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Traumatic injury of the knee extensor mechanism in skeletally immature patients: Outcome and classification☆

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ABSTRACT

Background: The literature is limited on the etiology and outcome of acute traumatic knee extensor mechanism injuries in skeletally immature patients with lack of a reliable classification system.
Methods: Data on patients who sustained an acute traumatic injury of the knee extensor mechanism were reviewed with a minimum of 12-month follow-up. Functional outcome was evaluated regarding knee active range of motion. Functional outcome was described using the Knee Society Score (KSS). Data were expressed as mean ± standard deviation.
Results: Seventy-two patients with 74 knee extensor mechanism injuries were identified. The age at the time of injury was 13.9 ± 1.9 years. They included 59 injuries with tibial tubercle avulsion fracture, six injuries with patellar tendon avulsion without bone injury, six injuries with combined patellar tendon avulsion with tibial tubercle fracture, two injuries with sleeve fracture, and one injury with quadriceps tendon avulsion. According to our classification, type IB1 injury was the commonest injury (79.7%). The time to return to sports was 5.23 ± 2.98 months. The flexion was 128.7° ± 13.3°. A mean terminal extension lag of 5.6° was detected in three patients (4.1%). The KSS was 94.8 ± 8.1 and the functional outcome was graded excellent in 64 patients (88.9%), good in seven patients (9.7%), and fair in one patient (1.4%).
Conclusions: Traumatic injuries of the knee extensor mechanism in skeletally immature patients represent a wide variety of injuries including bony injuries in 82.4% of cases reviewed, tendinous injuries in 9.5%, and both bone and tendinous injuries in 8.1%. Our proposed classification system provides a more precise description of the injury pattern.

1. Introduction

The knee is the most common site of injury in children during sports activity [1]. Traumatic disruption of the extensor mechanism of the knee can occur as a result of injuries of quadriceps muscle, patella, patellar tendon, tibial tubercle, or a combination of these [2,3]. The pediatric knee has particular anatomy due to presence of open physis, which makes it subject to distinct traumatic injuries. Failure of the extensor mechanism in skeletally immature patients occurs frequently at the bone–tendon junctions

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as avulsion injuries because of the high force required to mechanically disrupt the patellar tendon [2]. Injuries can be caused by direct trauma or acute knee flexion against a hardly contracting quadriceps muscle [2]. Although the occurrence of acute traumatic knee extensor mechanism injuries is relatively uncommon, they become more frequent due to increased participation in sports and high-energy recreational activities [2]. The literature is limited on the etiology and outcome of these injury patterns in skeletally immature patients and on their relative frequency.

Although tibial tubercle fractures were classified originally by Watson-Jones [4] then modified by Ogden et al. [5] and Ryu and Debenham [6], they are limited to the bony injuries only and used to describe the fracture pattern. The marked variability of the fracture patterns and the potential association with tendinous injuries make it necessary to develop a classification system for the knee extensor mechanism injuries that might affect the bone, tendon, or both in pediatric patients. The presence of such classification will help for accurate description of the injury pattern, provides uniform descriptive tool for research purposes, and allows for better communication between the surgeon and the child's parents as far as the expectation of postoperative course depending on the injury pattern. The aim of the study was to 1) define causes of acute traumatic injury of the knee extensor mechanism in skeletally immature patients; 2) impose a new classification for the identified causes; 3) evaluate the functional outcome of different injury patterns.

2. Patients and methods

After approval by the local institutional review board, a retrospective review of the electronic medical record was performed to identify pediatric patients who sustained acute traumatic injury of the knee extensor mechanism with a minimum of 12-month follow-up at a level I pediatric trauma center. Demographic and clinical data included age at time of injury, sex, laterality, mechanism of injury, medical history, associated co-morbidity or injuries, complications, diagnostic imaging such as plain radiographs, computerized tomography (CT), and magnetic resonance images (MRI), method of fixation, period of postoperative immobilization, time to return to sports activities, follow-up duration, and further need for surgery were reviewed. Tibial tubercle fractures, if present, were described according to the Ogden classification [5]. The original Watson-Jones classification divides the tibial tubercle fractures into three main categories: Type I with a fracture through tibial tubercle without affection of the physis; type II in which the fracture extends through the physis but not reaching the joint; type III in which the fracture extends across the epiphysis [4]. Ogden et al. [5] modified the classification by further dividing each category into A and B subtypes according to the degree of displacement and communication. Ryu and Debenham [6] added another fracture category (type IV) in which the fracture extends posteriorly through the proximal tibial physis. All patients were categorized according to the new classification system that is based on the site of the traumatic disruption and nature of injury whether bony, tendinous, or combined (Table 1).

The functional outcome was evaluated regarding the final knee active range of motion (AROM) using goniometer and the presence or the absence of terminal extension lag. Additional clinical outcome rating using the Knee Society Score (KSS) was performed based on pain (50 points), range of motion (25 points), and stability (25 points) [7]. Deductions from the calculated score were made if flexion contracture, extension lag, and/or varus or valgus malalignment were present. The functional outcome was further classified into four grades depending on the calculated score: excellent (80–100 points), good (70–79 points), fair (60–69 points), and poor (less than 60 points) [8].

Table 1
The new classification system of the knee extensor mechanism injuries.

Tendon affected	Site of the traumatic disruption	Nature of injury	Number of injuries	Treatment
Type I: lesion of the patellar tendon	IA: lesion at the proximal insertion	IA1. Bone injury only (patellar sleeve fracture)	2	Transpatellar suturing
		IA2. Tendon injury only	1	Transpatellar suturing
		IA3. Bone and tendon injury	0	
	IB: lesion at the distal insertion	IB1. Tibial tubercle avulsion fracture with intact tendon attached to the bone fragment (bone injury only)	59	Cannulated screws ± tension band wiring if small and/or multi-fragmented
		IB2. Tendon avulsion with intact tibial tubercle (tendon injury only)	4	Suture anchors or transosseous suturing ± screw or staple
		IB3. Tibial tubercle avulsion fracture with ruptured tendon (bone and tendon injury)	6	Cannulated screws + suture anchors or transosseous suturing
	IC: lesion at both the proximal and distal insertion	IC1. Bone injury only	0	
		IC2. Tendon injury only	1	Transpatellar suturing (proximally) + suture anchors or transosseous suturing (distally)
		IC3. Bone and tendon injury	0	
Type II: lesion of the quadriceps tendon	IIA: with osteochondral fragment		1	Transpatellar suturing
	IIB: without ostechondral fragment		0	

Table 2
Sports activity associated with traumatic injury of the knee extensor mechanism.

