The Adjustable Locking Suspension Sling Technique for Fixation of the Tibial Eminence Fracture in Adolescents

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Abstract: Avulsion fractures of the tibial eminence, although generally a rare injury pattern, are more common in children and adolescents than in adults. Many open and arthroscopic techniques are available with variable degrees of satisfying results and incidence of complications and adverse effects. Arthroscopic fixation appeared to improve the functional outcomes with fewer complications than the open fixation. New techniques were reported using commercially available suspension sling devices for the acromioclavicular joint that offers an easy and rapid method of fixation. However, this technique has the disadvantages of the presence of hardware (button) over the tibial anterior cruciate ligament attachment inside the joint and the need to drill a relatively large tunnel through the center of the avulsed fragment that may increase the chance of fracture. So small-diameter tunnels need to be drilled that will decrease bone loss and growth plate injury in children and adolescents. We describe here a technique that offers a better 4-point fixation through the anterior cruciate ligament with fewer complications by avoiding drilling through the avulsed fragment, absence of hardware inside the joint, and decreasing bone loss in adolescents by drilling only smaller transosseous tunnels and allowing for correction of the fixation using a special configuration of knots and cortical button.

Incidence of tibial eminence avulsion fractures is significantly lower than direct rupture and tears of the anterior cruciate ligament (ACL) and is generally more common in children and adolescents compared with adults. The severity of the lesion varies from nondisplaced to completely displaced and comminuted fragment; therefore, the treatment will vary too from temporary immobilization of the knee to surgical intervention.

Many open and arthroscopic techniques were described for reattachment, fixation, and repair of this lesion. Arthroscopic techniques improve the functional outcomes with lower complications than open techniques, particularly the incidence of nonunion or malunion of the fracture, implant loosening, breakage, or migration.

Arthroscopic techniques also vary from each other, and according to a recent systematic review published in 2015, suture fixation appeared to be equivalent to screw fixation in the rate of late ACL reconstruction and patient-reported instability outcome measures. However, clinically measured instability outcome measures and the rate of hardware removal are significantly higher with screw fixation.

Recently, a fixation method was described using a suspension sling device designed originally for the arthroscopic fixation of the acromioclavicular joint (AC TightRope, Arthrex, Naples, FL). The oblong button of the AC TightRope is introduced through a transtibial tunnel and through the fragment after reduction and then flipped over the intra-articular side of the fractured fragment. Finally, the suture ends are tied over the external button on the anteromedial surface of the proximal tibia to reduce and fix the fragment to its bed. The disadvantages of this technique are drilling through...
Table 1. Advantages and Disadvantages of the Adjustable Locking Suspension Sling Technique

| Advantages                                                                 | Disadvantages                                                                 |
|---------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 1. No drilling through the fragment (less chance of fracture)             | 1. Multiple passages of sutures through the anterior cruciate ligament may be sometimes troublesome for the inexperienced arthroscopic surgeons |
| 2. No preliminary reduction is required                                   | 2. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |
| 3. Small-diameter tunnels through the epiphysis (a single TightRope tunnel) (4-mm-diameter tunnel produces approximately 50 mm² bone loss, whereas a 2-mm-diameter tunnel produces only 12.5 mm² bone loss). | 3. The medial and lateral ends of the No. 5 FiberWire can be passed under the loop passing in the second and third holes of the button to create a locking mechanism |
| 4. Adjustable and locking mechanism (TightRope equivalent)                 | 4. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |
| 5. No intra-articular metal buttons or hardware (as with the TightRope device) that may displace or migrate | 5. Tunnels are drilled on the anteromedial and anterolateral margins of the fragment bed to act as a tension band |
| 6. No accordingly need for implant removal                                | 6. Double shuttle mechanism is used in each tunnel to pass sutures in either direction |
| 7. Arthroscopically performed (minimal morbidity with the ability to manage associated lesions) | 7. The medial and lateral ends of the No. 5 FiberWire can be passed under the loop passing in the second and third holes of the button to create a locking mechanism |
| 8. Secure to allow early and adequate rehabilitation (unlike other methods) that may reduce arthrofibrosis | 8. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |
| 9. Four points of fixation/compression (2 medial and 2 lateral points) over the spine fragment that offers early and adequate rehabilitation and reduces arthrofibrosis | 9. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |
| 10. Easily reproducible                                                   | 10. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |
| 11. Low cost of hardware and material                                      | 11. Passage through the anterior cruciate ligament should be at different anterior to posterior planes to create multiple points of fixation |

