Anterior Cruciate Ligament Injury at the Time of Anterior Tibial Spine Fracture in Young Patients: An Observational Cohort Study

Meredith H. Mayo, MD, Justin J. Mitchell, MD,*† Derek P. Axibal, MD,* Jorge Chahla, MD,† Claire Palmer, MS,*‡ Armando F. Vidal, MD,* and Jason T. Rhodes, MD*‡*

Background: Anterior tibial spine fractures (ATSF) in the skeletally immature parallel anterior cruciate ligament (ACL) tears in adult patients, yet these injuries are generally regarded as mutually exclusive. Biomechanical analysis suggests that intrinsic ACL damage occurs during ATSF, and long-term clinical studies demonstrate residual anteroposterior knee laxity following ATSF. We aim to describe prevalence, demographics, and characteristics of pediatric patients who sustained ATSF with concomitant ACL injury.

Methods: We included 129 patients with ATSF over a 16-year period. Age, sex, injury mechanism, ATSF type, magnetic resonance imaging (MRI) evaluation, treatment modality, ACL injury, and concomitant meniscal/chondral injuries were analyzed. Concurrent ACL injury was confirmed either from MRI or intraoperatively.

Results: Nineteen percent (n = 25) of ATSF patients had concomitant ACL injury, with ACL injury significantly more likely in type II or type III ATSF compared with type I ATSF ($P = 0.03$). Patients with combined ATSF/ACL injury were significantly older ($P = 0.02$) and more likely to be male ($P = 0.01$). Mechanism of ATSF injury was not associated with ACL injury ($P = 0.83$). Preoperative MRI had low sensitivity (0.09) for recognizing ACL injury at the time of ATSF relative to intraoperative assessment. Half of ATSF/ACL-injured patients had additional meniscal or chondral injury, with meniscal repair or debridement required in 37.5% of the type II ATSF/ACL injury.

Conclusions: There are demographic characteristics, such as age (older) and sex (male), associated with a higher risk of concomitant ACL injury at the time of ATSF. Type II and type III ATSF patterns had a higher prevalence of ACL injury. MRI failed to correctly identify ACL injury at the time of ATSF. Concomitant ACL injury at the time of ATSF is highly prevalent in the skeletally immature, occurring in 19.4% of patients with ATSF.

Level of Evidence: Level IV—case series.

Key Words: anterior tibial spine fracture, anterior cruciate ligament, arthroscopy

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From the *Department of Orthopaedic Surgery, University of Colorado Hospital; ‡Department of Orthopedic Surgery, Children's Hospital of Colorado, Aurora; and †The Steadman Philippon Research Institute, Vail, CO.

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Reprints: Meredith H. Mayo, MD, Department of Orthopedic Surgery, University of Colorado School of Medicine, 12631 E. 17th Avenue, Mail Stop B202, Aurora, CO 80045. E-mail: meredith.h.mayo@gmail.com.

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Anterior tibial spine fractures (ATSF) occur as the anterior cruciate ligament (ACL) insertion site on the proximal tibia is avulsed away from relatively weak cancellous bone. Such avulsion fractures occur in all age groups, but are commonly seen in the pediatric population, most commonly in 8- to 14-year olds.[1,2] In addition to skeletal immaturity, weakness of the musculature surrounding the knee joint and increased elasticity of the ligaments[3–6] may contribute to this pediatric injury. Thus, the same mechanisms and forces that cause an ACL injury in an adult population can cause an ATSF.

The classification system for ATSFs was described by Meyers and McKeever[3,4] in 1959 with type I constituting nondisplaced fractures, type II representing displacement of the anterior fragment with a posterior cortical hinge, and type III involving complete fragment displacement (Fig. 1). Treatment of an ATSF is dependent on fracture displacement and the presence of concomitant pathology.

Operative planning for ATSFs often includes magnetic resonance imaging (MRI) evaluation of the knee to evaluate for concomitant meniscal, ligamentous, or chondral pathology. Although Johnson et al[7] and Mitchell et al[8] found a high rate (> 30%) of concomitant meniscal pathology requiring operative management at the time of ATSF fixation, the prevalence of ACL damage at the time of ATSF injury remains uncertain.

