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Tibial Tubercle Osteotomy in the Adolescent Patient

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Abstract
Patellofemoral instability (PFI) is an increasingly prevalent issue affecting pediatric and adolescent patients. Anatomic factors, including lateralization of the tibial tubercle and patella alta, can contribute to increased risk of initial and recurrent PFI. In the case of recurrent PFI, chondral injuries of the patellofemoral compartment can occur. These anatomic pathologies can be surgically addressed using tibial tubercle osteotomy (TTO), adjusting the angle and direction of the osteotomy as needed to achieve the desired correction. We discuss the indications and present our technique for performing TTO, including the modifications that can be made to the procedure to address the specific pathoanatomy of the patient.

Key Concepts
- Lateral patellar instability is a common condition impacting adolescent patients with tibial tubercle lateralization and patella alta being common modifiable risk factors for recurrence.
- The tibial tubercle osteotomy is a versatile procedure permitting the treatment of patellofemoral instability and associated cartilage injuries by adjusting the angle of the osteotomy cut and tubercle transfer as needed to address the specific pathology.
- Risks of osteotomy are greater than soft tissue reconstruction procedures alone, but many can be mitigated with meticulous osteotomy and soft tissue closure techniques.

Introduction

Patellofemoral Instability (PFI) is a common condition impacting young patients, peaking in mid-adolescence.[1-6] Recurrent PFI is a frequent indication for surgical intervention. In the last decade, evidence has emerged suggesting injury prevalence may be rising, resulting in more frequent surgical intervention for patellar stabilization in pediatric and adolescent patients.[7-9] Numerous demographic and anatomic risk factors for recurrent PFI have been identified with tibial tubercle lateralization and patella alta among the most frequently cited modifiable risk factors. The tibial tubercle osteotomy (TTO) is a versatile and reproducible procedure facilitating precise correction of multiple anatomic aspects of patellofemoral dynamics.

Three primary TTO techniques have been described, including those by Maquet (tubercle anteriorization),[10] Elmslie-Trillat (tubercle medialization), and Fulkerson (tubercle anteromedialization).[11] In practice, however, osteotomies performed represent a confluence of these techniques depending on the actual osteotomy angle (Figure 1). Medialization corrects tubercle lateralization and addresses increased TT-TG distances. Some degree of anteriorization can also be utilized to reduce patellofemoral contact pressures and improve symptoms in the setting of chondral injury.[12] Finally, through disruption of the distal cortical hinge, tubercle osteotomies can also be distalized to permit correction of excessive patella alta.

Due to concerns regarding proximal tibial physeal injury and growth arrest, the use of this technique is confined largely to skeletally mature populations. As a result, its utilization in the field of pediatric orthopaedics is more limited, but it remains an important consideration in the treatment of patellofemoral disorders in skeletally mature adolescents. The purpose of this article is to describe the tibial tubercle osteotomy technique, its relative indications and utility in the surgical management of PFI in adolescent patients.

Radiographic Evaluation

All PFI patients being considered for surgical treatment should undergo a comprehensive clinical and radiographic evaluation to identify and address modifiable anatomic risk factors for recurrence.[13] Physical exam evaluation and full-length lower extremity radiographs can identify any valgus alignment that may indicate distal femoral osteotomy. Magnetic Resonance Imaging (MRI) of the knee is frequently used to evaluate patellar height, extensor mechanism lateralization, trochlear and patellar morphology, and chondral injury. Rotational profile testing and imaging, including the hip, knee, and ankle, can evaluate for femoral anteversion and external tibial torsion.

Various methods of assessing tibial tubercle lateralization have been described; however, Tibial Tubercle-Trochlear Groove[14-18] distance remains the most frequently cited in the literature (Figure 2). A TT-TG distance above 20 mm, as measured on CT, is frequently used as a relative indication for performing distal realignment, although there is limited evidence to support this specific cut-off. In pediatric patients, the average TT-TG distance

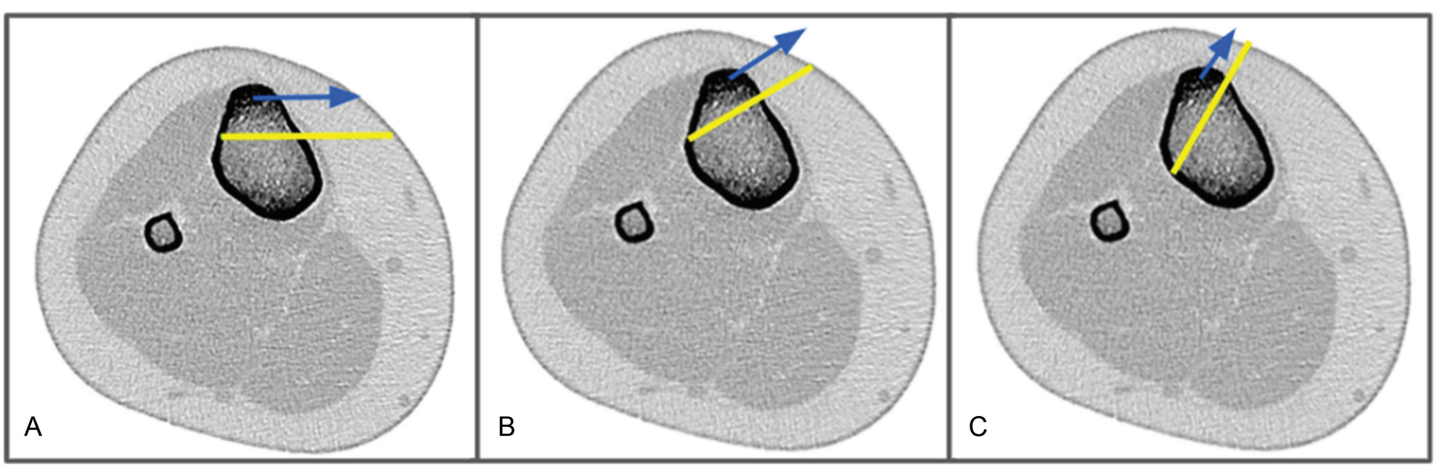

Figure 1. *Figures 1A-C demonstrate various types of tibial tubercle osteotomy cuts (yellow line) providing medialization (Figure 1A), anteromedialization (Figure 1B), and predominant anteriorization (Figure 1C).*