The inner anterolateral portal is used for visualization and the remaining 3 portals are working portals. Alternatively, only 1 anteromedial portal may be used with the 2 anterolateral portals.

First, the fracture fragment is mobilized and the adhesions and fracture hematoma, as well as minor unstable bone debris, are removed using a metal curette and motorized shaver (Arthrex). A 45° suture lasso (Arthrex) introduced from the outer anteromedial portal is passed through the base of the ACL from medial to lateral (Fig 1) to pass a Nitinol suturing suture or alternatively a nonabsorbable monofilament strong suture (No.1 Proline). The end of the suturing suture is retrieved from the lateral side of the ACL with a grasper or a suture retriever instrument from the outer anterolateral portal.

A No. 2 TigerWire (white polyester/polyethylene suture, Arthrex) as a second shuttling suture is tied to the lateral end of the first shuttling suture and the medial end of the first shuttling suture is pulled out through the anteromedial portal to retrieve the TigerWire through the ACL and out of the anteromedial portal (Fig 2). This strong TigerWire suture is used to pass a stronger and thicker No. 5 FiberWire (blue) from lateral to medial in the same manner. We believe that this is essential to avoid cutting the monofilament first shuttling suture if used directly to shuttle the doubled and thick No. 5 FiberWire suture. The 45° suture lasso is passed for the second time through the ACL from medial to lateral just above the first suture, and the same process is repeated to shuttle the white No. 2 TigerWire through the ACL. The medial end of the white TigerWire suture is retrieved with a grasper introduced through the outer anterolateral portal to pass it in front of the ACL to outside the outer anterolateral portal (Fig 3). This end is tied over the lateral end of the blue No. 5 FiberWire suture. Pulling on the lateral end of the No. 2 TigerWire suture (in the outer anterolateral portal) will shuttle the lateral end of the blue No. 5 FiberWire suture through the ACL from the medial side to the lateral side making a figure-of-eight loop.

Surgical Technique

In this technique (Video 1), we use 4 portals: 2 anterolateral portals (outer anterolateral portal, inner anterolateral portal) and 2 anteromedial portals (outer anteromedial portal and inner anteromedial portal).
configuration through and around the base of the ACL tibial attachment (Fig 4). Now there are 2 ends of the blue No. 5 FiberWire suture: a medial end passing through the outer anteromedial portal (a) end and a lateral end passing through the outer anterolateral portal (b) end.

A longitudinal incision is made on the anterior surface of the tibia to pass a drill pin using the tibial ACL guide (Arthrex), and a small (2 mm) tunnel is drilled through the tibia to the joint surface directly to the anterolateral end of the fragment bed (Fig 5). A Nitinol loop introduced from below through the tibial tunnel is used to shuttle the white No. 2 TigerWire from the outer anterolateral portal to outside through the lateral tibial tunnel. This is subsequently used to pull a looped (folded twice) stainless steel thin cerclage wire from the outer anterolateral portal to exit the end of the lateral tibial tunnel with its loop directed downward. A second looped stainless steel wire is passed through the loop of the first one making a double loop pulling on each other to be used as a double shuttling mechanism used for shuttling sutures in either direction (to outside and inside of the joint) (Fig 6).

A second medial tibial tunnel is drilled to the anteromedial edge of the fragment, and the same process is repeated to pass a double looped stainless steel wire from the inner anteromedial portal into the joint and out through the medial tibial tunnel.