Dual ACL/ATSF injury has been reported in cadaveric, biomechanical analysis as the ACL suffers intrinsic damage before full avulsion of the anterior tibial spine.[9] Clinically, patients with ATSFs have demonstrated long-term, often asymptomatic, anteroposterior laxity on ligamentous examination regardless of the treatment.[5,6] With a successful reduction of the ATSF, residual laxity could be because of intrinsic ACL damage and/or partial tearing that was not addressed by ATSF

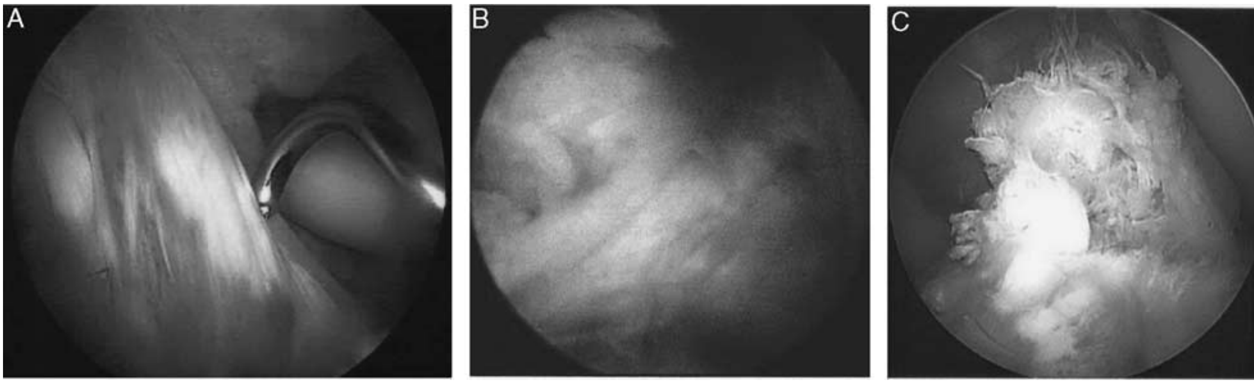

FIGURE 1. Arthroscopic images of anterior tibial spine fracture with concomitant anterior cruciate ligament hyperemia (A), partial tear (B), and complete tear (C).

fixation alone, so it is critical to consider it as an additional injury. Partial ACL damage has been reported to progress to complete ligamentous failure in up to 38% of pediatric patients and therefore, it is vital to recognize this entity.[10]

The purpose of this study was to describe the demographics and characteristics of those patients who sustained ATSF and ACL injuries concomitantly. Further, we aim to identify those patients who were at risk of a partial or an intrasubstance ACL tear during ATSF injury. It is hypothesized that there are no sex or age differences between ATSF and ATSF/ACL cohorts. Furthermore, we postulate that the risk for ACL injury as well as additional intra-articular injury will correlate with the severity of ATSF, and that MRI diagnosis will be concordant with arthroscopic findings of intrinsic ACL injury.

METHODS

Collection of Subjects

After International Review Board approval, International Classification of Diseases-9 and Current Procedural Terminology codes were used to retrospectively identify all subjects who were treated for an ATSF at a single large tertiary pediatric hospital between 1998 and 2014. Patients between the ages of 5 to 18 years with an ATSF confirmed by plain radiograph followed by MRI and/or surgery were included in the study. Those who underwent an MRI and/or surgery >35 days after the injury were excluded because of the risk of further injury with continued activity. Patients with previous ACL injury and/or reconstructions, infectious antecedents, or rheumatologic diseases were also excluded.

The demographics (age at injury, sex) and clinical characteristics (time from injury to surgery, type of evaluation, and mechanism of injury) were recorded for all eligible subjects and study data were collected using the REDCap database, an electronic data capture tool. MRI evaluations were completed by fellowship-trained pediatric radiologists and subsequently reviewed by pediatric or sports medicine–trained orthopaedic surgeons. Operative reports and images were reviewed by one of the authors to identify all concomitant ACL injury at the time of ATSF and any additional meniscal and/or chondral injuries associated with ACL injury. ATSFs were classified according to the Meyers and McKeever classification system as previously described.