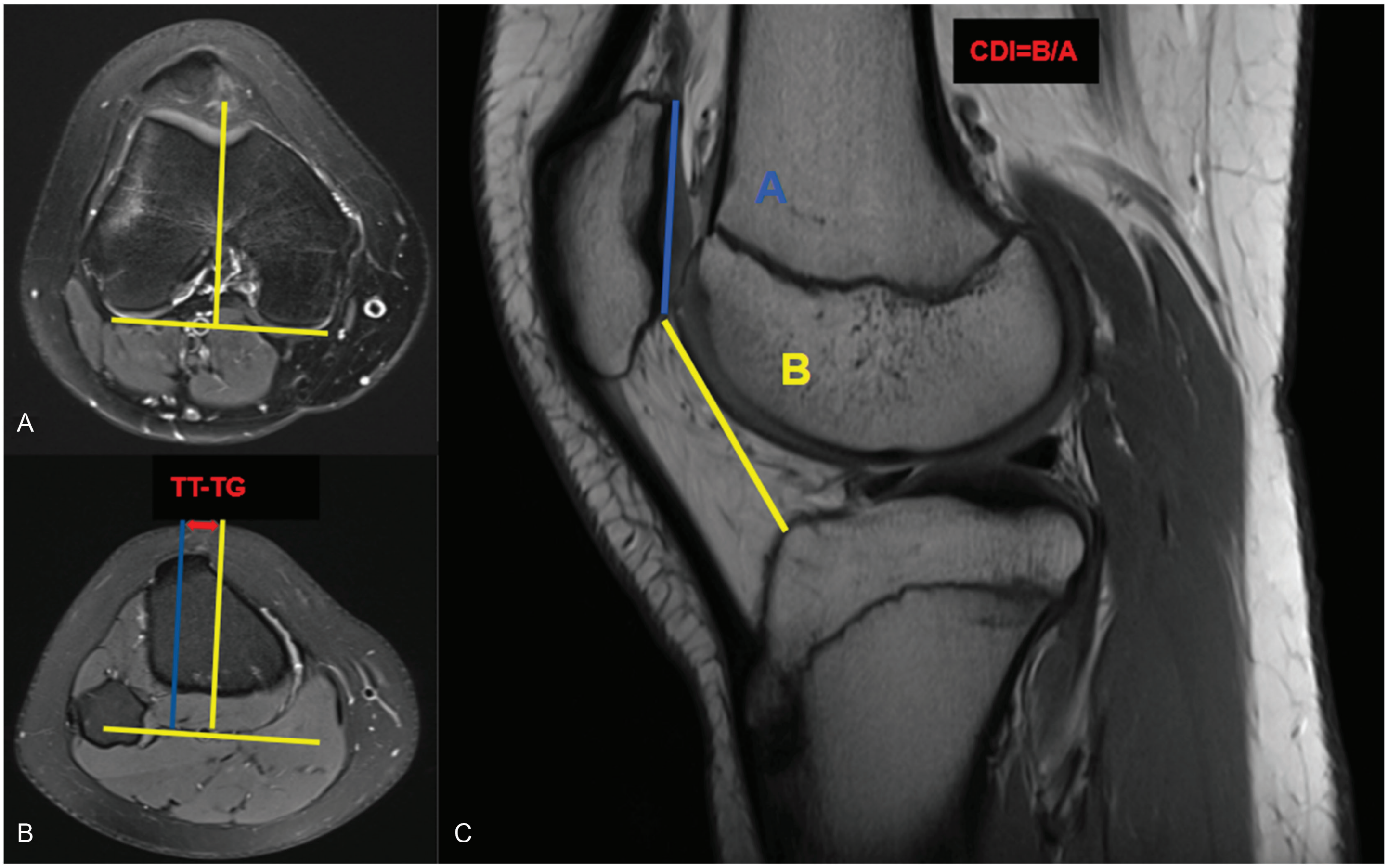

Figure 2. *The Tibial Tubercle-Trochlear Groove distance is represented in Figures 2A and 2B. Figure 2A demonstrates the posterior condylar axis (PCA, solid green line) with a perpendicular line drawn though the deepest point of the femoral trochlea (dotted green line). Figure 2B shows a perpendicular line to the PCA through the center of the tibial tubercle (dotted blue line). The horizontal distance between these lines is the TT-TG distance (double red arrows). Figure 2C demonstrates the calculation of the Caton-Deschamps Index. The sagittal MRI slice with the largest visible articular surface of the patella is identified. Line A is drawn along the patellar articular surface. Line B is drawn from the inferior aspect of the patellar articular surface to the anterior aspect of the tibial plateau. CDI is calculated as a ratio of Line B:Line A.*

increases with chronological age;[14] therefore, the 20 mm cut-off may be less applicable in this patient group. Additionally, MRI may be preferred over CT to limit radiation exposure in pediatric patients, although MRI may underestimate TT-TG distance.[19,20]

Several methods have been described to quantify patellar height, but prior work has suggested the Caton Deschamps index (CDI) to be the most reliable in children and adolescents.[21] Patellar height is known to gradually decrease during skeletal maturation[21] with a CDI >1.3 considered abnormal at the time of skeletal maturity.

Indications and Contraindications

The authors' preference is to utilize Tibial Tubercle-Trochlear Groove (TT-TG) Distance in the assessment of tubercle lateralization and Caton-Deschamps Index (CDI) to assess patellar height (Figure 2). In patients with a TT-TG >20 mm, a medializing or anteromedializing tibial tubercle osteotomy may be indicated. If patella alta is also present, concurrent distalization may also be considered at the discretion of the treating surgeon. In the setting of a more modestly elevated TT-TG distance (15-20 mm), but with other notable clinical or radiographic findings such as significant J-sign or a tibial tubercle that is uncontained and lies outside of the confines of the trochlear groove (i.e., an “off track” Tibial Tubercle-Lateral Trochlear Ridge distance[22]) on MRI, concurrent osteotomy may also be a reasonable consideration. In the setting of patella alta without significant tubercle lateralization, sufficiently clear benefits of correction are unclear from the literature and thus do not outweigh the surgical risks of osteotomy. Therefore, TTO for pure distalization purposes is not recommended by the authors.

