Evaluating Differences in Baseline Knee Hyperextension and Postoperative Stiffness Between Patients With Tibial Spine Fracture Versus ACL Tear

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Background: While generalized ligamentous laxity is a risk factor for anterior cruciate ligament (ACL) reconstruction failure, there is a paucity of literature evaluating underlying dynamic risk factors predisposing pediatric and adolescent patients to ACL tears or tibial spine fractures.

Purpose: To (1) evaluate differences in baseline knee hyperextension and postoperative knee stiffness between patients who sustained tibial spine fractures versus ACL tears and (2) determine whether there were other demographic and dynamic injury differences between these patients.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: We evaluated patients aged between 9 and 17 years old who were treated at a tertiary pediatric hospital between 2012 and 2020 for a tibial spine fracture or an ACL tear. Patients in each injury group were matched based on age and physeal closure status. The demographic characteristics and pre- and postoperative clinical variables were recorded, and bivariate analysis and binomial logistic regression were performed to compare the proportion of patients with knee hyperextension— denoted as uninjured knee hyperextension $>3°$—between injury types and evaluate additional risk factors for injury, respectively.

Results: Overall, 405 patients were included, 81 with tibial spine fractures and 324 with ACL tears. Patients with ACL tears were more likely to have increased knee hyperextension compared with those with tibial spine fractures (36% [115/324] vs 24% [19/81]; *P* = .047). This was also observed when controlling for age and physeal closure status. In patients aged ≤14 years with open physes, 39% with ACL tears had hyperextension versus 18% with tibial spine fractures (*P* = .003). No difference was observed in the proportion of patients who developed postoperative stiffness (2.5% for ACL tears vs 6% for tibial spine fractures; *P* = .091). Patients with ACL tears were more likely to have sustained a noncontact mechanism of injury compared with patients with tibial spine fractures (62% [202/324] vs 39% [32/81]; *P* = .0002).

Conclusion: Patients with ACL tears were more likely to have increased knee hyperextension and to have sustained a noncontact injury compared with those with tibial spine fractures. Postoperative knee stiffness after tibial spine fixation may be related to this baseline reduced knee extension rather than the injury itself.

Keywords: anterior cruciate ligament rupture; anterior cruciate ligament tear; knee hyperextension; pediatric orthopaedics; pediatric sports medicine; postoperative stiffness; tibial spine fracture

Tibial spine fractures and anterior cruciate ligament (ACL) tears both occur in the skeletally immature knee. ACL tears are a common sports injury seen in the adult and pediatric populations, with an estimated 100,000 to 200,000 cases per year in the United States.[18,19] In contrast, tibial spine fractures are reported much less frequently than ACL tears and account for 2% to 5% of all pediatric knee injuries.[33] Most tibial spine fractures occur

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in patients aged between 8 and 14 years.[2,5] The pathophysiology suggests that at this age, the subchondral bone underlying the nonarticular portion of the tibial eminence is weak, thus the bone fails (or avulses) before the ACL ruptures.[24,40] Therefore, historically, tibial spine fractures were referred to as *the pediatric ACL tear*.[12] With an increase in participation in high-level youth athletics, there has been an increase in the incidence of knee injuries—including both tibial spine fractures and ACL tears, with injuries occurring at younger ages.[37]

Differences in injury patterns have been attributed to a variety of factors—including loading conditions (loading the ACL in tension frequently at low velocity leads to tibial spine fractures before ACL fails in continuity),[12,30] relative strength of the tibial eminence at the ACL insertion,[42] and anatomic differences (eg, intercondylar notch width,[43] posterior slope of the proximal tibia, and angle of inclination of the intercondylar roof).[3,11,22,32,34,36,38] While these previous studies have evaluated structural differences between injury patterns, few studies have examined dynamic parameters as risk factors for tibial spine fractures versus ACL ruptures. One such risk factor that has been implicated is baseline knee hyperextension.[15,25] Previous studies have demonstrated that generalized ligamentous laxity is associated with an increased risk of ACL injury[23,29,31,39]; however, there is a paucity of literature comparing ligamentous laxity between patients sustaining tibial spine fractures and those sustaining ACL tears, especially in the pediatric and adolescent patient population. Furthermore, postoperative knee stiffness is a common concern after tibial spine avulsion fracture operative fixation; nonetheless, the exact etiology continues to be explored.[9,13]

The primary aim of this study was to determine whether baseline knee hyperextension in the pediatric and adolescent patient population was correlated with ACL tears versus tibial spine fractures and detect whether there was a difference between pre- and postoperative knee motion between injury types. The secondary aim was to determine whether other demographic or dynamic injury characteristics were associated with tibial spine fractures versus ACL tears. We hypothesized that patients with ACL tears would have more baseline knee hyperextension than patients with tibial spine tears and less postoperative knee stiffness.

