought to be rare (28). However, these injuries have recently received increasing attention, likely due to increased recognition of injury in this age group, increased participation in competitive sports, and the advent of arthroscopy (1–4,12,14,17–

27,30,32,35–37). Although the true incidence and prevalence of injury in the pediatric age group is unknown, ACL injury has been reported in 10%-65% of pediatric knees with acute hemarthroses in reported series ranging from 35–138 patients (9,15,31,34). The results of this questionnaire suggest that ACL injuries in the pediatric age group are not uncommonly seen in a sports medicine practice, with 88% of respondents having treated a skeletally immature patient with midsubstance ACL injury during the last year.

Nonoperative initial management of ACL injuries in skeletally immature patients is often recommended. However, the reported results of nonoperative treatment are, in general, poor. Graf et al. (12), Mizuta et al. (24), and Janarv et al. (14) 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. Similarly, when comparing the results of operative versus nonoperative management of complete ACL injuries in adolescents, McCarroll et al. (21,22) and Pressman et al. (27) 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. Because of the potential for growth deformity complications resulting from ACL reconstruction in skeletally immature patients, many surgeons still prefer initial nonoperative management despite the generally poor prognosis. The majority of respondents in this survey favored initial nonoperative management of ACL injury in skeletally immature patients. However, this was age-related with 84% of respondents favoring nonoperative initial management in the prepubescent patient scenario (8-years-old), while 64% of respondents favored nonoperative initial management in the adolescent scenario (13-year-old).

ACL reconstruction in skeletally immature patients has recently received increasing attention (1–4,12,14,17–27,30,32,35–37). Operative techniques include direct repair, extra-articular tenodesis, nontransphyseal reconstruction, partial transphyseal reconstruction, and transphyseal reconstruction. Nontransphyseal techniques avoid both the proximal tibial and distal femoral physes by using an over-the-top femoral position with an epiphyseal tibial tunnel (18) or an over-the-front tibial position using hamstrings (5), iliotibial band (23), or hemipatellar tendon (7). Partial transphyseal techniques violate the proximal tibial physis and avoid the distal femoral physis by using an over-the-top femoral position, usually with a hamstrings graft (1,4,17–19). Transphyseal techniques violate both the proximal tibial and distal femoral physes, usually using a hamstrings or bone-patellar tendon-bone graft (3,17,20,21,22). In general, nonphyseal techniques avoid complications of growth deformity but provide a non-anatomic reconstruction, whereas transphyseal techniques provide a more anatomic reconstruction but have the potential for growth disturbance. There is substantial controversy and practice variation in terms of ACL reconstruction technique in skeletally immature patients. In this survey, there was no consensus on reconstruction technique. Transphyseal techniques are frequently performed and are more frequently performed on the tibial side. On the femoral side, 68% of respondents perform a transphyseal technique, by either one or two incisions, while 32% perform a nonphyseal technique with over-the-top positioning. On the tibial side, 79% perform a transphyseal technique, while 21% perform a nonphyseal technique with either an epiphyseal tunnel or an over-the-front technique. For graft source, soft tissue hamstrings graft is most frequently used, 70% of respondents, in comparison to bone-patellar tendon-bone graft, 20% of respondents.

Other factors, such as chronological age, skeletal age, Tanner stage (33), pubertal status, or growth velocity, may affect decision making regarding initial management and surgical technique. Younger patients have the potential for greater growth disturbances given their greater growth remaining. Thus, in older patients reaching skeletal maturity, many favor initial operative management and transphyseal techniques. In this survey, decision making regarding initial management was affected by age. In the prepubescent patient scenario (8-year-old), 16% of respondents selected ACL reconstruction as initial management, whereas 34% of respondents selected reconstruction as initial management in the adolescent patient scenario (13-year-old). In addition, decision making regarding surgical technique was also age-related. Twenty-four percent of respondents wrote in that their reconstruction technique in a skeletally immature patient varied by chronological age, skeletal age, Tanner stage, or pubertal status.

The potential for growth disturbance as a complication of ACL reconstruction in skeletally immature patients is of great concern and is a major factor affecting decision-making regarding initial management and surgical technique. 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, Stadelmaier et al. (29) 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. In a rabbit model using a semitendinosis graft through 2-mm tunnels, Guzzanti et al. (13) did have cases of growth disturbance, however these were not common: 5% shortening (1/21) and 10% distal femoral valgus deformity (2/21). Examining the effect of a tensioned soft-tissue graft across the physis, Edwards et al. (8) found a substantial rate of deformity. In a canine model with iliotibial band graft tensioned to 80 N, these investigators found significant increases, compared with the nonoperated control limb, in distal femoral valgus deformity and proximal tibial varus deformity despite no evidence of a bony bar.

Clinical reports of growth deformity after ACL reconstruction are unusual. Cases of mild leg length discrepancy have been reported (1,17). However, cases of clinically significant growth disturbances are rare. 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 (17). This was associated with staple graft fixation across the physis. Koman and Sanders (16) reported a case of distal femoral valgus deformity requiring osteotomy and contralateral epiphyseodesis after transphyseal reconstruction with a doubled semitendinosis graft. This case was also associated with fixation across the distal femoral physis. This survey revealed 15 additional cases of clinically significant growth disturbances. There were 8 cases of distal femoral valgus deformity with an arrest of the lateral distal femoral physis, 3 cases of tibial recurvatum with an arrest of the tibial tubercle apophysis, 2 cases of genu valgum without arrest due to a lateral extra-articular tether, and 2 cases of leg length discrepancy (1 shortening and 1 overgrowth). Associated factors included fixation hardware across the lateral distal femoral physis in 3 cases, bone plugs of a patellar tendon graft across the distal femoral physis in 3 cases, large (12 mm) tunnels in 2 cases, lateral extra-articular tenodesis in 2 cases, fixation hardware across the tibial tubercle apophysis in 2 cases, of the over-the-top femoral position in 1 case, and suturing near the tibial tubercle apophysis in 1 case.

Based on the factors associated with growth disturbance in these cases, 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. 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 (6,10,11). 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, similar to the tensioned graft canine model of Edwards et al. (8). 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.

Acknowledgments: The authors thank the participation by members of The Herodicus Society and The ACL Study Group. None of the authors received financial support for this study.

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