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Tibial Tubercle Osteotomy: Anterior, Medial, and Distal Correction

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For patients with patellofemoral pain who fail exhaustive nonoperative treatment, surgical intervention may be a viable option for selected patients who have pain on the bases of pathomechanics and/or cartilage lesions. Treatments may be directed at proximal soft tissues and distally at the tibial tubercle such as in a tibial tubercle osteotomy. Tibial tubercle osteotomies can include medialization, anteriorization and/or distalization of the tibial tubercle. Proximaltaization can also be performed in the setting of patella baja, however, it is rarely performed and is outside the scope of this article. Medialization may be used to improve force vectors and contact area, anteriorization can decrease contact pressures, and distalization can normalize patellar height. Factors influencing which techniques are used include concomitant chondral pathology and specific measurements on imaging such as the tibial tubercle-trochlear groove distance, tibial tubercle-posterior cruciate ligament distance, and Caton-Deschamps Index. The following article reviews the indications for and techniques of anteriorization, medialization, distalization, and combinations of the 3, for tibial tubercle osteotomies.

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KEYWORDS tibial tubercle osteotomy, "patellar instability", "patellofemoral pain", "surgical technique", anteriorization, medialization, anteromedialization, distalization, indication

Patellofemoral pathology, including instability and pain, is a prominent problem in today's population. The annual incidence of primary patellar dislocation is 5.8 ± 1 per 100,000 when evaluating all age groups and rises to 29 ± 8 per 100,000 when evaluating those 10-17 years old.[1] Furthermore, patients who experience lateral patellar instability are at increased risk for future ipsilateral instability events, with a reported cumulative recurrence rates as high as 36%.[2] A variety of risk factors including age <18, trochlear dysplasia, elevated tibial tubercle-trochlear groove (TT-TG) (>20 mm), and patella alta have been identified.[2-4] Balcarek et al has described a patellar instability severity score (IIS) to quantify a patient's risk of redislocation based on 6 risk factors: trochlear dysplasia, TT-TG distance, bilateral instability, age <16, patellar height, and patellar tilt.[5] Hevesi et al developed an additional model: "recurrent instability of the patella." (RIP) [6] In this model a patient would receive a score between 0 and 5 based on risk factors including age <25 (2 points), skeletal immaturity (1 point), Dejour dysplasia (1 point), and TT-TG/PL ≥0.5 (1 point). Finally, Hiemstra et al proposed a classification system, "weak atraumatic risk anatomy pain subluxation and strong traumatic anatomy normal instability dislocation" (WARPS/STAID), where patients are stratified into one of these 2 groups based on quadricep strength and the presence of anatomic disposition to dislocation.[7,8] In patients with these risk factors, such as trochlear dysplasia or young age, redislocation has been reported to occur in up to 70% of patients.[9] In a subset of patellofemoral patients, surgical intervention may include a realignment procedure, such as a tibial tubercle osteotomy (TTO). The tibial tubercle is the most distal anchor of the extensor mechanism of the knee, thus giving it the potential to alter the biomechanics of the patellofemoral joint if its position is moved. Specifically, changing the location of the tibial tubercle allows for

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improved contact area and forces and leading to decreases of stress/pressures between the patella and femur.[10-12]

Tibial tubercle osteotomies may be classified as anteriorization, medialization and/or distalization. Medialization can aid in stability of the patella through redirecting force vectors as well as normalizing the patella position from a chronic lateral position, anteriorization can decrease contact pressures, and distalization can normalize patellar height.[13-20] The indications for these procedures are detailed below.

Patient Evaluation

When evaluating a patient with patellar instability and/or patellofemoral pain, it is important to establish the primary pathology and then map out all the comorbidities. Physical exam of the bilateral extremities includes overall limb alignment, looking for excessive valgus alignment, with range of motion of the hip and knee. Hip range of motion may be assessed supine or prone and is helpful to determine assess femoral/hip anteversion. Thigh foot angles should also be obtained to assess for tibial torsion. Beighton scoring assesses hypermobility. Muscle tone and strength is noted. Regarding patellar mobility, the patellar tilt, height, and tracking is documented. Functional examination may include stepping up and down with note of limb control and position of maximal pain. Finally, the specific areas of maximal tenderness about the anterior knee are noted for correlation with underlying pathoanatomy.