Sports activity	Number of patients	Percentage
Basketball	31	43.1%
Fall	12	16.6%
Football	11	15.3%
Hurdling	9	12.5%
Kickball	3	4.1%
Running	2	2.8%
Gymnastics	2	2.8%
School physical education	1	1.4
Cheerleading	1	1.4

Data were expressed as mean ± standard deviation. We studied the difference between the knee extensor mechanism injury patterns (bone injury, tendon injury, and both bone and tendon injury) that have been used in the new classification regarding the postoperative immobilization period and the time to resume sports activity using analysis of variance (ANOVA) test. Statistical analysis of the difference between the proportion of functional outcome grades based on the knee extension mechanism injury patterns was performed using Chi-square test. Statistical significance was set at $P < 0.05$.

3. Results

Seventy-two patients (68 males and four females) with 74 knee extensor mechanism traumatic injuries were identified. The left knee was involved in 40 patients, and the right knee in 30. There were bilateral knee injuries in two patients. The age at the time of injury was 13.9 ± 1.9 years (range: 6–16 years). They included 59 injuries (79.7%) with tibial tubercle avulsion fracture, six injuries (8.1%) with patellar tendon avulsion without bone injury, six injuries (8.1%) with combined patellar tendon avulsion with tibial tubercle fracture, two injuries (2.7%) with sleeve fracture, and one injury (1.4%) with quadriceps tendon avulsion. The injury occurred in relation to sports activities in 62 patients (83.8%) (Table 2). The mean follow-up duration was 17.1 months (range: 12–40 months). Associated medical conditions were detected in 16 patients (22.22%) (Table 3). Osgood–Schlatter disease was detected in five patients (6.9%). The most commonly detected type of tibial tubercle fracture was IIIB in 31 traumatic injuries (47.7%) according to the Ogden classification (Table 4). According to our classification (Table 1), type IB1 injury was the commonest injury pattern detected in 59 traumatic knee injuries (79.7%). Among 74 traumatic knee extensor mechanism injuries, 67 bone injuries (90.5%) and 13 tendon injuries (17.6%) were found. There were 61 bone injuries only (82.4%), seven tendon injuries only (9.5%), and six combined bone and tendon injuries (8.1%).

Bilateral knee injuries were detected in two patients. The first patient was a 16-year-old male who had bilateral tibial tubercle fractures (IIIB on the right knee and IV on the left knee) and nondisplaced proximal left fibular fracture after falling from height. The patient was classified as IB1 based on our new classification. The second patient was a 14-year-old male who experienced bilateral tibial tubercle fractures (IB on the right knee and IIIB on the left knee). The patient was classified as IB1 on the right knee and IB3 on the left knee because on associated patellar tendon injury.

Plain radiographs were helpful in the diagnosis of tibial tubercle avulsion fractures in 65 injuries (87.8%) (Figure 1). Although the X-ray has less sensitivity and specificity for the diagnosis of tendinous injuries, certain radiological signs were helpful to suspect underlying tendinous injury (Figure 2). Patellar tendon injury was suspected in four patients by the presence of high riding patella detected by the measurement of Insall–Salvati ratio [9], which was calculated on the lateral X-ray of the injured side with the knee in 30° flexion by dividing the length of a line connecting the lower pole of the patella to the tibial tubercle, which represents the patellar tendon length, over the length of a line connecting the upper and lower pole of the patella, which represents the patellar length [2]. The mean measured Insall–Salvati ratio was 2.18 (range: 1.7–2.5). Patellar sleeve fracture was suspected in two patients by the presence of a shadow of detached tiny fragment along the line of patellar tendon, which more likely represents an avulsed periosteal flap that is still attached to the patellar tendon. Combined avulsion fracture of the tibial tubercle and patellar tendon rupture was suspected in six injuries by the measurement of patellar displacement ratio, which was calculated on the lateral images while the knee in 60° flexion by dividing the length of a line connecting the lower pole of the patella to the avulsed tibial tubercle fragment over the length of a line connecting the upper and lower poles of the patella [3]. The mean

Table 3
Co-morbidity associated with the traumatic injury of the knee extensor mechanism.

Associated co-morbidity	Number of patients
Osgood–Schlatter disease	5
Osteogenesis imperfecta	3
Patellar chondromalacia	4
DiGeorge syndrome	1
Epilepsy	1

Table 4
Types of tibial tubercle fracture detected in our study population according to Ogden classification.

Fracture type	Number of injuries	Percentage
IA	1	1.5%
IB	17	26.2%
IIA	1	1.5%
IIB	10	15.4%
IIIA	2	3.1%
IIIB	31	47.7%
IV	3	4.6%
Total	65	100%

measured patellar displacement ratio was 1.6 (range: 1.5 - 2). Quadriceps tendon injury was suspected in one patient by the presence of cortical irregularity involving the superior patellar pole. Also, patella baja might be seen with complete quadriceps disruption.

CT was performed in nine patients (12.5%) with comminuted complex fractures. Non-displaced Salter–Harris type IV fracture of the proximal tibia and displaced intraarticular fracture of the proximal tibial metaphysis were detected in two patients in addition to the tibial tubercle fracture. Bilateral CT arteriogram of the lower extremity was performed in one patient for suspected arterial injury.