METHODS

After receiving institutional review board approval for the study protocol, we performed a retrospective case-control study evaluating patients who sustained either a tibial spine fracture or an ACL tear at a single tertiary pediatric hospital. Patients were identified using the International Classification of Diseases (ICD)-9 and ICD-10 codes (8442, 82300, 82310, S83.511, S83.512, S83.519, and S82.11). Patients aged between 9 and 17 years who were treated for either a tibial spine fracture or an ACL tear between January 2012 and December 2020 were included. Patients aged between 4 and 8 years were initially evaluated; however, they were ultimately excluded from the study because of the small number of patients with ACL tears in the same age range and the inability to match appropriately. We excluded patients with an incorrect initial diagnosis, previous knee injury or surgery, or incomplete follow-up, as defined by missing $\geq$1 of the following: documented pre- and posttreatment knee range of motion; pre- and posttreatment imaging to assess physeal closure status, or having only a single orthopaedic visit.

Tibial spine fracture and ACL tear diagnoses were confirmed based on the patient's electronic medical records (history and physical examination), radiographs for tibial spine fractures, and magnetic resonance imaging for ACL tears. Tibial spine fractures were classified based on the Meyers and McKeever classification,[27] and ACL tears were characterized as either partial or complete based on preoperative imaging.

Data were collected and organized for all patients who met the inclusion criteria—including information on pre- and posttreatment knee range of motion, presence or absence of generalized ligamentous laxity, physeal closure status, and mechanism of injury. The uninjured knee was assessed for hyperextension, as defined by a passive motion of $>3^\circ$ of hyperextension, and this measure provided a baseline surrogate for the injured knee. As per our institution-specific criteria for documentation of normal knee motion, knee hyperextension during the initial visit was based on clinical examination by fellowship-trained orthopaedic surgeons (B.A.W., J.T.L., T.J.G., K.M.) with at least 3 years of experience. The range of knee motion was evaluated by each orthopaedic surgeon via visual assessment. If there was no initial documentation of the uninjured knee, this measurement was taken from the most recent follow-up visit. As per routine institutional practice, treating physicians also documented their overall impression regarding the presence or absence of generalized ligamentous laxity, which was collected similarly to hyperextension measurements. Generalized ligamentous laxity was defined as either normal (no increased laxity) or increased laxity.

The physeal status of the distal femur and proximal tibia was characterized as either open/closing or completely closed. Knee radiographs at the time of injury

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Ethical approval for this study was obtained from the Children's Hospital of Philadelphia (reference No. 15-012614).

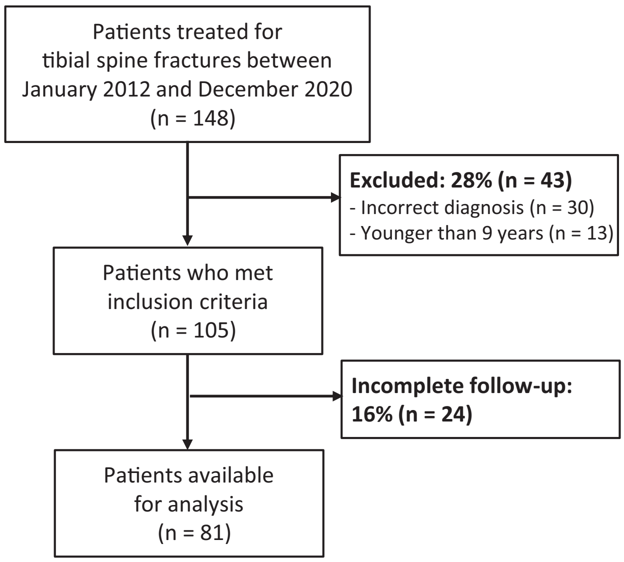

Figure 1. The STROBE flow chart of the study inclusion process for patients with tibial spine fractures. STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

were used to determine growth plate status in patients, when available. If radiographic data were not available at the time of injury or patients had questionable physeal closure status, advanced imaging with magnetic resonance imaging and/or computed tomography scan was used to document physeal closure status. Mechanism of injury was noted at the initial visit and was characterized as either contact or noncontact.