Imaging

Standard knee radiographs identify not only patellofemoral (PF) problems but also possible contributing tibofemoral pathology. These typically consist of anteroposterior for evaluation of anterior tibiofemoral osteoarthritis, 45° flexion posteroanterior (PA) (Rosenberg) for evaluation of posterior tibiofemoral osteoarthritis, true lateral for evaluation of patellar height and trochlear dysplasia, low flexion angle axial view, and mechanical axis view of the both limbs to check coronal alignment (Table). Radiographs establish basic alignment of the knee, arthritic change within the 3 compartments of the knee, and general position of the patella.

Magnetic resonance imaging (MRI) is useful in many ways. Soft tissue assessment includes the articular cartilage, the medial and lateral restraints as well as correlating patella position with the bony anatomy as Staubli demonstrated the chondral and bone contours may differ.[21,22] The bone aspect of the MRI may reveal sclerosis, bone loss or stress fracture reactions (radiologists use the term bone marrow edema) from altered load, impact or chondral loss. Sagittal views can be used to evaluate for patellar height and patellar trochlear index. If there is clinical suspicion of increase femoral anteversion, Noyes et al published the technique using hip/knee ankles MRI cut to measure femoral anteversion and tibial torsion (avoiding computed tomography [CT] radiation).[23] CT more precisely visualizes the bone and may allow for multiple angle PF views as well as quad active views. In cases with questionable degrees of chondrosis, a thin section CT arthrogram has improved resolution over a standard MRI cut. Both MRI and CT can be used to assess the TT-TG distance, the tibial tubercle-posterior cruciate ligament (TT-PCL) distance, patellar trochlear index, and patellar height.[24-26] In multiple studies, asymptomatic controls have a TT-TG of 10-13 mm and a subset of patient with instability have TT-TG over 15. There is general agreement that a TT-TG over 20 mm is abnormal and Seitlinger noted TT-PCL of over 24 to be outside of the normal range.[25] MRI and CT can also be used to assess for trochlear dysplasia.[24,25]

Table Important Measurements and Findings on MRI and X-ray Based on View

Modality	View	Measurements & Findings
Radiographic view	AP	Anterior tibiofemoral osteoarthritis, Patellar positioning
	PA	Posterior tibiofemoral osteoarthritis, Patellar positioning
	True lateral	Trochlear dysplasia, Patellar height
	Mechanical axis	Coronal alignment
	Merchant view	Patellar tilt, Patellofemoral arthritis, Patellar dysplasia
MRI	Axial	TT-TG, TT-PCL, Patellofemoral cartilage
	Sagittal	Patellar height, Patellar trochlear index
	Hip/knee ankles MRI	Femoral anteversion, Tibial torsion

Indications

The key to a successful TTO is having well-defined indications and failure of conservative treatment. That is, understanding what the TTO is to accomplish. For cartilage restoration patients, the goal is to optimize the force and contact area for the implant. Anteromedialization (AMZ) is most frequently used when there is an excessive TT-TG/TT-PCL, while straight anteriorization is used if these measurements are near "normal." Likewise, for those patients with isolated distal lateral lesions not undergoing cartilage restoration, Fulkerson and Pidoriano demonstrated excellent outcomes with AMZ TTO. Both AMZ and straight anteriorization can have the addition of a component of distalization to optimize patellar height.

Medialization is often performed with anteriorization as there is often concomitant chondral pathology, specifically the distal and lateral patella. Anteriorization effectively offloads the patellofemoral joint.[16] Combining the procedure, anteromedialization, is often indicated in individuals with a TT-TG of >20 mm, excessive lateral tilt, subluxation, and

the absence of central trochlea chondral pathology.[13,14] Adding a TTO during patellofemoral cartilage restoration procedures have also been shown to be beneficial.[17,19,20,27]

The role of TTO in a patient with recurrent patellar instability (RPI) has evolved. In the distant past, tubercle medialization with lateral release was the treatment for RPI. However, the current algorithm for RPI calls for addressing medial restraint patholaxity most commonly with medial patellofemoral ligament (MPFL) and/or medial quadriceps tendon-femoral ligament (MQTFL) reconstructions. Isolated MPFL reconstruction can have positive outcomes in patients with TT-TG greater than 20 mm.[15,28] Within this subgroup of patients that have chronic lateral positioning of the patella and RPI, those with elevated TT-TG/TT-PCL could benefit in the long-term by normalization patella position (and stress) through the addition of tubercle medialization to the medial restraint reconstruction. Distalization may be indicated for the subset of RPI patients with excessive patellar alta ($\geq$1.4). It should be noted that alta is frequently associated with trochlear dysplasia,[24,29] which requires further review of all comorbidities to develop a comprehensive treatment plan. The goal of the procedure is to normalize the Caton-Deschamps Index (CDI) to ~1.0.