Advanced imaging and surgical protocol were on the basis of surgeon's preference. Patients sustaining type I fractures generally underwent plain radiographs alone, with MRI reserved for those with clinical concern for associated meniscal or ligamentous pathology. Isolated type I fractures were all treated nonsurgically in a cast or brace with the knee in full extension. Type II fractures identified by plain radiographs were generally treated by 1 of the 2 methods. Nonoperative management involved a single attempt at closed reduction and extension casting or bracing with postreduction radiographic verification of anatomic or near anatomic ATSF position (<2 mm displacement). MRI was frequently obtained to ensure that concomitant meniscal or chondral injury was not present. MRI evaluation of the ACL injury included notation of complete avulsion or tear or previously described[11] partial injury findings of edema, abnormal ligament contour, or single-bundle tear. If MRI evaluation did not reveal any further pathology, the patient completed nonoperative treatment. Operative management was either arthroscopic or open reduction and fixation at the discretion of the treating surgeon. This was pursued for 3 scenarios: patients with associated pathology on MRI, clinical evidence of concomitant injury, or failure of attempted closed reduction. MRI preceded treatment (nonoperative or operative) in 47.5% (28/59) of type II fractures. Type III fractures were recommended for surgical intervention at the time of initial presentation or if successful reduction was not obtained at the discretion of the treating surgeon. The decisions to obtain MRI preoperatively and to treat these patients arthroscopically versus open reduction were based on surgeon's preference. Fracture reduction was verified intraoperatively with fluoroscopy, and patients had repeat radiographs obtained approximately 6 weeks after surgery. After surgical fixation, Lachman examination was repeated intraoperatively and 6 weeks after surgery. All operative reports and images (Fig. 1) included a description of any ACL injury, including hyperemia, partial tear, avulsion, complete midsubstance tear, or laxity with the postfixation Lachman examination.

Statistical Analysis

Descriptive statistics were used to summarize demographic and clinical characteristics of all subjects included in the cohort. Group differences for categorical variables (sex, MRI testing, mechanism of injury, and concomitant intra-articular injury) were analyzed using χ^2 tests. A 2-sample *t* test was used to compare groups regarding age. The proportions of subjects with associated ACL or ACL and meniscal/chondral injuries were calculated. Sensitivity and specificity were calculated for MRI evaluation and surgery, agreement between MRI relative to intraoperative assessment.

Logistic regression was used to test the association between age, sex, and MRI administration as well as between age and ACL revision surgery. Hypothesis tests were assumed to be 2-sided with a significance level of 0.05. R version 3.1.1 software (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/) was utilized.

RESULTS

Demographics

Between 1998 and 2014, 129 patients (44 females, 85 males) with fractures of the anterior tibial spine met inclusion criteria, of which 27 were type I fractures, 59 were type II fractures, and 43 were type III fractures.

Characteristics of ACL injury

There were 25 ACL injuries identified at the time of ATSF. Only one of the type I fractures sustained ACL injury at the time of ATSF. Sixteen of the type II fractures (27.1%) and 8 of the type III fractures (18.6%) had grossly visible concomitant ACL injury intraoperatively or on MRI.

Overall, males were significantly more likely to have ATSF/ACL injury ($P \leq 0.01$, 87.5%). Patients with ATSF/ACL injury were also significantly older than those with isolated ATSF injury ($P = 0.02$). Pooling the type II and type III ATSF/ACL injuries, 22 patients (91.7%) underwent ATSF surgical fixation, whereas 73.1% of type II or type III ATSF without ACL injury required surgery (57/78) ($P = 0.01$). There was no difference in mechanism of injury or type of ATSF surgery between ATSF and ATSF/ACL cohorts. Please see Table 1 for characteristics of type II and type III injury patterns.