Patients were matched in a 4 to 1 ratio of ACL tear to tibial spine fracture based on age and physeal closure status to minimize the difference in ligamentous laxity attributed to age and skeletal maturity. The 4 to 1 matching was selected to maximize the statistical power to detect a difference between the 2 injury types. A total of 118 patients sustained tibial spine fractures and 1625 patients sustained ACL tears during the 8 years and in patients aged between 5 and 17 years. Of the tibial spine fractures, 11% (13/118) were removed because of age <9 years, and 20% (24/118) were excluded for incomplete follow-up. A total of 81 patients with tibial spine fractures were included in the study (Figure 1). Overall, 1.5% (25/1625) of patients with ACL tears were reviewed but not included in the study because of incomplete follow-up, and 4.6% (75/1625) of patients with ACL tears were reviewed but not included in the study because of our 4 to 1 ACL tear-to-tibial spine fracture matching criteria based on physeal closure status. For proper 4 to 1 matching, data were collected on a total of 324 patients with ACL tears who were matched to the tibial spine fracture cohort according to age and physeal closure status (Table 1).

TABLE 1
Overview of Matched Tibial Spine Fracture and ACL Tear Cohorts[a]

Age at Injury	Tibial Spine Fracture Patients, n	4:1 Matched ACL Tear Patients, n
9 y		
Open physis	4	16
Closed physis	0	0
10 y		
Open physis	4	16
Closed physis	0	0
11 y		
Open physis	6	24
Closed physis	0	0
12 y		
Open physis	16	64
Closed physis	0	0
13 y		
Open physis	14	56
Closed physis	2	8
14 y		
Open physis	13	52
Closed physis	0	0
15 y		
Open physis	6	24
Closed physis	4	16
16 y		
Open physis	2	8
Closed physis	3	12
17 y		
Open physis	5	20
Closed physis	2	8
Total	81	324

[a]Statistical analysis was conducted using SPSS statistical software (IBM Corp). Chi-square analysis, Fisher exact tests, independent *t* tests, and multivariable binomial logistic regression were used. The significance level was set at $P < .05$. ACL, anterior cruciate ligament.

RESULTS

The characteristics of the tibial spine fracture cohort (n = 81) and the 4 to 1 sex- and physeal status-matched ACL tear cohort (n = 324) are summarized in Table 2. A significant sex-based difference was observed between the groups, with 78% (63/81) of patients with tibial spine fractures being men compared with 56% (183/324) of patients with ACL tears ($P < .001$) (Table 2). Most patients treated had open or closing physes (Table 2). Fourteen years was the oldest age group that had no patients with closed physes. Also, 46 patients (56%) with tibial spine fractures were <14 years. The most common type of tibial spine fracture was type 3, and the most common type of ACL injury was a complete tear (Table 2). The mean follow-up length was 11 ± 13 months for tibial spine fractures and 13 ± 9 months for ACL tears.

Patients with ACL tears were more likely to have baseline knee hyperextension (defined as uninjured knee hyperextension >3° on physical examination) compared with patients with tibial spine fractures (36% [115/324] vs 24% [19/81]; P = .047). This result was also noted when controlling for age and physeal closure status (Table 3). In patients aged ≤14 years with open physes, increased knee hyperextension was more frequent in patients with

TABLE 2
Distribution of the Patient and Injury Characteristics for the Study Population[a]

Variable	All Patients (N = 405)	Tibial Spine Fracture (n = 81)	ACL Tear (n = 324)	*P* (2-sided)
Sex				**<.001**[b]
Male	246 (61)	63 (78)	183 (56)	
Female	159 (39)	18 (22)	141 (44)	
Race				.326[c]
White	268 (66)	49 (61)	219 (68)	
Black	80 (20)	22 (27)	58 (18)	
Asian	15 (4)	3 (3.5)	12 (4)	
Hispanic	11 (3)	3 (3.5%)	8 (2)	
Other	31 (7)	4 (5)	27 (8)	
Height, m	1.63 ± 0.12	1.65 ± 0.13	1.62 ± 0.12	.065[d] (95% CI, –0.002 to 0.06)
Weight, kg	58.63 ± 16.98	55.9 ± 15.03	59.28 ± 17.39	.123[d] (–7.48 to 0.89)
Mechanism of injury				**.001**[c]
Noncontact	221 (55)	31 (38)	190 (59)	
Contact	171 (42)	49 (61)	122 (38)	
Unknown	13 (3)	1 (1)	12 (3)	
Laterality				.456[b]
Left	197 (49)	36 (44)	161 (49)	
Right	208 (51%)	45 (56)	163 (51)	
Type of tibial spine fracture[f]				
Type 1	11 (14)	11 (14)	—	
Type 2	19 (23)	19 (23)	—	
Type 3	51 (63)	51 (63)	—	
Type of ACL tear				
Complete	286 (88)	—	286 (88)	
Partial	34 (11)	—	34 (11)	
Not specified	4 (1)	—	4 (1)	
Knee hyperextension				**.047**[b]
$<3^\circ$	271 (67)	62 (77)	209 (64)	
$\geq3^\circ$	134 (33)	19 (23)	115 (36)	
Generalized laxity				**.02**[b]
No	215 (77)	47 (89)	168 (74)	
Yes	66 (23)	6 (11)	60 (26)	
Time to surgery, wk	5.6 ± 6.1	1.6 ± 3.7	5.5 ± 5.9	**.001**[e]
Length of follow-up, mo	12.77 ± 9.8	11.3 ± 13.31	13.14 ± 8.8	0.128[d] (95% CI, –4.3 to 0.54)