Surgical Technique

Anesthesia

General anesthesia or regional anesthesia (eg, adductor canal block/SPANK block) with monitored anesthesia care are the most common methods.

Patient Positioning and Exam Under Anesthesia (EUA)

The patient is positioned supine on the operating room table. It is important to position the patient so that the patella is parallel to the floor. This may require a bump under the hip or use of the "tilt" function of the operating room table. A non-sterile tourniquet is applied to the proximal thigh. A side post is also placed at the level of the tourniquet to aid in the diagnostic arthroscopy. In patellar instability patients, an exam under anesthesia is performed to confirm the characteristics of the patient's instability. This begins with range of motion of both the hip and knee. We also routinely perform a ligamentous exam of the knee. Specific to patellar instability includes grading medial and lateral patellar translation. Patients typically exhibit a 3B lateral translation which indicates the ability to subluxe and nearly dislocate the patella without a firm endpoint. Patellar crepitus is noted during knee range of motion in addition to the knee flexion angle at which the patella reduces.

Diagnostic Arthroscopy

A standard diagnostic arthroscopy of the knee is routinely performed unless the patient recently underwent a diagnostic arthroscopy for staging purposes. A standard inferolateral portal is made. A diagnostic arthroscopy is performed paying close attention to the patellofemoral joint and lateral femoral condyle. An inferomedial portal is used for probing the joint. For RPI patients it is important to evaluate the lateral aspect of the lateral femoral condyle for an exit impaction injury as well as the posterior compartments for loose bodies. Upon completion of the diagnostic arthroscopy, fluid is evacuated, the side post in dropped, and the foot and ankle are then placed in an articulated arm holding device (Spider2 Limb Positioner, Smith & Nephew, Andover, MA).

Incision and Tibial Tubercle Exposure

Bony landmarks are identified including the medial, lateral, superior, and inferior borders of the patella, the patellar tendon, and the tibial tubercle. A midline longitudinal incision is marked from the top of the tibial tubercle 4-6 cm distal (Fig. 1). This midline incision may incorporate the inferolateral portal but would require slight lateralization of the incision. The tibial tubercle is exposed using a combination of blunt and sharp dissection (Fig. 2). It is also during this time that exposure may be brought proximal to include concomitant procedures such as MPFL reconstruction and/or cartilage restoration procedures. A 1-2 cm incision is made sharply medial and lateral to the retinaculum at the distal extent of the patellar tendon. A blunt instrument is used to free the patellar tendon from the fat pad posteriorly (Fig. 3). This is an important step for the future TTO. A longitudinal incision is then made subperiosteally elevating the anterior compartment laterally to allow for appropriate exposure of the lateral tibial

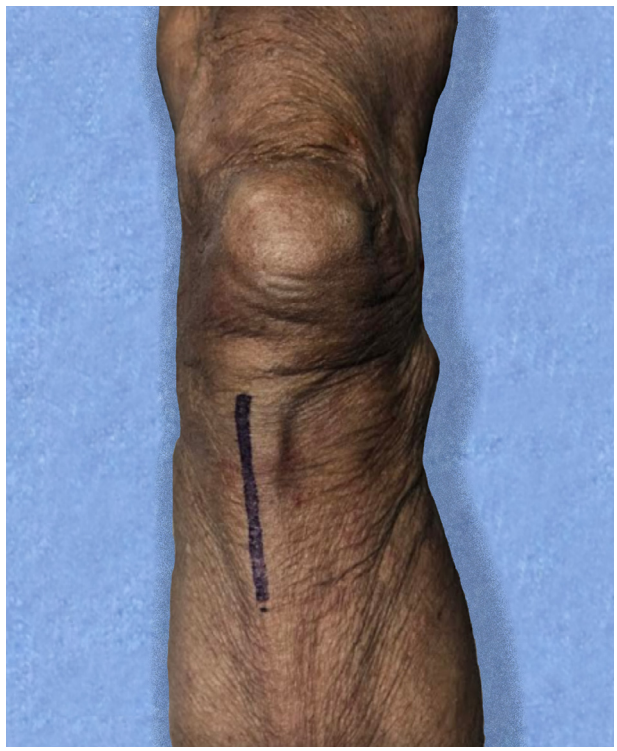

Figure 1 Marked incision for tibial tubercle osteotomy.