MRI was performed in 12 patients (16.6%) with suspected tendinous injuries before the surgery. In four patients, it showed complete patellar tendon rupture without bone avulsion fracture. Partial tear of the patellar tendon was detected in one patient. In two patients, the MRI scans showed no ligamentous or intraarticular injury beside the tibial tubercle fracture type IIIB. In one patient with displaced tibial tubercle fracture type IIIB, scans showed mild partial tearing of the distal patellar tendon laterally at the site of the comminuted fracture fragments with a small portion (less than or equal to 10%) remained attached to the proximal tibia. More than 50% of the medical collateral ligament (MCL) had been avulsed anteriorly in another patient with tibial tubercle avulsion fracture type IIIB. In one patient with tibial tubercle avulsion fracture type IB, MRI scans showed comminuted and displaced tibial eminence anterior cruciate ligament (ACL) avulsion fracture with the anterior and posterior roots of the lateral meniscus attached to the avulsed fragment. There was also a horizontal tear of the posterior root of the lateral meniscus and interbody medial meniscal white zone contusion. MRI scans revealed complete disruption of the quadriceps tendon fibers that were retracted superiorly with a displaced avulsed fragment of the superior patellar cartilage in one patient (Figure 3). In another patient, MRI showed slight irregularity at the free edge of the lateral meniscus equivocal for a small radial tear.

Most cases were diagnosed immediately after the injury without delay, while three patients with tendinous injuries were diagnosed late by seven to 10 days after the time of injury. This was because the X-ray did not show signs of fracture, so it was thought that it might be a contusion and were treated conservatively with immobilization; while in another patient with juvenile idiopathic arthritis (JIA), it was assumed that trauma might exacerbated an arthritis flare and the patient's complaint was more likely due to JIA flare rather than an acute injury. Associated knee ligamentous injury was detected in two patients (2.7%) including MCL tear and ACL avulsion. Meniscus injury was reported in two patients (2.7%).

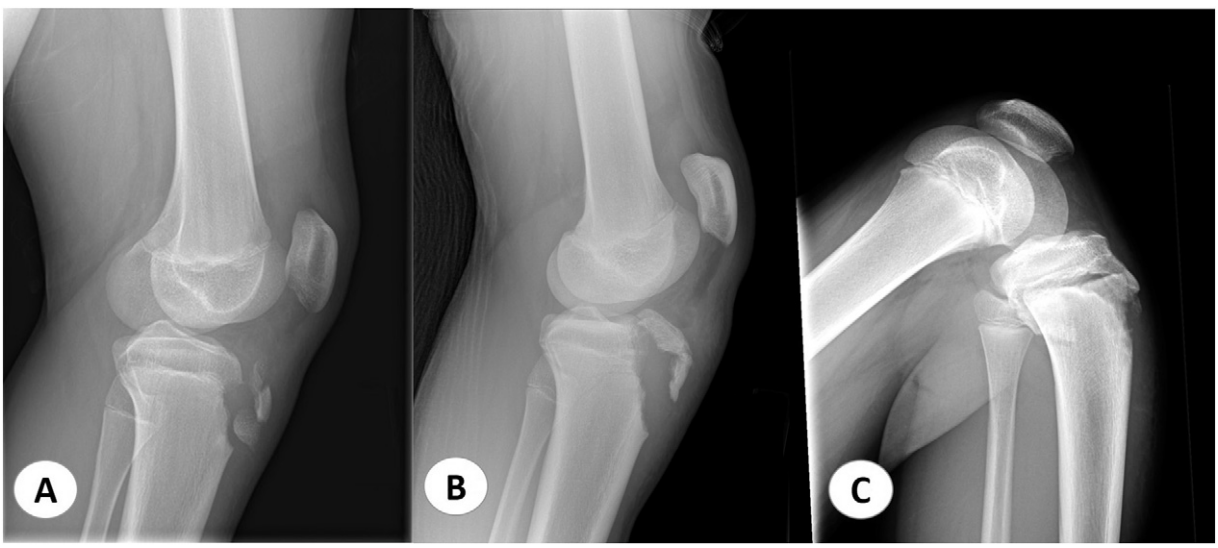

Figure 1. Plain radiographs of the knee show different types of tibial tubercle fracture according to Ogden classification. A) Patient with type IIB fracture; B) patient with type IIIB fracture; C) patient with type IV fracture.

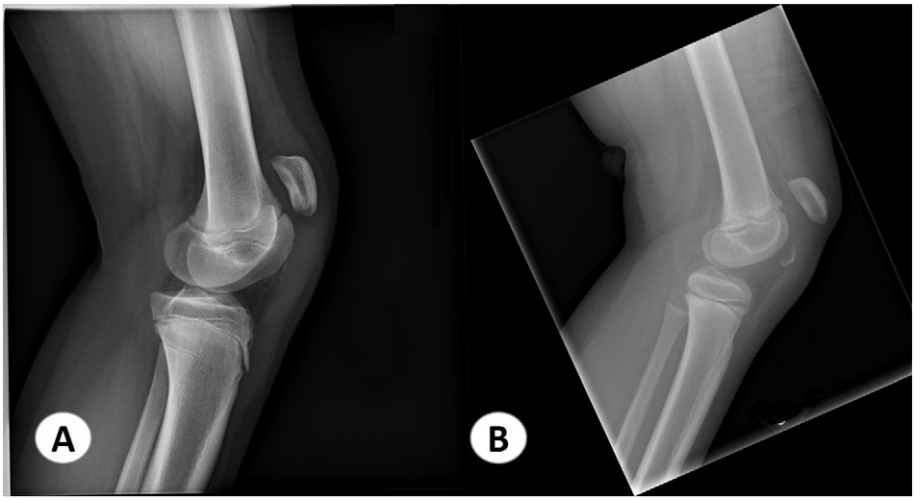

Figure 2. Plain radiographs of the knee in patients with patellar tendon injury. Picture A shows high riding patella with increased Insall–Salvati ratio. Picture B shows detached fragment detected along the line of patellar tendon with high riding patella indicating patellar sleeve fracture.

All patients were treated operatively. Screw fixation (n = 66), transosseous suturing (n = 18), suture anchors (n = 7), tension band wiring (n = 5), and staples (n = 2) were used for the reconstruction for such injuries. Cannulated screws were used with washer (n = 45) or without washer (n = 21). The washers were used to optimize the compression across the fracture site and prevent the screw head from going beyond the cortex. The screws were placed in perpendicular direction to the fracture line and parallel to the epiphyseal plate (Figure 4). The screws were inserted while a derotation pin was used to provisionally fix the avulsed tubercle fragment to the tibia. The screws were used in the treatment of bony and tendinous injuries but when used for patellar tendon reattachment, they were inserted through the periosteal flap still attached to the tendon over a spiked washer.

