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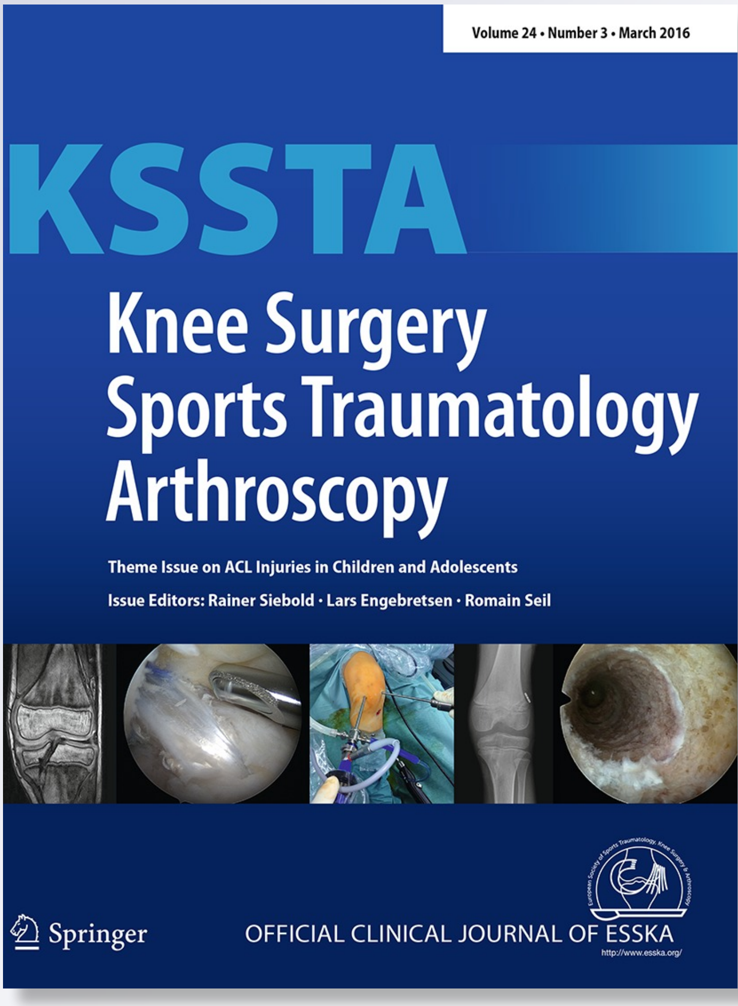

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Abstract The purpose of this report was to describe the surgical technique for and outcomes after a modified physeal-sparing posterolateral corner reconstruction in a 12-year-old skeletally immature male with a mid-substance fibular collateral ligament tear, a proximal posterior tibiofibular ligament tear, and an anterior cruciate ligament avulsion fracture of the medial tibial eminence. A modified physeal-sparing posterolateral corner reconstruction was used to provide a near-anatomic reconstruction of the fibular collateral ligament and proximal posterior tibiofibular ligament. An anterior cruciate ligament repair was also performed. Varus stress radiographs obtained at 6 months postoperatively demonstrated resolution of lateral knee stability. Physical examination results demonstrated stability to anterior tibial translation and a stable proximal tibiofibular joint. Computed tomography showed that the surgical technique successfully avoided breeching the patient's physes.

Keywords Open physes · Posterolateral corner · Fibular collateral ligament · Proximal tibiofibular joint · Anterior cruciate ligament avulsion · Reconstruction

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Introduction

Descriptions of grade III (complete) posterolateral corner (PLC) injuries and treatment approaches in skeletally immature patients are currently limited [1, 13]. Treatment options typically include non-operative management, primary repair, and surgical reconstruction [3, 8, 10, 11]. Compared to treating patients with closed physes, traditional surgical techniques in patients with open physes carry the added risk of growth perturbation secondary to iatrogenic physeal damage [14]. In cases of multiligament knee injuries, multiple repairs and reconstructions compound the risk of physeal disruption. Thus, great care must be taken in treating these patients.

Posterolateral corner injuries treated non-operatively reportedly lead to poor long-term outcomes [4, 6, 10, 11]. Furthermore, PLC injuries treated with primary repair result in higher failure rates compared with reconstruction, especially for mid-substance tears [12, 15]. Therefore, surgical reconstruction is often preferred following grade III PLC injuries, even in skeletally immature patients. While evidence suggests that reconstruction is the best approach in many of these patients, surgical techniques to avoid physeal damage are lacking. Therefore, the purpose of this case report was to describe a physeal-sparing modified PLC reconstruction technique utilized in the case of a 12-year-old male athlete presenting with a mid-substance tear of the fibular collateral ligament (FCL), a proximal posterior tibiofibular ligament tear with significant instability of the proximal tibiofibular joint, and an anterior cruciate ligament (ACL) avulsion fracture of the medial tibial eminence. Note that this case is very rare, particularly in skeletally immature patients, and provides the first reported surgical treatment for the unique combination of posterolateral and

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proximal tibiofibular joint instability in a patient with open physes.