Imaging

All isolated ATSFs were identified on plain XR, with MRI utilized for identifying concomitant pathology. Neither age nor sex was significantly associated with increased likelihood of obtaining an MRI ($P = 0.25$ and 0.10, respectively). Ten of the 27 type I ATSFs underwent MRI, and none noted ACL injury. Overall, only 33% of combined ATSF/ACL injury was diagnosed on imaging. Patients with type II or type III ATSF/ACL injury were significantly more likely to have undergone MRI than those with ATSF injury alone (72% vs. 35%, $P \leq 0.01$). Of the 44 MRI-imaged type II and type III ATSF patients, 17 (38.6%) had ACL injury either noted on MRI or during surgery. There was no difference in rate of imaging diagnosis between type II and type III ATSF/ACL injuries ($P = 0.08$).

Method of Diagnosis

Totally, 33 patients had both preoperative MRI and surgery, 16 of whom had combined ATSF/ACL injuries (11 type II, 5 type III), whereas the other 17 had isolated ATSF injury. There was 100% MRI and intraoperative agreement regarding whether an ATSF injury was or was not present. One of the 16 patients with combined ATSF/ACL was diagnosed both on MRI and intraoperative evaluation, whereas 5 were noted only on preoperative MRI and 10 were noted only intraoperatively. The specificity of MRI diagnosis of ACL injury in ATSF patients was 0.77, whereas the sensitivity was 0.09. There was no agreement between the 2 diagnostic instruments, MRI and intraoperative observation, with a $\kappa = -0.15$.

Type I ATSF patients had MRI and/or operative evaluation 44% of the time. As there was only 1 ATSF/ACL injury, further comparison was not performed.

Of the 59 patients with type II ATSF, 50 patients (85%) had MRI and/or operative evaluation of ACL injury. MRI evaluation was significantly more common in type II ATSF/ACL-injured patients (75%) than in those with isolated ATSF injury (37%) ($P = 0.02$). Of the 28 type II ATSF patients with MRI imaging, 12 (42.8%) had ACL injury noted either on imaging (33%, 4/12 patients) or subsequent surgery (67%, 8/12 patients). Four of the 31 patients who did not have MRI (12.9%) were subsequently found to have ACL injury during surgery.

Of the 43 patients with type III ATSF, 39 (91%) had MRI and/or operative evaluation. There was no significant difference in the rate of MRI evaluation between ATSF and ATSF/ACL groups ($P = 0.13$). Five of the 16 patients (31.3%) with MRI imaging had ACL injury on either imaging (80%, 4/5 patients) or arthroscopy (20%, 1/5). Three of the 27 patients without MRI (11.1%) were subsequently found to have ACL damage intraoperatively.

Prevalence of ACL Injury

The 3 most common ACL injuries in pooled type II and type III ATSFs were MRI edema (7), ACL tear (partial or full) (6), and intraoperative residual ACL laxity with Lachman testing following fixation (6). Of the 16 ACL injuries noted in type II ATSF, 12 (75%) were identified intraoperatively (4 hyperemia, 3 residual laxity, 4 partial tears, and 1 femoral avulsion), whereas 50% of the ACL injuries in type III ATSF were visually identified intraoperatively (1 hyperemia and 3 residual laxity). Table 2 further characterizes ACL injuries.

TABLE 1. Characteristics of Type II and Type III ATSF and ATSF/ACL Injury Patterns