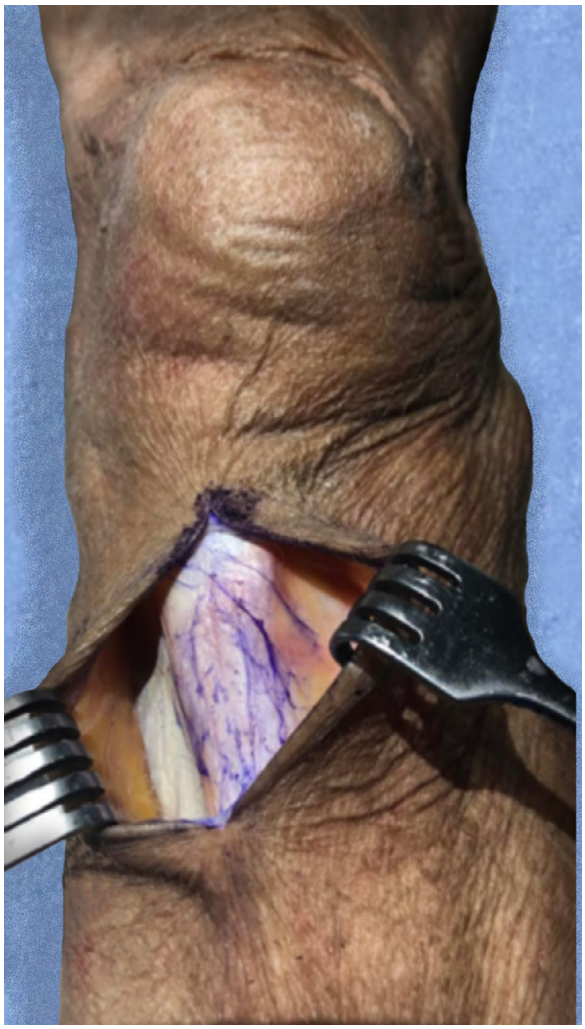

Figure 2 Exposure of the tibial tubercle.

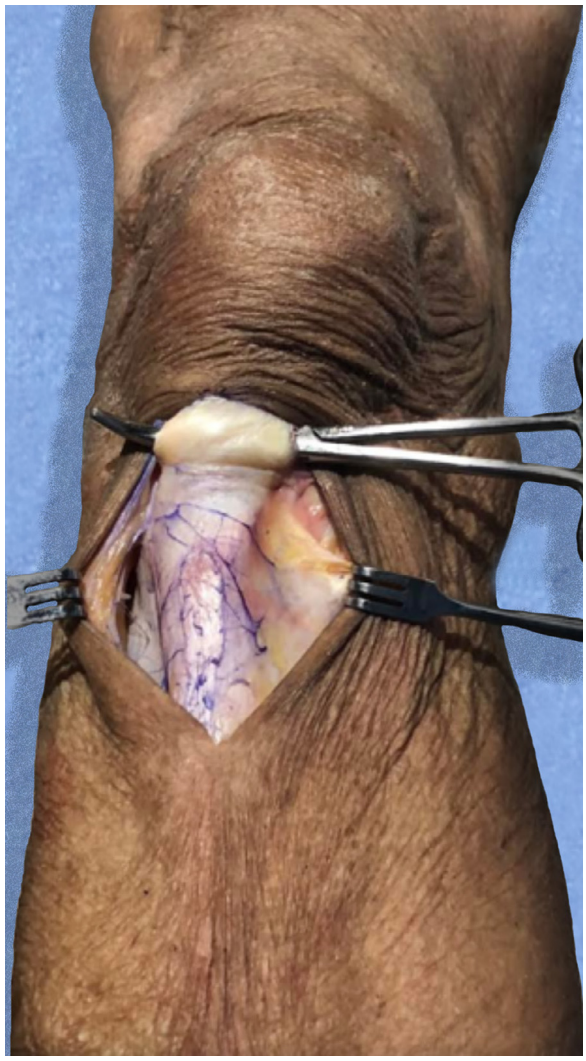

Figure 3 Patellar tendon exposed medial, lateral, and posterior.

crest. A small flap of subperiosteal tissue is left for later closure. The tibial tubercle is exposed carefully not to disruption the posterior neurovascular structures including the deep peroneal nerve laterally and the recurrent branch of the anterior tibial artery anterolaterally.