Case Report

A 12-year-old skeletally immature male presented to clinic 3 days after suffering a non-contact football injury. While running, the patient felt a "pop" in his left knee and fell to the ground unable to walk. On physical examination, there was a moderately sized effusion in his left knee and significant tenderness to palpation along the lateral joint line. No endpoint was felt on the Lachman's test. Plain lateral radiographs revealed evidence of a medial tibial eminence ACL avulsion fracture. Varus stress radiographs showed 4 mm of increased lateral compartment gapping in his left knee, consistent with a grade III PLC injury, and an unstable proximal tibiofibular joint on physical examination [7]. Diagnostic magnetic resonance imaging (MRI) revealed a mid-substance FCL tear, a moderate strain of the popliteus muscle and tendon, and confirmed the ACL avulsion fracture off the tibia (Fig. 1). After discussing all options, the patient and his parents elected to proceed with surgery.

Combined Fibular Collateral Ligament and Proximal Posterior Tibiofibular Ligament Reconstruction Technique

The examination under anesthesia was consistent with the previous clinical examination. It was decided that given the patient's unique pattern of instability of both the FCL and proximal tibiofibular joint, two previously described surgical techniques would be merged to address both instabilities with a single graft [2, 5, 9].

A lateral hockey-stick-shaped incision was carried down to the superficial iliotibial band creating a posteriorly based skin flap [16]. A peroneal nerve neurolysis was performed to minimize the risk of a foot drop postoperatively due to swelling. The biceps bursa was entered, and a mid-substance FCL tear was visualized. After dissecting posteriorly to the fibular head, the proximal tibiofibular joint was examined and found to be very unstable. The proximal posterior tibiofibular ligament was torn mid-substance and could not be reapproximated; therefore, a complete reconstruction was required.

After splitting the iliotibial band, fluoroscopy was then used to determine the location of the open physes prior to creating the FCL reconstruction tunnels. The location of the patient's physes allowed for true anatomic placement of the 25-mm closed-socket femoral reconstruction tunnel. However, the fibular physes dictated a more distal and horizontal fibular tunnel placement than indicated by the native FCL footprint, which required the peroneal nerve neurolysis to be extended further distally. A tibial reconstruction tunnel for the proximal posterior tibiofibular ligament was then prepared by dissecting posteriorly under the popliteus muscle and anteriorly, distal and medial to Gerdy's tubercle. Live fluoroscopy was utilized during all guide pin placements and tunnel reaming. Passing stitches were placed through the reconstruction tunnels.

ACL Repair Technique

Attention was then turned to the arthroscopic portion of the procedure. Examination of the ACL confirmed an intact ligament mid-substance with a complete avulsion fracture of the medial tibial eminence. A 25° angled left suture passer was used to place a nitinol wire and shuttle four #2 nonabsorbable sutures (FiberWire, Arthrex, Naples, Florida) through the avulsed fragment. A tibial tunnel was reamed vertically through the center of the avulsion site on the

Fig. 1 Preoperative MRI fat suppressed sequences demonstrating coronal views of a **a** mid-substance FCL tear and **b** popliteus tendon strain, and confirming an **c** ACL avulsion of the medial tibial eminence on the sagittal view indicated by *arrows*

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tibial plateau. Sutures were shuttled down the tunnel and later tied over a cortical button on the tibia.

A semitendinosus allograft was prepared to reconstruct the FCL, passed into the femoral tunnel, and secured with a 7 × 23 mm bioabsorbable screw. The free end of the graft was passed deep to the superficial iliotibial band and the lateral aponeurosis of the long head of the biceps femoris. The graft was fixed in the fibular head with a 7 × 23 mm bioabsorbable screw with the knee in 20° of flexion, neutral tibial rotation, and under a slight valgus reducing force. The FCL graft remnant was threaded into the posterior aperture of the tibial reconstruction tunnel, pulled anteriorly, and fixed with a 7 × 23 mm bioabsorbable screw at 60° of flexion on the anterior tibia while the proximal tibiofibular joint was held reduced (Fig. 2). The ACL avulsion was then anatomically reduced, and sutures were fixed over a cortical button with the knee in full extension. The knee was placed in an immobilizer brace, and the patient was transferred to recovery in stable condition.