Skeletal immaturity is widely accepted as a contraindication of tibial tubercle osteotomy, as premature physeal arrest could result in growth disturbance and recurvatum deformity. However, the acceptable skeletal or chronologic age at which TTO can be safely considered is less clear. The closure of the regional physes of the knee occurs over a multiple year period with the proximal tibia closing in a predictable pattern well before the distal femur. The physis and its closure can also be reliably evaluated on MRI using intermediate-weighted (T1) sequences.[23] It is the authors opinion that tubercle osteotomy can be safely considered in patients once central closure of the proximal tibial physis has begun, which can be as much as 2 years prior to closure of the distal femoral physis.

Surgical Technique

The procedure is performed under general anesthesia, and the addition of regional or local anesthetic can be used to assist with postoperative analgesia. The patient is placed supine, with optional upper thigh tourniquet on the operative leg and a bump under the ipsilateral hip. An incision is made slightly lateral to midline, extending from the middle of the patella tendon to approximately 5-6 cm distal to the proximal extent of the tibial tubercle (Figure 3). While a direct midline incision may also be utilized, staying slightly lateral to midline decreases the risk of prominent hardware below the incision and improves access to and visualization of the lateral proximal tibia during the osteotomy. The incision can be extended proximally and distally as needed for exposure. Proximally, the anterolateral arthroscopy portal can be incorporated into the incision, if needed.

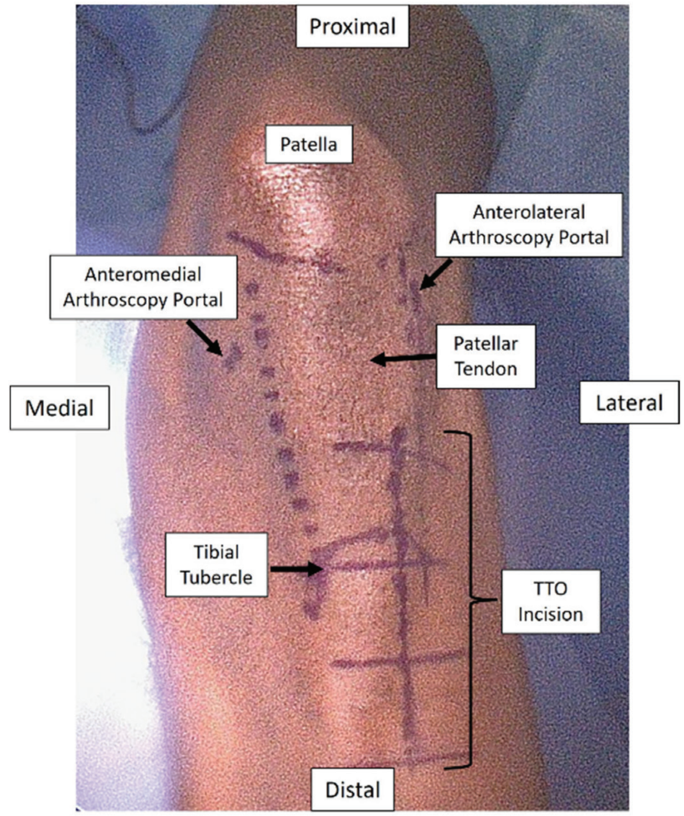

Figure 3. *The planned incision for the osteotomy and relevant anatomy is pictured. The incision is just lateral to midline, extending from mid-patella tendon to 5-6 cm distal to the proximal aspect of the tibial tubercle.*

Full-thickness flaps are elevated medially and laterally, exposing the peritenon. The lateral border of the patella tendon is identified, and the peritenon is incised at the lateral border. This is extended proximally and distally—distally, the peritenon becomes confluent with periosteum, and the incision is taken through the periosteum at the lateral border of the tibial tubercle, staying out of the anterior compartment. The paratenon is elevated off the patella tendon until the medial border of the tendon and the medial proximal tibia are identified. The paratenon is preserved for later repair, which can provide further coverage for the tendon as well as the osteotomy fixation screws.

A prophylactic anterior compartment release of fascia is performed, and muscles are elevated subperiosteally off the lateral surface of the tibia (Figure 4). This is usually started with electrocautery to achieve hemostasis