For patellar tendon avulsion injuries from the tibial tubercle, Krackow stitch type using two No. 2 FiberWire sutures (Arthrex, USA) was placed in the patellar tendon putting one suture at the peripheral side of the tendon, while the other through the central part ending in four suture strands at the distal end of the avulsed tendon. We also used the FiberWire suture passed in a Krackow configuration through the patellar tendon when the avulsed tubercle fragment was small to be held securely by a screw for additional stability. Then, the four FiberWire suture strands were fixed to the tibia using either suture anchors or transosseous tunnel. The used suture anchors were BioComposite suture anchors (Arthrex, USA) and Mitek QuickAnchor (DePuy Synthes, USA). Two suture anchors were placed just medial and lateral to the tibial tubercle after pre-drilling. Two of

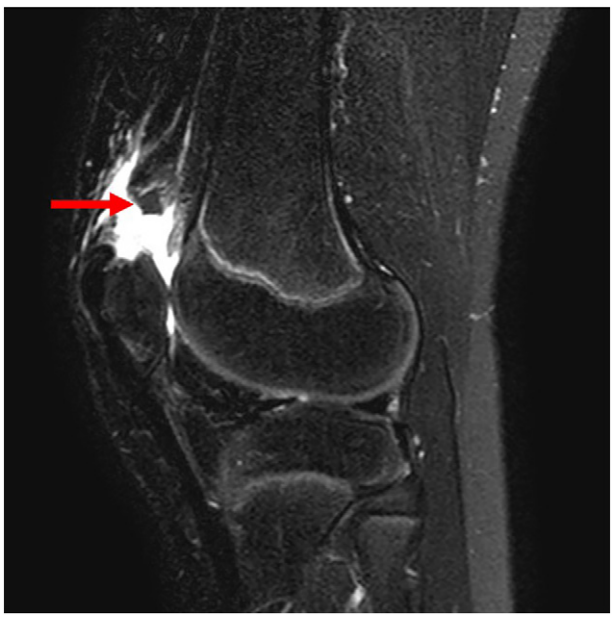

Figure 3. Sagittal T-2 weighted SPIR magnetic resonance image of the knee reveals complete disruption of the quadriceps tendon fibers that were retracted superiorly with a displaced avulsed fragment.

the suture strands (one from the central and one from the peripheral suture strands) were tied to the corresponding suture anchor. A third suture anchor was used in two patients, which was placed just distal to the tibial tubercle. The suture strands of the third anchor were passed through the middle of the patellar tendon using Bunnell suture technique for additional repair reinforcement.

In the patients where the transosseous suturing was performed, two surgical techniques were used. In the first technique, two drill tunnels were made with one tunnel from the center of the tibial tubercle out medially and another from the center of the tibial tubercle out laterally. The FiberWire sutures were passed from the center out; two through each tunnel. Then, a transverse bone tunnel was performed just distal to the tibial tubercle through which the FiberWire sutures were brought from medial to lateral and tied laterally under cover of the anterior compartment musculature. In the second technique, two bone tunnels were performed transversely at the level of tibial tubercle (one tunnel is posterior than the other) through which the suture strands were passed from medial to lateral in one tunnel and from lateral to medial in the other tunnel. The two peripheral FiberWire strands went through the more posterior tunnel, while the two central FiberWire strands went through the more superficial tunnel and tied down. The site of patellar tendon–bone repair was reinforced in all patients by either a screw over a spiked washer, staple, or combination. Any tears of the medial and lateral retinaculum were repaired simultaneously. Surgeon must pay attention to avoid over tightness of the patellar tendon repair; otherwise, patella baja (Figure 5) and limitation of range of motion would ensue.

Tension band wiring was performed to provide additional fixation in patients with patellar tendon avulsion either from the patella or the tibial tubercle and in patients with small and/or multi-fragmented tibial tubercle fracture where the screw fixation alone was not adequate. For that purpose, we drilled transverse tunnel through the middle third of the patella and another transverse tunnel through the anterior tibial cortex just distal to the tibial tubercle. Then, cerclage wire was inserted in a figure of eight fashion and tightened. Measures to prevent over tightness of the wires were taken such as allowing the knee to flex to 90° intraoperatively and using fluoroscopy to get lateral images of the injured and normal knees to ensure comparable patellar height.

For patellar tendon avulsion from the distal patellar pole (sleeve fracture injury), transpatellar suturing was performed in which three longitudinal tunnels were made through the patella. The central two strands of FiberWire suture placed in a Krackow configuration through the patellar tendon and still attached patellar periosteal flap were passed from distal to proximal in the middle tunnel using suture passer, while the peripheral two strands were passed in the lateral and medial tunnels. Then, each central strand was tied with the corresponding peripheral strand over the proximal patellar pole and tightened with the knee in full extension.

For quadriceps tendon avulsion, two FiberWire sutures was placed in a Krackow configuration through the quadriceps tendon and the attached osteochondral fragment ending in four suture strands at the distal end of the avulsed tendon. Then, three bone