Type II	ATSF/ACL (N = 16)	ATSF (N = 43)	P	Type III	ATSF/ACL (N = 8)	ATSF (N = 35)	P
Age (mean ± 2SD)	13 (12, 14)	10 (10, 11)	< 0.01	Age (mean ± SD)	10 (8, 12)	10 (9, 11)	0.64
Sex [n (%)]			< 0.01	Sex [n (%)]			1
F	1 (6)	20 (47)		F	2 (25)	11 (31)	
M	15 (94)	23 (53)		M	6 (75)	24 (69)	
MRI [n (%)]	12 (75)	16 (37)	0.02	MRI [n (%)]	5 (62)	11 (31)	0.13
Mechanism [n (%)]			0.66	Mechanism [n (%)]			0.19
AP	2 (12)	2 (5)		AP	0 (0)	1 (3)	
Bike	4 (25)	10 (23)		Bike	0 (0)	9 (26)	
Fall	1 (6)	8 (19)		Fall	3 (38)	7 (20)	
HE	1 (6)	1 (2)		HE	1 (12)	0 (0)	
Sport	7 (44)	18 (42)		Sport	4 (50)	17 (49)	
Unknown	1 (6)	4 (9)		Unknown	0 (0)	1 (3)	
Surgery [n (%)]	14 (88)	25 (58)	0.03	Surgery [n (%)]	8 (100)	29 (83)	0.21
Other injury [n (%)]	8 (50)	8 (19)	0.02	Other injury [n (%)]	4 (50)	5 (14)	0.05

ACL indicates anterior cruciate ligament; AP, auto versus pedestrian; ATSF, anterior tibial spine fractures; F, female; HE, hyperextension; M, male; MRI, magnetic resonance imaging.

Concomitant Injury

Fifteen concomitant injuries were noted in 13 (54.2%) of the 25 patients with type II or type III ATSF/ACL injuries, which was significantly higher than concomitant injury in ATSF injuries without ACL damage (15%) ($P \leq 0.01$). Type II and type III combined ATSF/ACL injuries were equally likely to have an additional associated injury, at a rate of 50%. Meniscal tear represented 9 of the 15 injuries. The most common injury in both type II and type III combined ATSF/ACL injuries was a lateral meniscus tear. Although 3 type II ATSF/ACL patients had associated meniscal injuries requiring surgery, no type III ATSFs required any meniscal or chondral surgery. Please see Figure 2 for more details.

ACL Reconstruction

Of the 25 patients with ACL injury at time of surgery, 5 patients (20%) went on to require later ACL reconstruction from 3.5 to 48 months following index ATSF/ACL injury. All 5 patients sustained their initial ATSF during sport. Four of the 5 patients had ACL injury noted intraoperatively and not on MRI. Eighty percent of these patients were male and required ACL reconstruction within 15 months of ATSF fixation. The 1 female requiring reconstruction did so 4.5 years later following a second injury mechanism. Four of the 16 type II combined ATSF/ACL injuries (25%) required ACL reconstruction, whereas 1 of the 8 type III combined ATSF/ACL injuries required ACL reconstruction.

TABLE 2. Combined ATSF/ACL Injuries by ATSF Type

Injury	Type II ATSF/ ACL	Type III ATSF/ ACL	Total
Edema	3	4	7
Partial ACL tear	4	0	4
Complete ACL tear	1	0	1
Laxity	3	3	6
Femoral avulsion	1	0	1
Hyperemia	4	1	5
	16	8	24

ACL indicates anterior cruciate ligament; ATSF, anterior tibial spine fractures.

DISCUSSION

Our primary finding was that 19.4% of skeletally immature patients with ATSF had an associated ACL injury. Older, male adolescent populations seem to be at highest risk for a combined ATSF/ACL injury. MRI evaluation poorly identified these ACL injuries in the setting of ATSF, such that 75% of type II and 50% of type III combined ATSF/ACL injuries were not diagnosed until surgery.

Patients who sustained ACL injury at the time of ATSF (mean, 12 y old) were significantly older than those with isolated ATSF (mean, 11 y old). The average age for combined ATSF/ACL injury in type II (13.1 y) and type III (9.8 y) was within the established age range of 8 to 14 for pediatric ATSF fractures.[1,2] It has been well described that this age group is predisposed to tibial spine fractures because of the immature cancellous bone surrounding the