Rehabilitation

Postoperative restrictions included limited range of motion from 0° to 90° for 2 weeks and non-weight-bearing for 6 weeks. The patient was instructed to avoid posterior tibial sag, external rotation, and open chain hamstring exercises for the first 4 months. Range-of-motion exercises in a hinged knee brace from 0° to 90° were initiated four times daily starting on postoperative day one to minimize the risk of arthrofibrosis. After 2 weeks, knee flexion was gradually increased as tolerated with the goal of achieving maximum flexion and extension by 6 weeks while protecting the repair and reconstructions. After 6 weeks, rehabilitation progressed in a periodized approach focusing on muscular endurance, muscular strength, balance, and agility, with the goal of full return to activities at 6 months following clearance by a physician.

Outcomes

At 6-month follow-up, the patient reported no symptoms of pain or instability. Varus stress radiographs demonstrated 0 mm side-to-side difference in lateral compartment gapping. The proximal tibiofibular joint was stable to anteroposterior translation on physical examination. Physical examination revealed a 1 + Lachman with a firm endpoint. KT-1000 testing demonstrated 1 mm of increased anterior tibial translation in his left lower extremity. A thin-slice computed tomography (CT) scan was also obtained and used to create three-dimensional models of the patient's open physes and reconstruction tunnel placement (Mimics, Materialise Inc, Leuven, Belgium), which demonstrated preservation of physeal integrity and healing of the tibial eminence avulsion fracture (Fig. 3).

Discussion

The most important finding in this case was the successful restoration of lateral knee and proximal tibiofibular joint

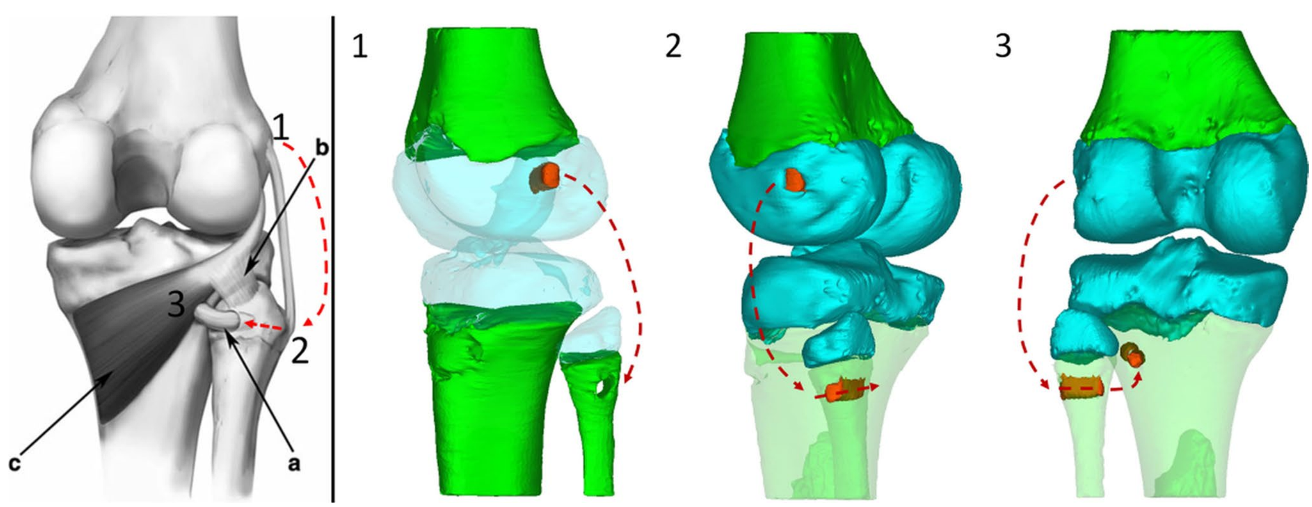

Fig. 2 Diagram of the combined FCL and proximal posterior tibiofibular ligament reconstruction using a single semitendinosus allograft. *Left* Illustration modified from Horst and LaPrade illustrating the **a** allograft reconstruction and its relationship to the **b** popliteofibular ligament and **c** popliteus muscle [5]. *Right* Composite three-dimensional images created from post-surgery computed tomography scan demonstrating the three reconstruction tunnels and their relationship to the physes. *Left/Right* The graft was first (1) secured in the femoral tunnel and then (2) threaded through the fibular tunnel and fixed in the fibular head. The FCL graft remnant was then (3) pulled through and fixed in the tibial reconstruction tunnel