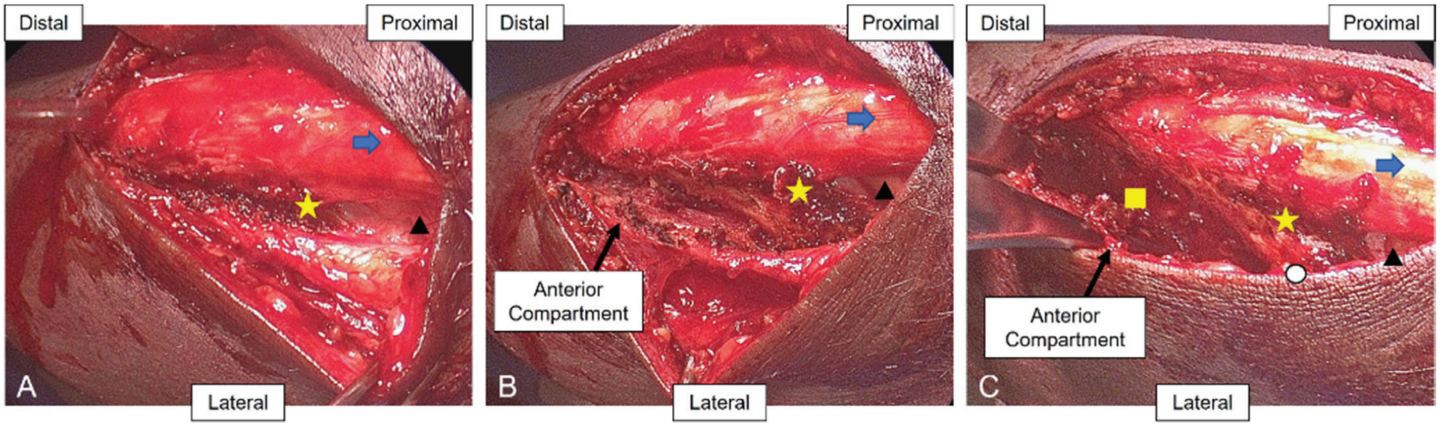

Figure 4. *Exposure of the lateral tibia. (A) The patella tendon (blue arrow) is dissected off of the underlying fat pad (black triangle) from lateral to medial. The distal insertion of the tendon onto the tibial tubercle is identified (yellow star). (B) The dissection of the anterior compartment musculature off of the lateral tibia is started with a Bovie electrocautery, starting just lateral to the patella tendon insertion and staying against the bone. (C) The anterior compartment dissection is carried proximally to Gerdy's tubercle (white circle). Elevation is continued using an elevator or cobb until the lateral tibia (yellow square) is exposed. Large Homan retractors are inserted to retract the anterior compartment and protect posterior structures.*

and completed using a Key or Cobb elevator. Two large Homan retractors are placed to retract the anterior compartment musculature and protect posterior structures. Proximally, the patella tendon is elevated off the fat pad from lateral to medial. An army-navy retractor is placed under the tendon for protection and to identify the tendinous insertion on the tibial tubercle.

A tibial guide and cutting block can be used to make the osteotomy cut (Figure 5). Alternatively, a guided freehand osteotomy can be performed using K-wires as guides placed in the trajectory of the planned cut. If the cutting block is used, it is placed medial to the tibial tubercle, angled more anteriorly at the distal extent to taper the osteotomy cut. The breakaway guide pins are placed in the middle slots of the cutting block to hold it in place, and the saw blade exit indicator can be used to check positioning. Electrocautery is used along the top slot, which is intended for the sagittal saw, to mark out the cut along the medial tibia. Marking out this line using a Bovie serves as a visual guide for the correct starting point for the osteotomy from the medial side and removes the periosteum to give the saw a stable base to initiate the cut. The authors prefer not to use the cutting block for the osteotomy, as it can at times misdirect the cut. However, this step of placing the cutting block along

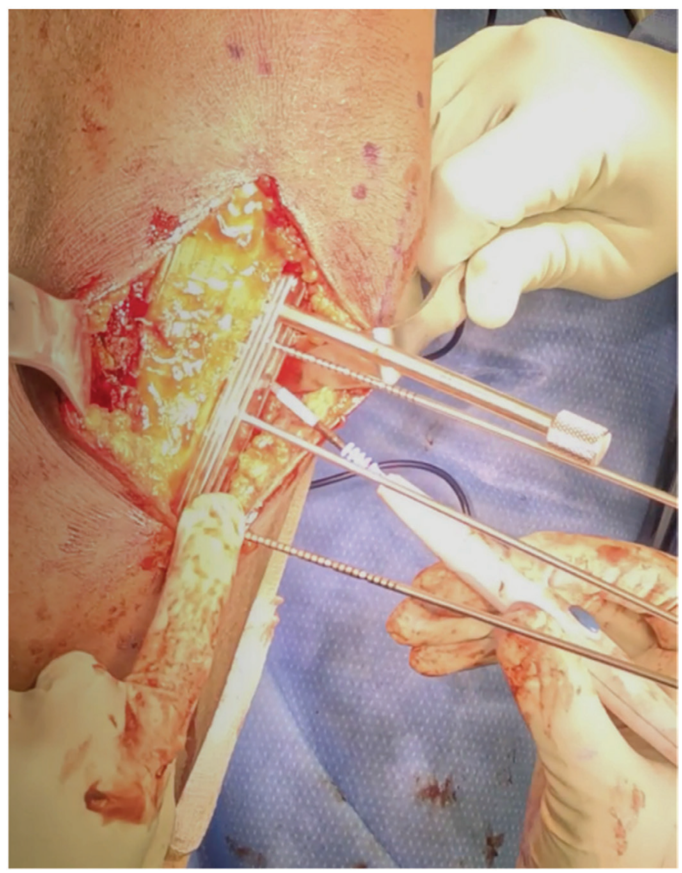

Figure 5. *Intraoperative image after application of TTO cutting block (Arthrex Inc., Naples FL). The proximal and distal breakaway pins are placed first. Once the osteotomy trajectory is confirmed, a central threaded pin can be placed to further stabilize the cutting block.*

the medial tibia and making the Bovie electrocautery mark is a helpful planning step to achieve the desired starting depth and taper of the cut.

The cutting block is removed, and the breakaway guide pins are redirected as needed to achieve the desired trajectory, with the proximal one aiming at the desired angle of the osteotomy and the distal pin aiming more horizontally. Both pins should be visualized exiting the lateral aspect of the tibia and their trajectories corrected as needed to match the desired angle of the cut. A more vertical cut can be made for a more anteriorizing osteotomy and a more horizontal cut made for increased medialization. For anteriorizing osteotomies, the more vertically oriented cut should not exit the posterior tibia, and a counter cut from the lateral side should be made to meet the vertical cut. Distally, the cut becomes more horizontally oriented to taper the osteotomy and allow for a distal hinge to remain intact. If distalization of the tubercle is desired, the distal cut is completed without leaving a hinge.

A 15 mm oscillating sagittal saw blade is used from the medial side along the Bovie mark, following the trajectory marked out by the guide pins. The cutting block can be left in place for this cut; however, we have found that this can at times misdirect the cut and we have preferred using the guide pins to direct the cut instead. The saw cut exits laterally, protected by retractors. A smaller 10 mm saw is used to make oblique cuts (in a chevron pattern manner) proximally to release the proximal aspect of the tibial tubercle, making sure that the tendon is protected with a retractor (Figure 6). The cuts are then completed using a wide straight osteotome from medial to lateral. Alternatively, an osteotome can be used for the entirety of the cut.