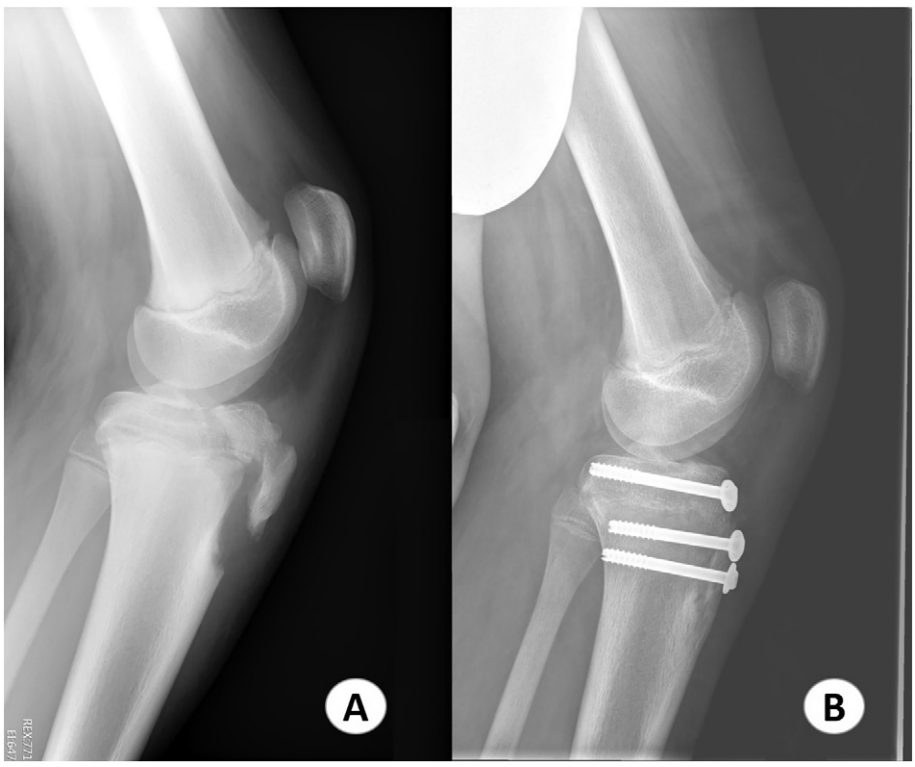

Figure 4. A) Preoperative lateral X-ray knee shows tibial tubercle fracture type IIIB. B) Follow-up X-ray after open reduction and international fixation using cannulated screws.

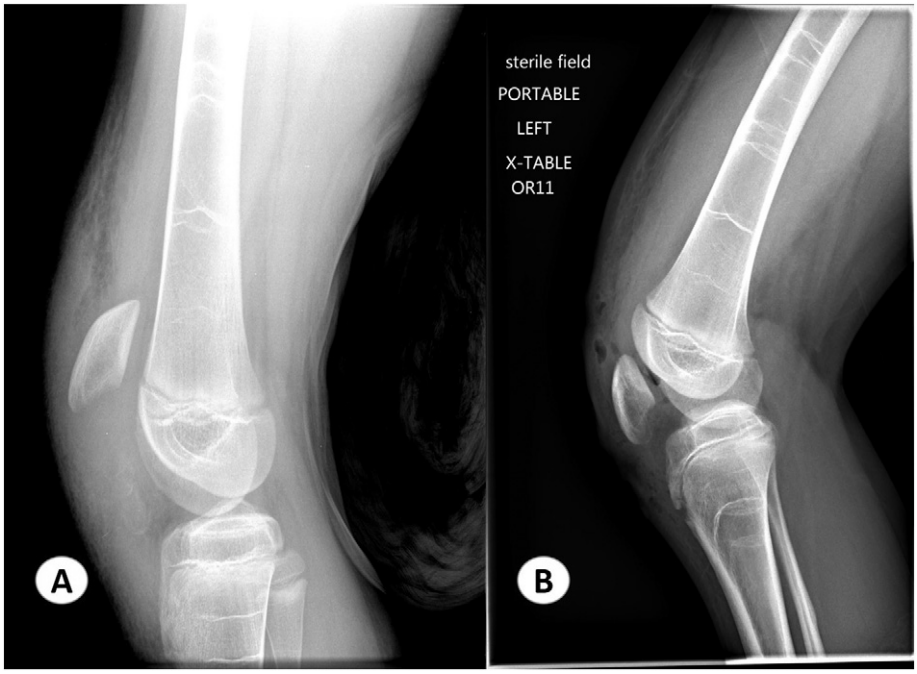

Figure 5. A) Preoperative lateral X-ray knee shows high riding patella with patella tilting due to patella tendon rupture. B) Intraoperative lateral view reveals low lying patella (patella baja) with decreased Insall–Salvati ratio due to over tightness of patellar tendon repair.

tunnels were drilled longitudinally from proximal to distal. The central two strands were passed through the middle tunnel, while the peripheral two strands were passed through the medial and lateral tunnels. The sutures were tied distally over a bridge of bone in the same manner as mentioned previously.

Fourteen adverse events were reported in 13 patients (18%) (Table 5) including patellofemoral pain syndrome in four patients, compartment syndrome in two patients that required fasciotomy, persistent knee effusion in two patients, postoperative fever in one patient that started on the fourth postoperative day with negative workup, growth arrest in one patient, wound infection in one patient that resolved with antibiotic treatment, hamstring muscle contracture in one patient who was not compliant to physiotherapy, heel sore in one patient, and malunion in one patient. Among the patients who developed adverse events after surgery, 11 patients (84.6%) had excellent functional outcome at the final follow-up.

Table 5
Reported adverse events in our study population.

Patient no.	Age	Side	Mechanism of injury	Ogden type	New classification	Surgical procedure	Complication	Knee Society Score	Functional outcome
1	15	Left	Baseball	IIIB	IB1	ORIF using cannulated screws and fasciotomy	Compartment syndrome	93	Excellent
2	15	Right	Basketball	IIB	IB1	ORIF using cannulated screws	Patellofemoral pain syndrome with hamstring contracture	90	Excellent
3	15	Right	Fall	IIIB	IB1	ORIF using cannulated screws and MCL repair using suture anchors	Heel sore	100	Excellent
4	13	Left	Soccer	IIIB	IB1	ORIF using cannulated screws and fasciotomy	Compartment syndrome	95	Excellent
5	16	Left	Fall	IV	IB1	ORIF using cannulated screws	Persistent knee effusion	91	Excellent
6	17	Right	Basketball	IB	IB1	ORIF using cannulated screws	Malunion	100	Excellent
7	14	Right	Basketball	IB	IB1	ORIF using cannulated screws	Patellofemoral pain syndrome	95	Excellent
8	14	Left	Basketball	IIIB	IB1	ORIF using cannulated screws	Wound infection	93	Excellent
9	14	Right	Basketball	IIIB	IB1	ORIF using cannulated screws	Patellofemoral pain syndrome	88	Excellent
10	15	Left	Basketball	IB	IB1	ORIF using cannulated screws	Patellofemoral pain syndrome	70	Good
11	12	Left	Gymnastic	IIB	IB1	ORIF using cannulated screws	Growth arrest	65	Fair
12	13	Right	Fall	IIIB	IB1	ORIF using cannulated screws	Postoperative fever	92	Excellent
13	16	Right	Fall	IIIB	IB1	ORIF using cannulated screws	Persistent knee effusion	91	Excellent

Abbreviations: ORIF, open reduction and internal fixation; MCL, medial collateral ligament.