[a]Data are presented as n (%) or mean ± SD. Bold *P* values indicate a statistically significant difference between the study groups ($P < .05$).
[b]Fisher exact test.
[c]Pearson chi-square test.
[d]Independent *t* test.
[e]Mann-Whitney *U* test.
[f]Based on Meyers and McKeever classification.[27]

ACL tears compared with tibial spine fractures (39% [88/227] vs 18% [10/57]; P = .003). No difference was observed in the proportion of patients in each injury cohort who had knee hyperextension in those aged ≥15 years with open physes (27% of patients with ACL tears [14/52] vs 46% of patients with tibial spine fractures [6/13]; P = .196). Also, no difference was found in the proportion of patients in each injury cohort who had knee hyperextension in those aged ≥15 years with closed physes (28% [10/36] vs 33% [3/9]; P = .704).

Patients with ACL tears were more likely to have generalized ligamentous laxity, per the treating clinician's clinic notes, compared with those with tibial spine fractures (26% [60/228] vs 11% [6/53]; P = .02). This was also seen in patients aged ≤14 years with open physes (Table 3). Patients who were aged ≥15 years did not demonstrate a difference in the proportion of patients who had generalized ligamentous laxity (23% [6/26] vs 43% [3/7]; P = .358 for open physes; 25% [5/20] vs 14% [1/7], $P \geq .999$ for closed physes, respectively).

No difference was observed in the proportion of patients who lost >3°, >5°, or >10° of knee extension based on injury type, with a minimum of 6, 9, or 12 months of follow-up (Appendix Table A1). No statistically significant difference was observed in the proportion of patients who developed postoperative stiffness requiring a return to

TABLE 3
Proportion of Patients with Knee Hyperextension or Generalized Ligamentous Laxity by Injury Type[a]

Variable	Tibial Spine Fracture	ACL Tear	P (2 sided)
All patients			
Hyperextension >3°	24 (19/81)	36 (115/324)	**.047**
Generalized laxity	11 (6/53)	26 (60/228)	**.02**
Patients aged <15 years with open physes			
Hyperextension >3°	18 (10/57)	39 (88/227)	**.003**
Generalized laxity	5 (2/38)	27 (48/177)	**.003**
Patients aged ≥15 years with open physes			
Hyperextension >3°	46 (6/13)	27 (14/52)	.196
Generalized laxity	43 (3/7)	23 (6/26)	.358

[a]Data are presented as % (n/total). Bold *P* values indicate a statistically significant difference between the study groups (2-sided Fisher exact test; $P < .05$). ACL, anterior cruciate ligament.

TABLE 4
Association of Relevant Patient and Injury Characteristics with Injury Type[a]

Variable	OR (95% CI[b])	P
Female sex	2.33 (1.3-4.2)	**.004**
Race		.15
White	—	
Black	0.48 (0.26-0.9)	
Asian	0.62 (0.16-2.4)	
Hispanic	0.64 (0.15-2.7)	
Other	1.5 (0.48-4.735)	
BMI	1.1 (1.03-1.17)	**.003**
Noncontact injury	2.3 (1.37-3.9)	**.002**

[a]ORs are for the likelihood of sustaining an ACL tear versus a tibial spine fracture . Bold *P* values indicate statistical significance ($P < .05$). ACL, anterior cruciate ligament; OR, odds ratio.
[b]Wald confidence interval.

the operating room for manipulation under anaesthesia or lysis of adhesions between those with tibial spine fractures and ACL tears (6% [5/81] vs 2.5% [8/324], $\chi^2 = 2.86$; *P* = .091). The mean loss of motion between baseline knee hyperextension of the uninjured knee and postoperative hyperextension of the injured knee was not statistically different between patients with tibial spine fractures versus ACL tears (–1.65 ± 4.06 vs −1.71 ± 3.4; *P* = .89 [95% CI, –0.80 to 0.93]). Of note, a difference was observed in time to the operating room between the 2 injury types, with patients sustaining tibial spine fractures undergoing surgery sooner than those with ACL tears (1.6 ± 3.7 vs 5.5 ± 5.9 weeks; *P* = .001).