Proximally, the chevron cuts are completed using a narrow straight osteotome. A wide curved osteotome is then inserted from the lateral side to gradually loosen the osteotomy and transfer it medially, rotating on its distal hinge (creating a "greenstick" type fracture at the distal hinge) (Figure 7). This should not be a forceful maneuver, as that can cause complete detachment

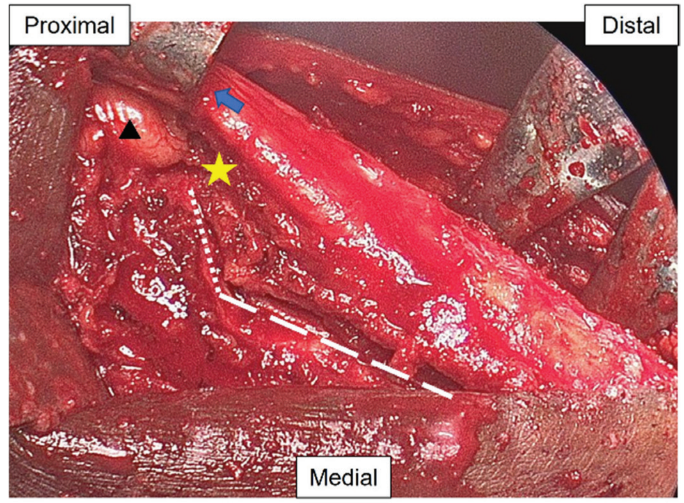

Figure 6. *Osteotomy cuts are started from the medial side of the tibia. The patella tendon (blue arrow) is protected by a retractor. The primary osteotomy (dashed white line) is made with a 15 mm oscillating saw, tapering at the distal aspect to leave a distal hinge intact. Proximally, a smaller 10 mm saw is used to make an oblique cut (dotted white line) to complete the osteotomy.*

distally. Instead, the distal hinge can be further tapered using the saw, or postage stamp technique can be performed using a small drill or K-wire to create multiple perforations in the distal hinge or periosteum to aid in mobilizing the fragment.

The desired amount of anteromedial and/or distal shift is determined preoperatively and can be measured intraoperatively using a ruler. If a primarily anterior shift is desired, a small tricortical wedge off the lateral border of the tibial tubercle osteotomy fragment can be utilized (See video). This can be removed from the main fragment using the narrow sagittal saw, protecting the tendon. It can then be placed within the osteotomy cut—more distally for a greater amount of anterior shift. If distalization is planned, the freed tubercle fragment can be shortened distally by the desired amount of planned distalization with a saw or rongeur to prevent overhand and translated distally by the same amount. Finally, if primarily medialization is planned, the medial cortex can be scored to create an optimal surface for bone healing. The desired position of the tibial tubercle osteotomy transfer is held using a counter pin.

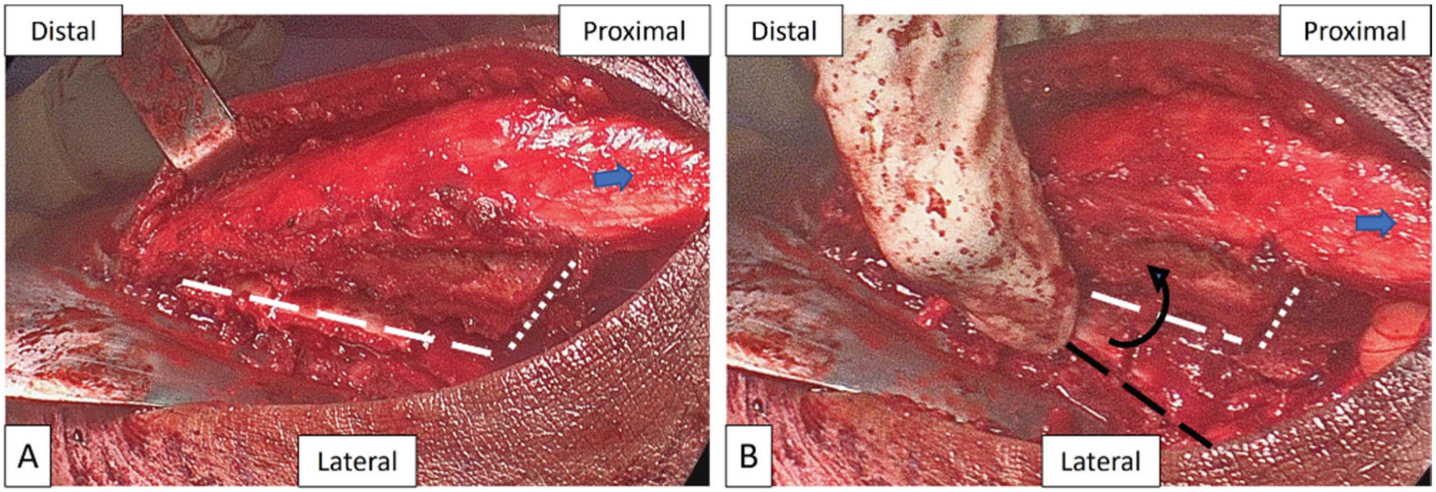

Figure 7. *Osteotomy cuts exit laterally. (A) Homan retractors protect the anterior compartment musculature and posterior structures as the primary cut (dashed white line) is completed using a wide straight osteotome, tapering distally. An oblique chevron cut is made proximally (dotted white line). (B) Once the osteotomy is completed, the tibial tubercle is rotated on its intact distal hinge to the desired amount of correction. Blue arrow = patella tendon. Dashed black line = intact lateral tibia. Black curved arrow = direction of translation of the tibial tubercle.*

The osteotomy can then be fixed in its desired position using the surgeon's preference of screw construct. In this case, cannulated unicortical 5.5 mm screws were selected (Figure 8). While no particular fixation construct has been shown to be superior, it should be taken into consideration that symptomatic screws and subsequent need for removal of hardware is common following a TTO.[24] As such, to facilitate possible later hardware