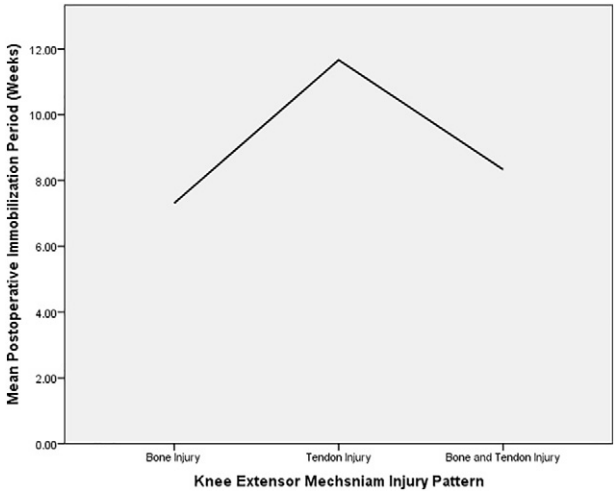

Figure 6. Graphical presentation of the mean postoperative immobilization period reported in the different knee extensor mechanism injury patterns.

The postoperative immobilization after surgery was 7.6 ± 3.5 weeks, which was variable among the different injury patterns (Figure 6). However, the difference was not statistically significant using ANOVA test ($P = 0.09$). The time to return to sports activities was 5.2 ± 2.9 months. The ANOVA test showed a statistically significant difference between the different knee injury patterns (bone injury, tendon injury, and both bone and tendon injury), which have been used in the new classification regarding the time to return to sports activity ($P = 0.001$) (Figure 7). The flexion at the last follow-up visit was 128.7° ± 13.3°. A mean terminal extension lag of 5.6° was detected in three patients (4.1%). Further surgery for implant removal was performed in 15 patients (20.8%). The KSS was 94.8 ± 8.1 (range: 65–100), and the functional outcome was graded excellent in 64 patients (88.9%), good in seven patients (9.7%), and fair in one patient (1.4%). There was a statistically significant increased proportion of excellent functional outcome in the bone injury group in comparison with the tendinous injury group (Figure 8) using Chi-square test ($P = 0.001$).

4. Discussion

The knee is a commonly injured joint in children particularly those who participate in sports activities [1]. Different injury patterns of the knee extensor mechanism were identified affecting bone, tendon, or both. Understanding the classification and outcome of each injury pattern will help the surgeons to provide the patient's family with better expectation of the functional recovery course. The motive behind our study was the increased frequency of knee extensor mechanism injuries in children. We observed different patterns of injuries, which made it necessary to study the causes of such injuries and evaluate their outcome. Pretell-Mazzini et al. [10] mentioned in his review of 23 studies of patients with tibial tubercle fractures that there is

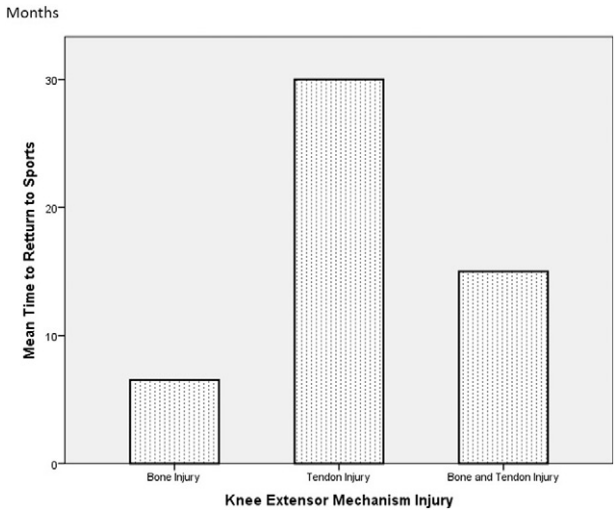

Figure 7. Diagram of the mean time to return to sports reported in different knee extensor mechanism injury patterns.

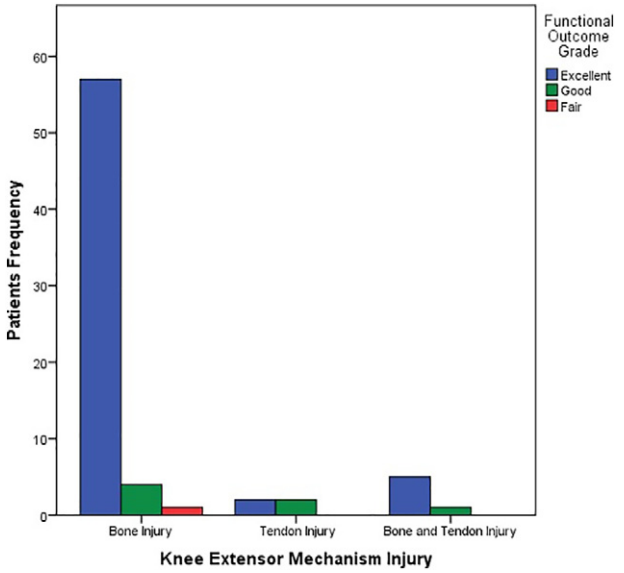

Figure 8. Graphical presentation of the functional outcome grade reported in the different knee extensor mechanism injury patterns.

still limited information regarding associated injuries, treatment recommendations, complications, and functional outcome due to small series studies and the heterogeneous classifications used. The commonly used classification is the Ogden classification, which relies on the tibial tubercle fracture pattern, but it does not consider tendinous injuries. In our study, tendinous injuries were found in 17.6% of our patients. Therefore, the need for more comprehensive classification that includes all injury patterns is emerging. Although the Ogden classification has been used traditionally for the classification of tibial tubercle fracture, it does not offer any prognostic value because no significant difference among fracture types was demonstrated in regard to functional outcome [10]. While our classification offers a prognostic value based on the injury pattern. Our current report demonstrates an earlier return to sports in patients with bone injury and shows increased frequency of excellent functional outcome in patients with bone injury when compared with other injury patterns as well. These data will help surgeons to provide a more reliable expectation for the patient's family regarding the functional recovery of their child based on the injury pattern. To the best of our knowledge, our study is considered the first report on the outcome and classification of different injury patterns of knee extensor mechanism in children. Also, our study represents the largest series of patients with such injury pattern.