Fig 1. A 45° suture lasso (Arthrex) (black arrow) introduced from the outer anteromedial portal is passed through the base of the anterior cruciate ligament (red star) from medial to lateral (A) to pass a nonabsorbable monofilament strong suture (No.1 Prolene) (green arrow) (B) to be used for shuttling the definitive fixation suture. (Right knee viewed from the inner anterolateral portal in 90° knee flexion.)

Fig 2. The medial end of the shuttling No. 2 TigerWire suture (black star) is pulled through the anteromedial portal (black arrow) to pass the No. 5 FiberWire suture (red star) through the anterior cruciate ligament from lateral to medial. (External view of the right knee flexed to 90° in the supine position.)

Fig 3. One end of the white No. 2 TigerWire suture passing in front of the anterior cruciate ligament (ACL, black arrow), whereas the other end (red arrow) is passing through the ACL just above the No. 5 FiberWire suture (green arrow), and both ends are exiting the joint cavity (right knee) through the anterolateral portal. (Arthroscopic view of the right knee viewed from the anterolateral portal.)
The medial (a) end of the blue No. 5 FiberWire is retrieved by a grasper through the inner anteromedial portal and loaded into the inferior loop of the medial double shuttle system. The lower end of the stainless steel shuttle is pulled downward until the medial (a) end of the blue No. 5 FiberWire suture exits the end of the medial tibial tunnel and released from the shuttle system. The medial stainless steel shuttle system is left in the tunnel for further passage of sutures through the tunnel. Alternatively and instead of the double loop stainless steel shuttle system used here for economic purposes, a double looped shuttle composed of 2 No. 2 FiberWire sutures may be used.

A 4-hole metal button is used for the final fixation of the blue No. 5 FiberWire suture over the tibia. The medial (a) end of the blue No. 5 FiberWire suture is passed through the second hole of the button from above downward and then back through the third hole of the button from below upward (Fig 7).

The medial (a) end of the blue No. 5 FiberWire suture after passing through the button is loaded into the upper loop of the lateral stainless steel double shuttle system, which is pulled upward to retrieve the suture end through the lateral tibial tunnel lateral to the fragment bed and then outside the joint through the outer anterolateral portal.

A 45° suture lasso introduced through the inner anteromedial portal is passed through the ACL base for the third time from medial to lateral just posterior to the previous 2 passages. The shuttling wire/suture in the lasso is retrieved through the outer anterolateral portal and then is used to shuttle the medial (a) end of the blue No. 5 FiberWire suture through the ACL and out of the inner anteromedial portal (Fig 8).

The medial (a) end of the blue No. 5 FiberWire suture retrieved through the inner anteromedial portal is loaded into the lower loop of the medial stainless steel double shuttle system to pass it again into the joint and then outside through the medial tibial tunnel, where it is passed through the first hole of the metal button (Fig 9).

The lateral (b) end of the blue No. 5 FiberWire suture is loaded into the inferior loop of the lateral double shuttle and retrieved downward through the lateral tibial tunnel and then passed through the fourth hole of the metal button (Fig 10).

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**Fig 4.** The No. 5 FiberWire suture (black arrows) is passing through and around the base of the anterior cruciate ligament tibial attachment (red star) in a figure-of-eight configuration. (Arthroscopic view of the right knee viewed from the anterolateral portal.)

**Fig 5.** (A) Tibial anterior cruciate ligament (ACL) guide (Arthrex) (red arrow) is used to pass a 2-mm drill pin through a longitudinal incision on the anterior surface of the tibia (black arrow). (External view of the right knee flexed to 90° in the supine position.) (B) The tibial ACL guide (Arthrex) (black arrow) is positioned at the anterolateral edge of the fragment bed (red star) for drilling the 2-mm lateral tibial tunnel. (Arthroscopic view of the right knee viewed from the anterolateral portal.)
The medial (a) end in the first hole and the lateral (b) end in the fourth hole are then pulled alternately to tighten the construct pushing the metal button against the anteromedial surface of the tibia reducing the fragment into its bed. Both ends of the suture can be passed below the suture loop passing from the second to the third button holes before tightening and thus making an adjustable self-locking construct for a more secure fixation. Both suture ends are finally tied firmly over the metal button (Fig 11).