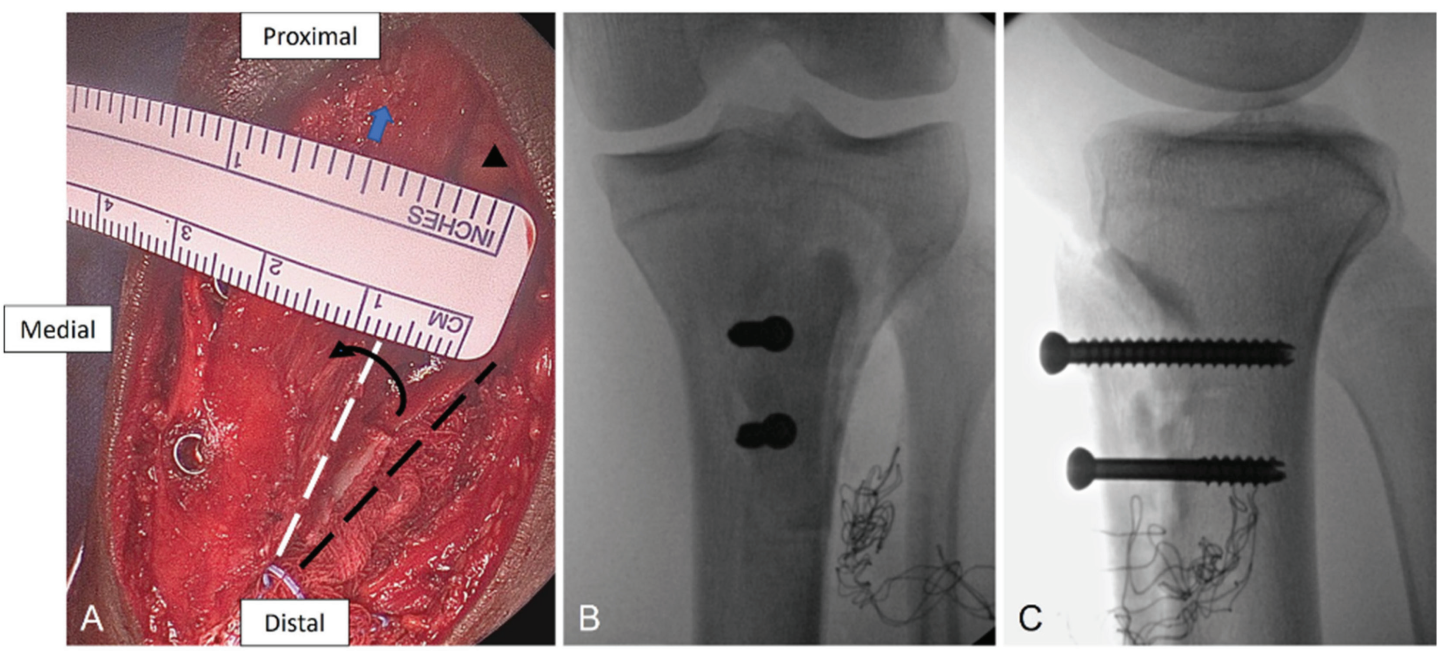

Figure 8. *The osteotomy correction is fixed with screws. (A) Post-fixation correction of approximately 10 mm. (B) and (C) Intraoperative fluoroscopy images. Blue arrow = patella tendon. Black triangle = fat pad. Dashed black line = intact lateral tibia. Dashed white line = lateral edge of osteotomy fragment. Black curved arrow = direction of translation of the tibial tubercle.*

removal, fully threaded screws are preferred, with lagging technique as indicated for fragment compression. Bicortical screw placement may increase the strength of the fixation construct; however, if bicortical screws are placed, care should be taken to avoid overlong screws due to risk of injury to posterior neurovascular structures. Orthogonal views of the screws should be taken using C-arm during the case to ensure adequate fixation and screw placement.

The screws should be placed as perpendicular to the direction of the shift as possible for greatest mechanical advantage (Figure 9). The screw heads should be adequately countersunk to prevent screw prominence. The remaining defect can be filled with the surgeon's preferred graft or bone substitute. During this step, the anterior compartment musculature should be covered and protected using a lap or raytec sponge. The medial edge of the osteotomy block should be smoothed using a rongeur or file to prevent prominence.

The tourniquet, if inflated, should be deflated at this point and hemostasis achieved. The procedure can be performed without tourniquet with meticulous hemostasis. Bone wax can be used on any remaining exposed bone surfaces to aid in hemostasis. If there is any concern, prophylactic anterior compartment fasciotomy can be considered. This can be performed by distal extension of the fascial incision made during the initial anterior compartment dissection, staying just lateral to the anterior crest of the tibia to avoid neurovascular structures.

If no fasciotomy is performed, the anterior compartment musculature is loosely reapposed to the lateral edge of the periosteum along the tibial tubercle osteotomy. The periosteum of the medial proximal tibia can also be elevated and lengthened via pie-crusting technique to permit layered closure, contain any graft material, and improve the contour of the healed osteotomy site. The paratenon is closed using running 3.0 Monocryl, which achieves coverage of the tendon and often, with the exception of cases of primarily anterior shift, can completely cover the screw heads (Figure 10). The incision is closed in layered fashion.

Additional procedures for patella stabilization can be performed as indicated (Figure 11).