The mean age of our study patients at the time of injury was 13.9 years, which is comparable with 13.7 years reported by Frey et al. [11] and 14.6 years reported by Pretell-Mazzini et al. [10]. Although the age range for such injuries is 13–16 years [11], which is consistent with the time of tibial tubercle apophyseal fusion with the epiphysis [3], our age range was six not sex to 16 years. There were 11 patients (15.2%) in our study whose age was below 13 years; nine of them had their injuries during sports activity. Sixty-eight patients (94.4%) were male; similarly, other reports showed high predominance of tibial tubercle fractures in male with comparable percentage of 94.7% [11] and 97% [10]. Because in male, the tibial tubercle apophysis undergoes fusion with the tibia at a later age, when they are heavier with bulky strong muscles that exert higher tensile stress on the weak apophysis [11]. The left knee was affected in 40 patients (55.5%) in our study; similarly, other reports showed more injury predominance on the left side in 59% of patients [10]. Two patients (2.7%) developed bilateral injuries among our series, while one patient (5.2%) among 19 patients had bilateral injuries as reported by Frey et al. [11]. In our study, preexisting Osgood–Schlatter disease was found in five patients (6.9%). Several studies reported the occurrence of tibial tubercle fracture in patients with Osgood–Schlatter disease in different percentages such as 15.7% [11] and 23% [10]. Also, Ali Yousef and Rosenfeld [2] reported the occurrence of patellar tendon rupture in one patient with Osgood–Schlatter disease among a series of five patients. Three patients (4.1%) with osteogenesis imperfecta developed knee injuries including tibial tubercle fracture in two patients and patellar tendon rupture in one patient. Similarly, Frey et al. [11] reported the occurrence of tibial tubercle fracture in one patient with osteogenesis imperfecta. However, no association between Osgood–Schlatter disease or osteogenesis imperfecta and tibial tubercle fracture/patellar tendon rupture has been established.

In our study, the most commonly detected type of tibial tubercle fracture was III instead of IIIB in 33 instead of 31 traumatic injuries (50.8% instead of 41.9%). Similarly, Pretell-Mazzini et al. [10] reported that tibial tubercle type III was the commonest fracture pattern in 48% of patients. In our series, the injury occurred in relation to sports activities in 62 patients (83.8%) and basketball was the most common sports activity involved in such injuries (43.1%). Similarly, 84.2% of patients with tibial tubercle fracture had sports-related injury [11] and playing basketball was the most common cause of injury (42%) [10]. Also, Ali Yousef and Rosenfeld [2] reported the occurrence of patellar tendon rupture in 80% of skeletally immature patients who were engaged in sports activity at the time of injury.

Among our series, associated knee ligamentous injury was detected in two patients (2.7%) including MCL tear and ACL avulsion. Previous reports showed similar knee ligamentous injury in patients with tibial tubercle fracture such as MCL, ACL, coronary, and arcuate ligaments [12–14]. In our study, meniscus injury was reported in two patients (2.7%). Likewise, two percent of patients with tibial tubercle fracture were found to have a meniscal injury [10]. The intraarticular injuries occurred as a result of internal or external twisting forces produced by the body weight while the knee was held in hyperextension at the time of injury [15]. The chance of associated intraarticular injuries is increased in patients with tibial tubercle fracture type III [10,15]. Although the incidence of detected intraarticular injuries is relatively low (2.7%), Pretell-Mazzini et al. [10] believed that the observed low incidence is due to underdiagnosis. Pandya et al. [13] recommended the use of advanced imaging such as MRI, open arthrotomy, or arthroscopy at the time of surgery for the detection of associated intraarticular injuries.

Thirteen tendon injuries (17.6%) were detected. Among these injuries, six injuries (8.1%) included tibial tubercle fracture with ruptured patellar tendon. Although double-hit injury of the knee extensor mechanism is an extremely rare condition, it becomes more frequent due to increased participation in sports and high-energy recreational activities at younger age [3]. Previous report showed that two percent of patients with tibial tubercle fracture suffered from patellar tendon avulsions [10].

In our study, plain radiographs were helpful in the diagnosis of tibial tubercle fractures in 65 injuries (87.8%). Certain radiologic signs were helpful to suspect underlying tendinous injury such as high riding patella in patellar tendon rupture, patellar displacement ratio in combined tibial tubercle fracture and patellar tendon rupture, and possible patella paja in quadriceps tendon injury. However, Pandya et al. [13] believed that 50% of injuries associated with tibial tubercle fracture were underestimated by relying on plain radiographs alone, which often missed the detection of soft tissue injuries. They recommended the preoperative use of CT or MRI for further delineation of the extent of injury. Although CT would accurately provide significant amount of information about the fracture configuration, MRI is the modality of choice for detecting associated soft tissue injuries including ligaments, meniscus, and tendon injuries beside its accuracy for the detection of fracture displacement and bone comminution [16]. The role of MRI is not limited to the preoperative diagnosis of associated soft tissue injuries, but it is also important for surgical planning and selecting the proper treatment approach [16]. Among 52 patients with tibial plateau fractures that are relatively similar injuries to tibial tubercle fractures in children, Yacoubian et al. [17] showed that MRI findings changed the preoperative treatment plan in 23% of patients, which was based on plain radiographs and CT scans only. That was because MRI showed fracture comminution and articular surface depression not detected by X-ray or CT beside its higher sensitivity in the diagnosis of soft tissue injuries [17]. Similarly, the detection of intraarticular lesion or associated tendinous injury in patients with tibial tubercle fracture by the help of MRI would necessitate change in the operative approach by using arthroscopy or change in the modality of surgical fixation.