Patients with tibial spine fractures were more likely to have had a contact mechanism of injury compared with patients with ACL tears (61% [49/81] vs 38% [122/324]; *P* = .001). Based on the multivariable binomial logistic regression, patients with a noncontact mechanism of injury were more than twice as likely to have sustained an ACL tear compared with a tibial spine fracture (odds ratio [OR], 2.3 [95% CI, 1.37-3.9]; *P* = .002). Patient sex was also associated with injury type, where female patients were over twice as likely to sustain an ACL tear compared with a tibial spine fracture (Table 4). Patient pretreatment body mass index (BMI) was also correlated with injury type. Those with higher BMI were more likely to sustain an ACL tear (OR, 1.1 [95% CI, 1.03-1.17]; *P* = .003).

DISCUSSION

The findings of this study demonstrated that a significantly higher proportion of patients who sustained ACL tears had increased baseline knee hyperextension compared with those who sustained tibial spine fractures. Interestingly, we found that skeletal maturity plays a role in those patients with open physes and that increased knee hyperextension was more likely to sustain ACL tears than tibial spine fractures. However, the difference in the proportion of patients with closed physes who sustained an ACL tear compared with a tibial spine fracture with increased knee hyperextension was equivocal.

While previous studies have evaluated how loading conditions and biomechanical properties of the knee influence the different injury types, few studies have directly evaluated the contributions of knee hyperextension or ligamentous laxity to tibial spine fractures and ACL tears.[30,42] This distinction is important, as many studies have shown that generalized joint laxity places young adolescents at a higher risk for both ACL rupture and ACL reconstruction failure.[20,21,23,29,31,39] Furthermore, using a simple and common clinical test to identify at-risk populations due to hyperextension allows for informed training, therapeutic exercises, and selective risk reduction via targeted prevention strategies. To take appropriate preventative measures as well as accurately discuss injury outcomes, providers must understand the nonmodifiable risk factors that place patients at a higher risk for injury.[35] This association with baseline knee hyperextension may account for some of the variation in injury patterns in the skeletally immature knee. Additional factors that may contribute to these different injury patterns include developmental anatomy, growth rate, muscle and tendon imbalances, and neuromuscular control.

While this study demonstrated that baseline knee hyperextension was associated with injury type, this increased knee motion did not appear to influence postoperative knee stiffness in either study arm. One of the major concerns after tibial spine fractures is arthrofibrosis and postoperative stiffness, particularly the inability to achieve full knee extension.[10,17,28] Theoretically, this stiffness could be overlooked in patients who have baseline hyperextension or ligamentous laxity. Our study found no difference in the absolute amount of knee extension lost between patients with ACL tears versus tibial spine injuries. In addition, the proportion of patients who lost postoperative knee extension or required reoperation for knee stiffness was not significantly different between the 2 groups. These results suggest that there is no absolute value difference between patients who had ACL tears and tibial spine fractures in postoperative stiffness; nonetheless, there may be a perceived difference since patients with ACL tears have more hyperextension at baseline. While patients with tibial spine fractures may anecdotally appear to lose more knee extension, the absolute degrees of motion lost were similar to those of patients with ACL tears and may be more apparent because those patients are *stiffer* overall. There was no statistically significant difference between the 2 groups regarding the patient's need for additional surgery due to the functional impact of the loss of motion.

The study results also revealed that patients who sustained a noncontact mechanism of injury were twice as likely to have an ACL tear compared with a tibial spine fracture. Historically these 2 injuries were thought to share the same mechanism of injury.[1,4,41] While earlier studies have shown that patients with ACL tears are more likely to have a noncontact mechanism of injury,[8] no studies have directly compared the mechanism of injury patterns between tibial spine fractures and ACL tears. Recent studies have demonstrated that bicycling accidents and sports injuries were the most common cause of tibial spine fractures in adolescents.[5] Furthermore, there is a reported difference in the type of sports injury leading to these 2 injury patterns.[26] Football was the most common sport leading to tibial spine fractures and soccer was the most common for ACL tears. These studies lend credence to our results as well, given the risk of higher impact contact injuries in football compared with the known pivoting and noncontact injuries endured playing soccer. Because of the increased participation in youth sports and sports specialization, continued clinician awareness of how the type of sport and mechanism of injury influence the injury pattern can lead to improved diagnosis and prognostic predictions for each patient.