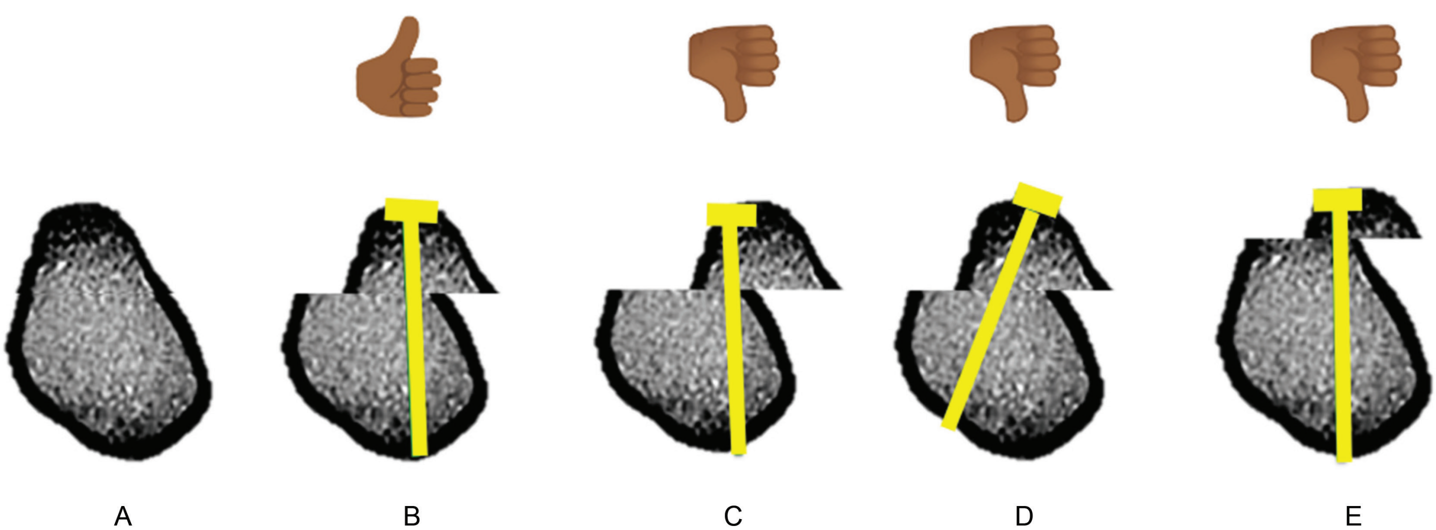

Figure 9. *Before (9A) and after (9B) medializing TTO with appropriate osteotomy translation and orthogonal screw fixation to optimize bony overlap for healing and mechanical advantage of fixation. Common errors of osteotomy and fixation are seen in 9C-E. Figure 9C demonstrates over translation of the osteotomy leaving minimal bony overlap for healing and fixation that may result in peri-implant fracture. Figure 9D demonstrates oblique screw fixation which may result in loss of osteotomy correction during screw compression. Figure 9E depicts an osteotomy that is too anterior leaving inadequate room for fragment translation and limited bony stock for screw fixation.*

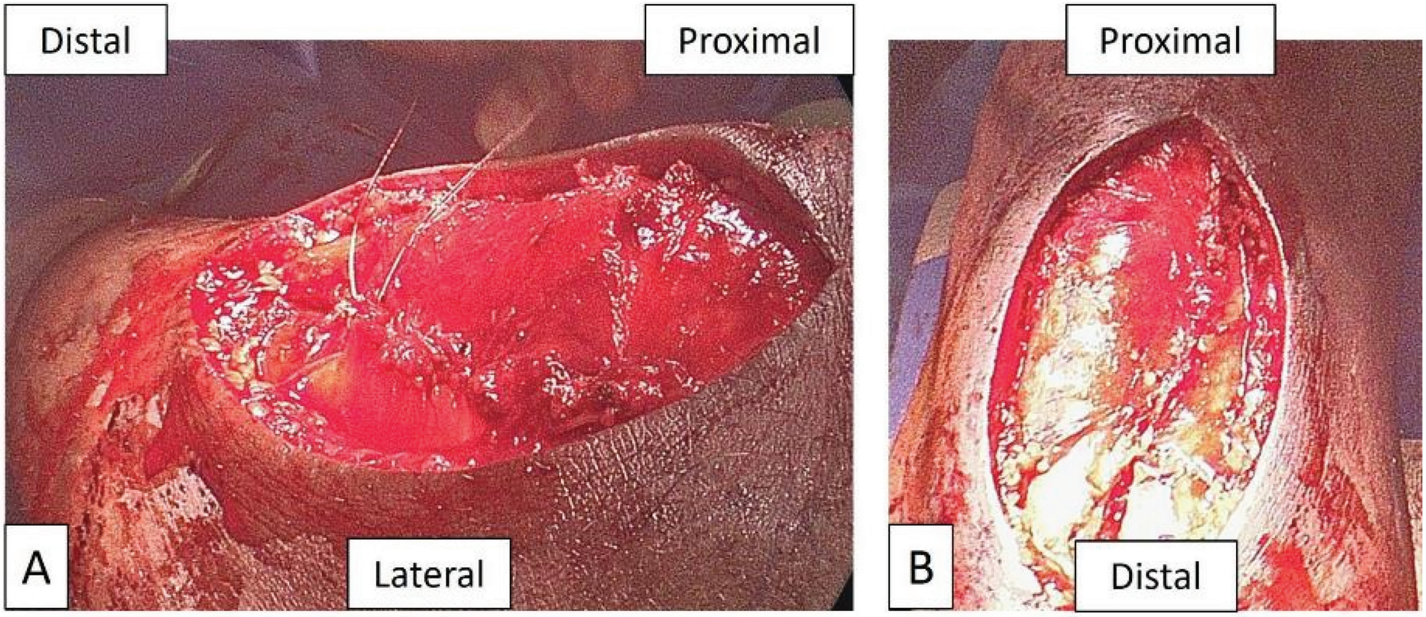

Figure 10. *Layered closure. (A) and (B) Peritenon closure can provide coverage of patella tendon and screw heads.*