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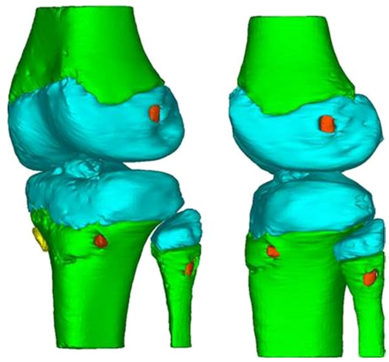

Fig. 3 Computed tomography scan taken at 6 months post-surgery used to create three-dimensional bone tunnel composite images indicate successful preservation of the patient's physeal integrity. The FCL reconstruction tunnel was placed distal to the ligament's native anatomic fibular attachment site to avoid physeal disruption

stability using a fluoroscopically guided physeal-sparing reconstruction technique. This technique reconstructed the FCL and posterior aspect of the proximal tibiofibular joint using a single semitendinosus allograft by merging two previously described techniques [2, 5, 9]. The fibular head physes were successfully avoided by distalizing the fibular reconstruction tunnel.

In the past, others have described cases of multiligament knee injuries in skeletally immature patients involving combinations of ACL, posterior cruciate ligament (PCL), and PLC injuries [1, 13]. However, cases of combined FCL and proximal tibiofibular joint instability in skeletally immature patients have not been described. With skeletally immature patients, multiple factors including timing of surgery, staging of procedures, and surgical technique must be considered. First, concern exists regarding the timing of surgical reconstruction and waiting for skeletal maturity. Second, with respect to staging, posterolateral ligament injuries are frequently addressed immediately, while cruciate ligament reconstruction is sometimes delayed to allow for skeletal maturation [1, 13]. Third, debate also exists over the optimal technique for physeal preservation and indications for repair versus reconstruction. In the case of PLC injuries, previous studies have demonstrated that reconstructions result in fewer failures than repairs [12, 15]. After weighing all of these factors, we contend that immediate, one-stage physeal-sparring FCL and proximal posterior tibiofibular ligament reconstruction and ACL repair provided the optimal course of treatment. Objective outcomes demonstrate evidence in favor of the efficacy of this approach.

Previous studies have described surgical approaches for treating multiligament PLC injuries in skeletally immature patients. Anderson and Anderson described a case of combined PCL and PLC injuries in a skeletally immature athlete treated with surgical reconstruction [1]. Varus laxity was addressed with an anterior tibialis graft pulled through an anterior-to-posterior tunnel in the fibular epiphysis with both free ends of the graft fixed on the femur with a screw and spiked washer. In a second report, Mascarenhas et al. [13] described a suture anchor-based repair of the FCL and biceps femoris tendon in a skeletally immature patient with a combined PLC and ACL injury in which the FCL and both heads of the biceps femoris were avulsed off their proximal fibular attachments. Other studies have repeatedly demonstrated that PLC reconstructions are superior to repairs, especially in the case of mid-substance tears, because they result in fewer failures and improved clinical outcomes [12, 15]. We sought to achieve a near-anatomic reconstruction using a biomechanically and clinically validated FCL reconstruction technique [2, 3, 8, 9]. Although our fibular tunnel was positioned distal to the physis and the free end was subsequently used to reconstruct the proximal posterior tibiofibular ligament, this position more closely recreated the native FCL anatomy and conferred improved stability compared to the anterior-to-posterior epiphyseal tunnel described by Anderson and Anderson [1].

However, despite differing techniques, Mascarenhas et al. and Anderson and Anderson also successfully utilized intraoperative fluoroscopy to avoid violating the open physes [1, 13]. While fluoroscopy significantly increases operating time and exposes the patient to radiation, intraoperative growth plate visualization is essential in cases involving skeletal immaturity due to the potential consequences of physeal disruption.

We acknowledge some limitations. First, this report presents a single case and the results observed need to be investigated across a larger group of patients. Given the excellent results observed in this patient, we believe that the technique presented warrants further investigation and may serve as a safe and reproducible treatment approach for other skeletally immature patients.

Conclusions

A physeal-sparing modified FCL and proximal posterior tibiofibular ligament reconstruction successfully and safely restored knee stability in the case of a complex knee injury in a skeletally immature patient. Future studies across a larger cohort of skeletally immature patients are needed to further investigate both short- and long-term outcomes following this reconstruction technique.

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