**Postoperative Rehabilitation**

A hinged ACL knee brace is recommended for 6 weeks postoperatively with limited range of motion (ROM) to 0° to 90° extension/flexion with only partial weight bearing allowed during this period. After the sixth week, gradually increasing weight bearing and ROM are allowed.

**Discussion**

Tibial intercondylar eminence avulsion fracture occurs more frequently in children and adolescents than adults. Many open techniques were described in the literature, but several complications were related to most of these techniques such as implant breakage, loosening or migration, and nonunion or malunion of the fracture. On the other hand, arthroscopic techniques offer improvement in functional outcome with fewer complications.

In 1997, an arthroscopic technique was described based on suture fixation of the avulsed fragment into the fracture bed by 4 sutures that were placed into the medial (2) and lateral (2) aspects of the ACL base (fragment bed) and tied against the anteromedial surface of the proximal tibia through 2 predrilled transosseous tunnels. This technique does not require screws or pins that need another procedure to remove it. In addition, it relies on the ACL, not on the avulsed fragment that may be very small or comminuted. A similar technique was described later with 2 transtibial tunnels instead of three and an additional portal through the patellar tendon.

A study comparing between screw fixation and suture fixation techniques showed that there was no significant difference in clinical outcomes and knee joint stability at a minimum 2-year follow-up. However, 4 of 16 patients in the screw group needed another operation to remove the hardware. Another study showed that the screw fixation was significantly better than suture fixation, but 7 of 25 patients underwent a second operation to remove the hardware. The suture fixation in the second study was based on the avulsed fragment because the sutures did not pass through the ligament itself that results in bad outcomes, whereas in the first study, they pierced the ligament that results in better outcomes with no significant difference than the screw fixation.

An AC Tightrope device (Arthrex) was used by Faivre et al. in another fixation technique, in which...
only 1 transtibial tunnel was drilled to shorten the time and effort of surgery. Nevertheless, drilling through the avulsed fragment in this technique increases the risk of its fracture. In addition, the oblong button of the device that remains over the fragment inside the joint may displace or migrate inside the joint. Also, the fixation was based on only 1 central point through the fragment that may not control the rotational stability of fixation with the possibility of secondary displacement. Most recently, Loriaut et al. used a very similar technique with the same device that resulted in nearly the same results as the first one.

Here we gathered the advantages of the previous techniques by increasing the points of fixation to 4 points (2 medial and 2 lateral) that are based on the ACL itself and not the avulsed fragment, which may be very small or comminuted and drilling was away from the avulsed fragment to avoid more damage for it. We did not use any hardware inside the joint space; only an oblong button with 4 holes was used to perform an adjustable locking mechanism against the anteromedial surface of the tibia. In addition, we used low-cost hardware and drilled only 2 small tunnels instead of large one to reduce the bone loss and penetration to the epiphyseal plate. Nevertheless, no clinical or

Fig 8. The medial (a) end of the blue No. 5 FiberWire suture (red arrow) is retrieved through the inner anteromedial portal (black arrow) after passing through the anterior cruciate ligament from lateral to medial for the third time. (External view of the right knee flexed to 90° in the supine position.)

Fig 9. The medial (a) end of the blue No. 5 FiberWire suture (red arrow) is passed through the first hole of the metal button (black arrow) after passing through the medial tibial tunnel. (External view of the right knee flexed to 90° in the supine position.)

Fig 10. The lateral (b) end of the blue No. 5 FiberWire suture (black arrow) is passed through the fourth hole of the metal button (red arrow) after being retrieved through the lateral tibial tunnel. (External view of the right knee flexed to 90° in the supine position.)

Fig 11. The metal button is firmly secured against the anteromedial surface of the tibia, and several knots are tied over it using a knot pusher to secure the stability of the construct. (External view of the right knee flexed to 90° in the supine position.)
biomechanical studies to support this technique were performed that are needed in the future.

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