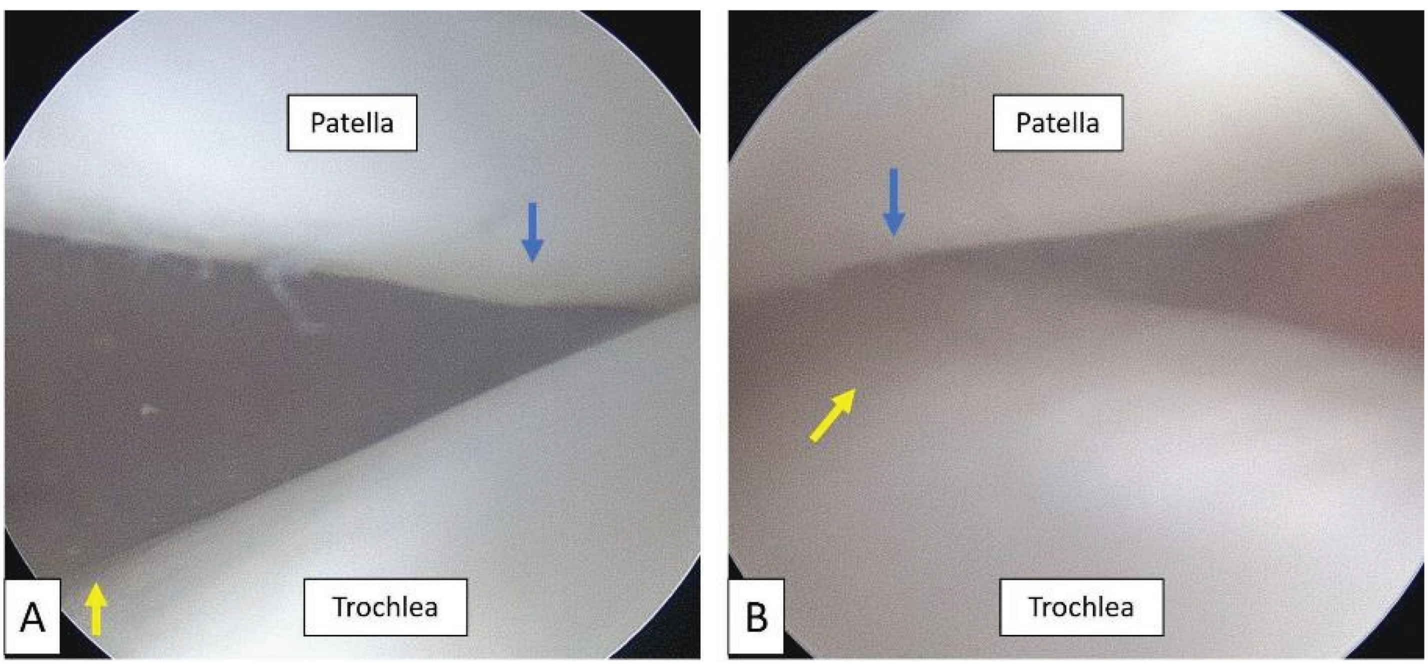

Figure 11. *Improvement in patella tracking (A) before and (B) after patella stabilization procedure including TTO. Blue arrow = median ridge of patella. Yellow arrow = Trochlear groove.*

At the end of the case, the patient is placed into a hinge knee brace with initial range of motion restrictions.

Postoperative Rehabilitation

Postoperatively, the patient is allowed to weight bear as tolerated with the hinge knee brace locked in extension in order to limit quadriceps activation during weight-bearing. Range of motion when not weight-bearing is initially restricted to 0-30 degrees and progressed gradually through the first 6 weeks. Brace use is continued for the first 6 weeks or until the patient is able to regain quad control. Full range of motion is usually allowed after 6 weeks or when signs of early healing are seen on radiographs. If a distalization procedure is performed, weight-bearing and range of motion restrictions should progress more slowly due to a less stable construct and increased time to healing. Outpatient physical therapy is an important component of the rehabilitation process, with initial goals of decreasing postoperative edema and regaining motion, progressing to restoration of normal gait and improving muscle function and in the final phases, increasing strength and eventual progression to return to full activity.

Comparison to Other Methods

A variety of approaches to the management of patients with PFI and increased extensor mechanism lateralization and/or patella alta have been described. Some have proposed that traditional criteria for correction of tubercle lateralization (TT-TG>20 mm) may be unnecessary, as isolated MPFL reconstruction may be sufficient in the management of many recurrent instability patients while avoiding the surgical risks of associated osteotomy with acceptable early outcomes. The authors believe this rationale may be less applicable to a younger and more active adolescent population who have greater long-term risk of recurrence, necessitating a more comprehensive corrective approach to their anatomic risk factors.

In skeletally immature patients, soft tissue distal realignment procedures such as the Roux-Goldwaithe and Modified Grammont have been described.[25-28] While these procedures appear to obviate the risk of physeal injury, making TTOs considered a contraindication in skeletally immature patients, other disadvantages may exist. First, these procedures have largely been described in skeletally immature patients, and therefore, their efficacy in older adolescents nearing or at skeletal maturity is uncertain, especially considering the less robust periosteum in an older patient population. Secondly, these procedures generally retain a portion of the distal extensor mechanism attachment point on the tibia, so the degree and precision of correction of concurrent patella alta is less exacting. Third, suture-based fixation of these soft tissue reconstructions may be less stable than osteotomy fixation constructs, limiting immediate postoperative mobilization. Finally, neither procedure facilitates concurrent extensor mechanism anteriorization, which may be preferred in the setting of patellofemoral chondral injury which is common with recurrent PFI.

Conversely, in comparison to soft tissue distal realignment procedures, TTO can result in greater levels of postoperative pain and stiffness. Osteotomy also carries an increased risk of postoperative bleeding and compartment syndrome, particularly within the anterior compartment. Nonunion of the osteotomy fragment can also occur, which may be higher risk in cases of complete detachment of the distal hinge. Longer term, the screws may be prominent and result in anterior knee pain and need for secondary procedure to remove symptomatic hardware.[29-31]

Summary

Tibial tubercle osteotomy (TTO) is a versatile procedure that can be customized to address a variety of pathologies in the setting of PFI, including lateralization of the extensor mechanism, patella alta, and associated patellofemoral chondral injury. The amount of correction is reliable, reproducible, and robust. Fixation with compression screws and preservation of a distal bony hinge results in a highly stable construct that permits early weight-bearing and postoperative knee motion. However, increased postoperative pain levels and theoretical complications of compartment syndrome and symptomatic hardware are important factors to take into consideration and discuss with the patient. The indications for performing a TTO and the assessment of extensor mechanism lateralization and its role in PFI are continually evolving subjects of research. Nonetheless, TTO is a multipurpose and powerful tool in the treatment of patellofemoral pathology.

Additional Links

- POSNAcademy: Tibial Tubercle Osteotomy
- AAOS Orthopaedic Video Theatre: Indications and Technique: Tibial Tubercle Osteotomies

- AAOS Orthopaedic Video Theatre: Medial Patellar Tendon Transfer with Proximal Realignment for Patellar Instability in the Skeletally Immature Knee

Disclaimer

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