Women were over 2 times more likely to sustain an ACL tear compared with a tibial spine fracture. Given that previous epidemiologic data have shown that men are more likely to sustain tibial spine fractures, and women are more likely to sustain ACL injuries, our cohorts mirror these differences between the injury types.[5,14] Last, increased BMI was associated with ACL tears. Elevated BMI and height have been considered to be risk factors for ACL tears.[26] While elevated BMI may increase the force of injury, it is unclear how BMI definitively plays a role in increasing the risk for ACL tears. Our study was aligned with earlier studies comparing tibial spine fractures and ACL tears and demonstrated that patient race was not associated with injury types.[26]

Limitations

Aside from the limitations inherent in any retrospective study, we acknowledge that this study has additional limitations. Notably, contralateral (uninjured) knee hyperextension was used as a surrogate for preinjury hyperextension of the injured knee. While the posttraumatic injured knee could not be assessed preoperatively given pain, guarding, and swelling, it is conceivable that there may be a baseline difference in motion and laxity between the knees. Since previous studies have documented relative symmetry in laxity between a patient's left and right knee at baseline,[7,16,18,38] the assumption was made that the contralateral (uninjured) knee can serve as a valid proxy. Our study initially sought to use Beighton scores on every patient, as a systemic and standardized evaluation of ligamentous laxity. However, this measure was insufficient to analyze and draw any meaningful conclusions due to limited clinical documentation.[6] Nevertheless, systemic evaluations may overlook hyperextension or ligamentous laxity of the knee, as there are likely patients who have isolated knee hyperextension without an abnormal Beighton score. Furthermore, knee motion was measured via visual assessment by each orthopaedic surgeon. While using a goniometer would have increased the precision of the study, the visual assessment allowed surgeons to follow their standard clinical workflow. Future studies could add goniometer measurements into the evaluations.

Aside from knee hyperextension, which could be objectively measured, a second variable used in this study was the surgeon's comment on the patients' *generalized ligamentous laxity*. While this was a complementary marker of knee laxity and the results mirrored the knee hyperextension, it will be important for future studies to compare the results to a systemic measure like the Beighton score.

CONCLUSION

The findings of this retrospective matched-cohort study demonstrated that skeletally immature patients with knee hyperextension may be more at risk for ACL injuries than tibial spine fractures. Postoperative loss of knee extension is comparable between the injury patterns, and the need to return to the operating room (for exam or manipulation under anesthesia, lysis of adhesions, or removal of loose body) to address loss of knee motion is similar between the groups. Furthermore, a contact mechanism of injury is associated with a higher risk of sustaining a tibial spine fracture compared with an ACL tear. These findings highlight the importance of conducting a thorough history and physical examination—including understanding the mechanism of injury. This information may help manage postoperative expectations, while future studies can explore direct injury prevention strategies in these patient populations.

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REFERENCES

1. Accousti WK, Willis RB. Tibial eminence fractures. *Orthop Clin North Am*. 2003;34(3):365-375.
2. Aderinto J, Walmsley P, Keating JF. Fractures of the tibial spine: epidemiology and outcome. *Knee*. 2008;15(3):164-167.
3. Anderson AF, Dome DC, Gautam S, Awh MH, Rennirt GW. Correlation of anthropometric measurements, strength, anterior cruciate