Among our series, two patients (2.7%) developed compartment syndrome that required fasciotomy. The reported average incidence of compartment syndrome in patients with tibial tubercle fractures was 4% [10] but might reach up to 20% [11], which is believed to be due to injury of the terminal branches of the anterior tibial recurrent vessels at the lateral border of tibial tubercle [18]. Frey et al. [11] reported that patients who underwent fasciotomy recovered well without sequalae. We observed similar findings in our patients who were treated with fasciotomy for compartment syndrome and their functional outcome was excellent.

The aim of treatment of such injuries is to restore the functional integrity of the quadriceps muscle. Variable methods of fixation including screws, transosseous suturing, suture anchors, staples, and tension band wiring were used for the reconstruction for such injuries. The choice of the method of fixation depends on the nature and complexity of injury and the surgeon's preference.

Initially, tibial tubercle fracture type I or II injuries were treated conservatively by immobilization for six weeks, while type III injuries were treated with internal fixation to achieve anatomical reduction [19]. However, some surgeons treated all patients with tibial tubercle fracture with open reduction and internal fixation regardless of the fracture type [20,21]. In the early stages, fixation with heavy chromic suture [4] and Kirschner wires [22] were the preferred method of fixation in skeletally immature patients. Hand et al. [23] and Bolesta and Fitch [20] used a combination of pins and screws for fixation, while Levi and Coleman [21] used variable methods of fixation such as heavy chromic suture, staples, and screws. Polakoff et al. [24] used multiple 6.5 mm cancellous screws supplemented with a tension band wire. For type III fracture pattern, most reports agreed that open reduction and internal fixation must be performed to achieve anatomical reduction. Internal fixation was performed using a screw confined to the epiphysis and parallel to the growth plate with tension band wiring for the apohyseal fragment [19]. However, Bolesta and Fitch [20] treated one patient with tibial tubercle fracture type III with closed reduction and cast after CT showed accurate reduction.

Currently, the primary indications of surgery are fracture displacement [5], intraarticular extension through the proximal tibial epiphysis [5], and tendon avulsion [2]. Open reduction is the mainstay of treatment [10,11,13]. However, conservative treatment by non-weight-bearing immobilization for six weeks might be considered in non-displaced tibial tubercle fracture type IA with intact knee extension [25]. Closed reduction is usually difficult to achieve due to the wide insertion of the patellar tendon, which makes the avulsed tibial tubercle fragment attached to a large periosteal flap, which in turn interferes with adequate fracture reduction [26]. Arthroscopic assisted fixation has been used mainly in fractures with intraarticular extension to evaluate accurate articular reduction and joint congruity. It can be used for the detection of associated ligamentous or meniscus injury as well [11,13,25]. Most surgeons use cannulated screws with or without washers, which are placed in transverse fashion to avoid crossing the epiphyseal plate and apply compression across the fracture line [11,13]. Suture anchors and tension band cerclage wiring were used as well beside screw fixation to provide additional fixation particularly in the presence of small fracture fragments or associated tendinous injuries [2,11,13].

The mean postoperative immobilization period was 7.6 weeks, which is relatively higher than the mean period reported after tibial tubercle fracture which is 5.2 weeks. This is due to the associated tendinous injuries that require a relatively longer period of immobilization. The mean knee flexion at the last follow-up visit was 128.7°, which is comparable with 130.1° reported by Pandya et al. [13]. However, a terminal extension lag of 5.6° was detected in three patients (4.1%). The extension lag might be correlated to quadriceps muscle weakness or joint stiffness. Further surgery for implant removal was performed in 15 patients (20.8%) due to implant-related bursitis. Similarly, Pandya et al. [13] reported secondary surgery for implant removal in 20% of patients. Complications were reported in 13 patients (18%) in our series, which is slightly lower than the overall complication rate of 28% reported by previous reports [10]. Among our patients, the development of complications after surgery did not greatly impact the functional outcome in those patients at the final follow-up visit.

The mean time to return to sports activities for our patients was 5.2 months, which is slightly earlier than 7.2 months reported by Pretell-Mazzini et al. [10]. The time to return to sports was statistically shorter in patients with knee bone injuries in comparison with patients with tendon injuries. The functional outcome was graded excellent in 64 patients (88.9%), good in seven patients (9.7%), and fair in one patient (1.4%). A higher percentage of excellent functional outcome was reported in the bone injury group in comparison with the tendon injury group.

Tendon-to-bone healing occurs slowly and of inferior quality in comparison with bone-to-bone healing [27]. The initial healing at the tendon–bone interface is fibrous and has poor mechanical properties [28]. Even more, the patellar tendon-to-bone repair site has higher failure stress when compared with patellar fracture bone-to-bone repair site [29]. Therefore, the tendon–bone repair site needs to be protected for much longer time in knee tendon injuries till bony integration occurs. These data were derived from experimental models, but its clinical implications have not been studied. In our series, patients with tendon injury had a delayed return to sports activities, while patients with bone injury had a higher proportion of excellent outcome.

In conclusion, among 74 traumatic injuries of the knee extensor mechanism reported in skeletally immature patients, there were 59 injuries (79.7%) with tibial tubercle avulsion fracture, six injuries (8.1%) with patellar tendon avulsion without bone injury, six injuries (8.1%) with combined patellar tendon avulsion with tibial tubercle fracture, two injuries (2.7%) with sleeve fracture, and one injury (1.4%) with quadriceps tendon avulsion. Traumatic injuries of the knee extensor mechanism included a wide variety of injuries that affected bone only in 61 injuries (82.4%), tendon only in seven injuries (9.5%), and both bone and tendon in six injuries (8.1%). Bone injuries were associated with earlier return to sports and higher proportion of better functional outcome compared with tendinous injuries. Our proposed classification system provides a more precise description of the injury pattern, which will assist physicians and investigators in data collection and analysis. It also allows for better effective communication with the family as far as the expectation of postoperative recovery depending on the injury pattern.

Ethical approval

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Declaration of competing interest

The author declares that there is no conflict of interest.

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