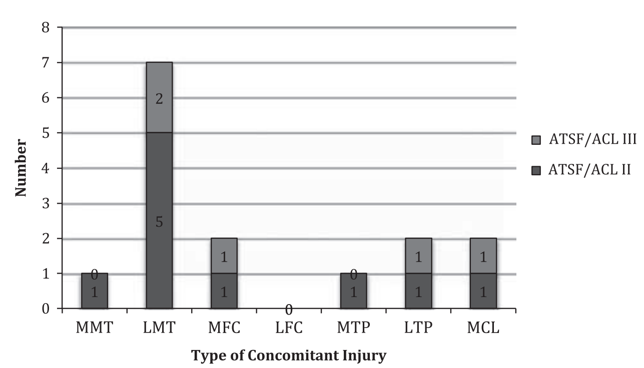

FIGURE 2. Concomitant knee injuries in type II and type III combined ATSF/ACL injuries. ACL indicates anterior cruciate ligament; ATSF, anterior tibial spine fractures; MMT/LMT, medial/lateral meniscus tear; MFC/LFC, medial/lateral femoral condyle fracture; MTP/LTP, lateral tibial plateau fracture; MCL, medial collateral ligament injury.

tibial spine, allowing it to avulse.[12] Our finding that increased adolescent age is associated with ACL injury has been similarly described in adolescents with symptomatic, isolated partial ACL injury. Kocher et al[13] studied 45 adolescents with partial ACL tears and found that 31% required subsequent ACL reconstruction for subjective instability. They reported that increased age was an independent risk factor for symptomatic instability requiring ACL reconstruction. Therefore, it can be inferred that an ATSF with an associated ACL injury in an older patient has an increased risk for future symptomatic instability and/or ACL reconstruction.

In our series, the vast majority, 87.5%, of ATSF/ACL injuries occurred in males. Previous studies found no sex differences when looking at ATSF injury alone.[1,2] Male-predominant ATSF/ACL injury also differs from sex patterns in ACL injury, as ACL injury has been shown to be 5 to 8 times more common in females.[14] Females have been described as relatively at risk for ACL failure because of increased ligamentous laxity, quadriceps dominance, and increased knee valgus.[15] Ahmad et al[16] found that older adolescent males have significantly decreased ligamentous laxity on KT-1000 testing when compared with females and younger adolescent males ($P = 0.0015$). Thus, when an older adolescent male sustains an injury pattern consistent with ACL rupture, force may propagate through the stiffer ACL, but ultimately manifest as an ATSF. The intrinsic damage to the ACL is likely still present, however, which is consistent with our findings in this older adolescent, male subpopulation.

Despite the ability of MRI to detect ACL injury at the time of ATSF, there was poor concordance between MRI evaluation and ACL injury diagnosis in the setting of ATSF. The majority of combined ATSF/ACL injuries were identified during surgical treatment. Limited effectiveness of MRI evaluation of delayed ACL injury in the setting of ATSF has been previously described. Wilfinger et al[17] clinically reevaluated 38 patients approximately 3 years after nonoperative management of ATSF and found 9 patients (23%) had ACL laxity on clinical examination. These patients had MRIs, and 5 of the 9 had evidence of ACL injury. This rate of ACL injury is similar to our finding that 19.4% of the patients experienced ACL injury at the time of ATSF. Although Wilfinger performed MRI examination long after ATSF injury, they did experience poor concordance between MRI damage and anteroposterior laxity on examination.

A recent meta-analysis reaffirmed diagnostic arthroscopy as the gold standard when compared with MRI for evaluation of ACL injury. Phelan et al[18] included 14 studies comprised 930 patients with ACL injury, who underwent MRI evaluation and knee arthroscopy. Knee MRI was 87% sensitive (0.77 to 0.94) and 93% specific (0.91 to 0.96) for diagnosing ACL injury. Although Lawrance et al[19] found MRI to have excellent sensitivity for diagnosing normal (92%) and completely torn ACLs (99%), the sensitivity of partial ACL tears was only 11%. The discordant diagnoses we found between MRI and intraoperative evaluations were likely because the combined ATSF/ACL injury is not previously described. We argue that MRI evaluation of ATSF patients may not identify ACL pathology, but should be utilized in type II and type III ATSFs because of the high rate of meniscal and chondral damage that could necessitate a transition from nonoperative to operative management.