ligament size, and intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. *Am J Sports Med*. 2001; 29(1):58-66.
4. Anderson CN, Anderson AF. Tibial eminence fractures. *Clin Sports Med*. 2011;30(4):727-742.
5. Axibal DP, Mitchell JJ, Mayo MH, et al. Epidemiology of anterior tibial spine fractures in young patients: a retrospective cohort study of 122 cases. *J Pediatr Orthop*. 2019;39(2):e87-e90.
6. Beighton P, Horan F. Orthopaedic aspects of the Ehlers-Danlos syndrome. *J Bone Joint Surg Br*. 1969;51(3):444-453.
7. Bishop E, Kukulski D, Ennes-Bray W, Frank C, Ronsky J. Differences in dynamic joint stability between dominant and contralateral knees in healthy individuals. Presented at the Orthopaedic Research Society Annual Meeting; Febrauary 4-7, 2012; San Francisco, California.
8. Boden BP, Dean CS, Feagin JA, Garrett WE. Mechanisms of anterior cruciate ligament injury. *Orthopedics*. 2000;23(6):573-578.
9. Bram JT, Aoyama JT, Mistovich RJ, et al. Four risk factors for arthrofibrosis in tibial spine fractures: a national 10-site multicenter study. *Am J Sports Med*. 2020;48(12):2986-2993.
10. Callanan M, Allen J, Flutie B, et al. Suture versus screw fixation of tibial spine fractures in children and adolescents: a comparative study. *Orthop J Sport Med*. 2019;7(11):2325967119881961.
11. Chandrashekar N, Slauterbeck J, Hashemi J. Sex-based differences in the anthropometric characteristics of the anterior cruciate ligament and its relation to intercondylar notch geometry: a cadaveric study. *Am J Sports Med*. 2005;33(10):1492-1498.
12. DeFrancesco CJ, Wilson L, Lebrun DG, Memtsoudis SG, Fabricant PD. Pediatric tibial spine fractures: exploring case burden by age and sex. *Orthop J Sports Med*. 2021;9(9):23259671211027237.
13. Gans I, Baldwin KD, Ganley TJ. Treatment and management outcomes of tibial eminence fractures in pediatric patients: a systematic review. *Am J Sports Med*. 2014;42(7):1743-1750.
14. Gornitzky AL, Lott A, Yellin JL, et al. Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44(10):2716-2723.
15. Guimarães TM, Giglio PN, Sobrado MF, et al. Knee hyperextension greater than 5° is a risk factor for failure in ACL reconstruction using hamstring graft. *Orthop J Sports Med*. 2021;9(11):2325967121 1056325.
16. Hannah RE, Morrison JB, Chapman AE. Kinematic symmetry of the lower limbs. *Arch Phys Med Rehabil*. 1984;65(4):155-158.
17. Vander Have KL, Ganley TJ, Kocher MS, Price CT, Herrera-Soto JA. Arthrofibrosis after surgical fixation of tibial eminence fractures in children and adolescents. *Am J Sports Med*. 2010;38(2):298-301.
18. Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Trends in incidence of ACL reconstruction and concomitant procedures among commercially insured individuals in the United States, 2002-2014. *Sports Health*. 2018;10(6):523-531.
19. Kaeding CC, Pedroza AD, Reinke EK, et al. Risk factors and predictors of subsequent ACL injury in either knee after ACL reconstruction. *Am J Sports Med*. 2015;43(7):1583-1590.
20. Keays SL, Newcombe P, Keays AC. Generalized joint hypermobility in siblings with anterior cruciate ligament injuries and matched unrelated healthy siblings. *Physiother Res Int*. 2020;25(2):e1826.
21. Kim SJ, Kumar P, Kim SH. Anterior cruciate ligament reconstruction in patients with generalized joint laxity. *Clin Orthop Surg*. 2010;2(3): 130-139.
22. Kocher MS, Mandiga R, Klingele K, Bley L, Micheli LJ. Anterior cruciate ligament injury versus tibial spine fracture in the skeletally immature knee: a comparison of skeletal maturation and notch width index. *J Pediatr Orthop*. 2004;24(2):185-188.
23. Krebs NM, Barber-Westin S, Noyes FR. Generalized joint laxity is associated with increased failure rates of primary anterior cruciate ligament reconstructions: a systematic review. *Arthroscopy*. 2021;37(7): 2337-2347.
24. LaFrance RM, Giordano B, Goldblatt J, Voloshin I, Maloney M. Pediatric tibial eminence fractures: evaluation and management. *J Am Acad Orthop Surg*. 2010;18(7):395-405.
25. Larson CM, Bedi A, Dietrich ME, et al. Generalized hypermobility, knee hyperextension, and outcomes after anterior cruciate ligament reconstruction: prospective, case-control study with mean 6 years follow-up. *Arthroscopy*. 2017;33(10):1852-1858.
26. LaValva S, Bram J, Reese T, Ganley T, Aoyama J. Comparing rates of tibial spine fractures to ACL tears: a 7-year trend. *Orthop J Sports Med*. 2020;8(7_suppl 6):2325967120S00500.
27. Meyers MH, McKeever FM. Fracture of the intercondylar eminence of the tibia. *J Bone Joint Surg Am*. 1959;41(2):209-220.
28. Millett PJ, Wickiewicz TL, Warren RF. Motion loss after ligament injuries to the knee: part I: causes. *Am J Sports Med*. 2001;29(5):664-675.
29. Myer GD, Ford KR, Paterno M V, Nick TG, Hewett TE. The effects of generalized joint laxity on risk of anterior cruciate ligament injury in young female athletes. *Am J Sports Med*. 2008;36(6):1073-1080.
30. Noyes FR, DeLucas JL, Torvik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain rate sensitivity and mechanisms of failure in primates. *J Bone Joint Surg Am*. 1974;56(2):236-253.
31. Price MJ, Tuca M, Cordasco FA, Green DW. Nonmodifiable risk factors for anterior cruciate ligament injury. *Curr Opin Pediatr*. 2017;29(1):55-64.
32. Samora W, Beran MC, Parikh SN. Intercondylar roof inclination angle: is it a risk factor for ACL tears or tibial spine Fractures? *J Pediatr Orthop*. 2016;36(6):e71-e74.
33. Scrimshire AB, Gawad M, Davies R, George H. Management and outcomes of isolated paediatric tibial spine fractures. *Injury*. 2018;49(2):437-442.
34. Shelbourne KD, Davis TJ, Klootwyk TE. The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears: a prospective study. *Am J Sports Med*. 1998;26(3):402-408.
35. Shelbourne KD, Rask BP. Controversies with anterior cruciate ligament surgery and rehabilitation. *Am J Knee Surg*. 1998;11(2):136-143.
36. Simon RA, Everhart JS, Nagaraja HN, Chaudhari AM. A case-control study of anterior cruciate ligament volume, tibial plateau slopes and intercondylar notch dimensions in ACL-injured knees. *J Biomech*. 2010;43(9):1702-1707.
37. Stanitski CL. Anterior cruciate ligament injury in the skeletally immature patient: diagnosis and treatment. *J Am Acad Orthop Surg*. 1995;3(3):146-158.
38. Stijak L, Herzog RF, Schai P. Is there an influence of the tibial slope of the lateral condyle on the ACL lesion? A case-control study. *Knee Surgery, Sport Traumatol Arthrosc*. 2008;16(2):112-117.
39. Sundemo D, Hamrin Senorski E, Karlsson L, et al. Generalised joint hypermobility increases ACL injury risk and is associated with inferior outcome after ACL reconstruction: a systematic review. *BMJ Open Sport Exerc Med*. 2019;5(1):e000620.
40. Tuca M, Bernal N, Luderowski E, Green DW. Tibial spine avulsion fractures: treatment update. *Curr Opin Pediatr*. 2019;31(1):103-111.
41. Wiley JJ, Baxter MP. Tibial spine fractures in children. *Clin Orthop Relat Res*. 1990;255:54-60.
42. Woo SLY, Hollis JM, Adams DJ, Lyon RM, Takai S. Tensile properties of the human femur-anterior cruciate ligament-tibia complex: the effects of specimen age and orientation. *Am J Sports Med*. 1991;19(3):217-225.
43. Yellin JL, Parisien RL, Talathi NS, Farooqi AS, Kocher MS, Ganley TJ. Narrow notch width is a risk factor for anterior cruciate ligament injury in the pediatric population: a multicenter study. *Arthrosc Sports Med Rehabil*. 2021;3(3):e823-e828.

APPENDIX

TABLE A1
Proportion of Patients Who Lost Knee Extension Postoperatively According to Injury Type[a]

Variable	Tibial Spine Fracture	ACL Tear	*P* (2 sided)
Patients with a minimum 6-month follow-up			
Loss of >3°	26 (12/46)	37 (102/274)	.144[b]
Loss of >5°	20 (9/46)	28 (77/274)	.227[c]
Loss of >10°	6.5 (3/46)	6.6 (18/274)	≥.999[c]
Patients with a minimum 9-month follow-up			
Loss of >3°	27 (9/34)	40 (86/216)	.136[b]
Loss of >5°	21 (7/34)	31 (66/216)	.235[c]
Loss of >10°	6 (2/34)	7 (16/216)	≥.999[c]
Patients with a minimum 12-month follow-up			
Loss of >3°	27 (7/26)	38 (53/139)	.276[b]
Loss of >5°	23 (6/26)	30 (41/139)	.506[b]
Loss of >10°	8 (2/26)	7 (10/139)	≥.999[c]

[a]Data are presented as % (n/total).
[b]Pearson chi-square test.
[c]Fisher exact test.