To our knowledge, there is no literature that has evaluated anteroposterior knee laxity or ACL injury at the time of ATSF. Multiple long-term studies have shown clinical, asymptomatic anteroposterior ligamentous laxity as well as increased translation with KT-1000 testing.[20,21] In a long-term follow-up of 10 pediatric patients requiring surgical fixation for ATSF, Perugia et al[20] reported 3 patients had 6 mm of anteroposterior laxity on KT-1000 testing compared with the contralateral knee. Six patients also clinically had grade 1 or grade 2 pivot shift. In our study, 6 patients who had surgery for ATSF were found to have persistent laxity with intraoperative Lachman examination following anatomic reduction and fixation of the tibial spine in concordance with the previous literature. Despite evidence of residual laxity and thus intrinsic ACL injury following surgical ATSF fixation, the clinical significance is debatable.

Symptomatic instability has been previously reported[22,23] following nonoperative management of displaced type II and type III ATSFs, up to 16.7% of which did require subsequent surgical stabilization. In addition, Mitchell et al[24] found that 19% of pediatric patients with ATSF went on to require delayed ACL reconstruction at least 2 years after ATSF management and that the only predisposing factor for secondary ACL surgery was increasing age ($P = 0.02$). This rate is very similar to our finding that 20.8% of patients with combined ATSF/ACL injury went on to require ACL reconstruction.

Concomitant intra-articular injuries in pediatric ATSF and ACL injuries have been described separately. We found a significant increase in concomitant injuries in ATSF/ACL patterns compared with those in isolated ATSF. Meniscal tears occurred in 32% of our cohort with ATSF/ACL injury and were predominately lateral. Shea et al's[25] MRI study of 20 skeletally immature ATSF patients showed a 40% rate of meniscal tear, equally medial and lateral. In addition, Johnson et al[8] and Mitchell et al[7] found that meniscal pathology was present in 30% of their 20 ATSF patients on MRI, mostly in type III ATSF. Anderson and Anderson[26] retrospectively evaluated 130 patients under age 17 with ACL reconstruction and found 70 lateral and 42 medial meniscus tears at the time of ACL reconstruction. In the same series, chondral injuries were found in 13% of patients and strongly associated with a delay to surgery. We believe our ATSF/ACL cohort concomitant injuries are more consistent with ACL injury with a high proportion of lateral meniscal tears and relatively low rate of chondral injury (16%).

Limitations

This is the first publication of concomitant ACL injury at the time of ATSF in a large cohort, but our study has multiple limitations. The retrospective design precludes high-level evidence appropriate for treatment guidelines, thus additional prospective studies are needed. Although multiple MRI and intraoperative ACL diagnoses were identified in the ATSF/ACL-injured patient, our cohort was not large enough to delineate which were clinically significant.

CONCLUSIONS

This study found that nearly 20% of patients with ATSF sustained concomitant ACL injury, and these findings have not been previously reported. Patients with a significantly higher rate of combined ATSF/ACL injury were older adolescent males. ATSF/ACL injury was most prevalent in type II and type III ATSFs when compared with type I. MRI evaluation was not reliable for ACL injury diagnosis, and many ACL injuries were diagnosed intraoperatively. Intra-articular injury in addition to ACL injury occurred significantly more in ATSF/ACL injuries as opposed to ATSF injury alone.

Recommendations

Given the known high rates of acute meniscal, chondral, and now ligamentous laxity associated with ATSF, providers must be cognizant of patients at risk. Adolescents with an ATSF who are older and male should be advised that they have an increased risk of having sustained an ACL injury, but it remains unclear if this ACL injury will be symptomatic. If there is any concern for intra-articular injury beyond ATSF, we recommend MRI evaluation and any necessary conversion from nonoperative to operative management to address the high concomitance of meniscal and chondral pathology. Parents and pediatric patients alike should be made aware of the possibility of intrinsic ACL injury at the time of ATSF that could result in symptomatic ligamentous laxity.

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