Osteotomy for Anteromedialization

After appropriate exposure of the tibial tubercle, a reference guide pin is placed perpendicular to the posterior cortex of the tibia just distal to the insertion of the patellar tendon to prepare for the AMZ. In this case the Arthrex T3 AMZ system is used (T3 System, Arthrex, INC, Naples, FL) (Fig. 4). Using preoperative calculations based off the TT-TG, the desired anteriorization and medialization is assembled with the cutting block and cutting block post. The guide is then placed over the reference pin and positioned just medial to the crest of the tibial tubercle in line with the medial border of the patellar tendon. The distal end of the guide is angled laterally to allow for a sharp exit of the osteotomy distally. Depending on the angle used for the osteotomy slope this changes the amount of medialization. It is also generally accepted that anteriorization should be kept between 10-15 mm as this decreases patellofemoral stress up to 20%. For example, utilizing a slope of 60° would create a medialization of 8.7 mm, whereas a slope of 45° would create a medialization of 15 mm.[24] This forms a triangular shape with a desired osteotomy length of 7-10 cm. Break away pins are placed, and the tips are broken away allowing for easy access of the oscillating saw (Fig. 5). The saw cut is made protecting all important neurovascular structures. An osteotome can be used to complete the cut distally (Fig. 6).

Osteotomy for Distalization

The TT is exposed similarly to an AMZ. The major difference in this osteotomy is the horizontal nature of the tibial tubercle cut. Additionally, preoperative calculations using the CDI are necessary to attempt normalize back to ~1.0. It should be noted that distalization of the tibial tubercle will also inherently medialize the tubercle slightly. For example, if the patient has a CDI of 1.35 based off the inferior pole of the articular surface distance to the anterior tibial tubercle of 42 mm and the distance of the patellar articular surface of 31, this would require a distalization of 11 mm to normalize

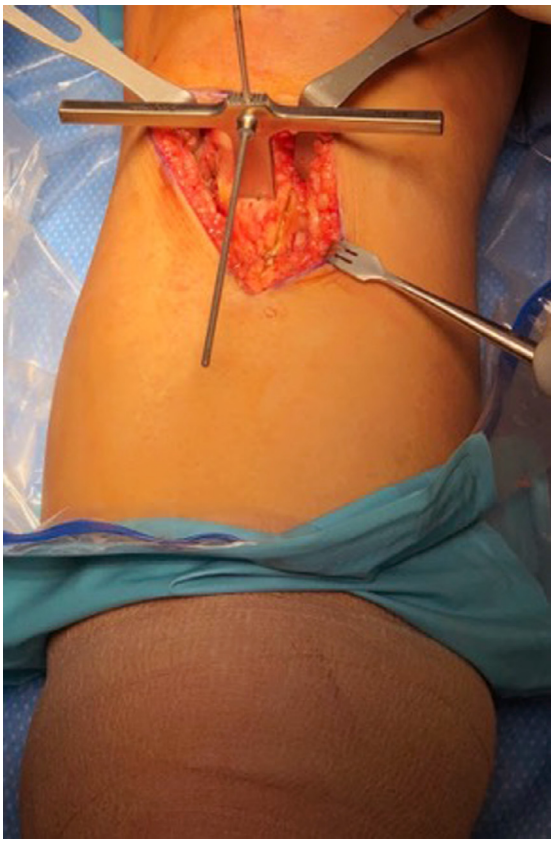

Figure 4 A reference guide pin is placed perpendicular to the posterior cortex of the tibia just distal to the insertion of the patellar tendon.

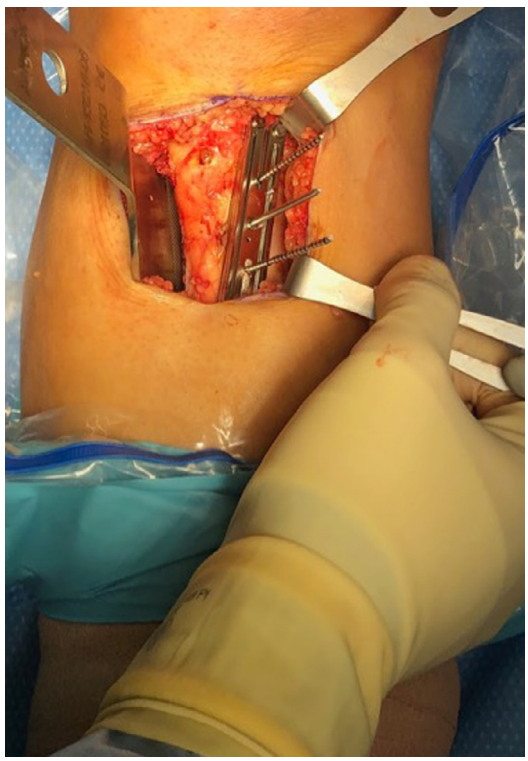

Figure 5 The guide is then placed over the reference pin and positioned just medial to the crest of the tibial tubercle in line with the medial border of the patellar tendon. Breakaway pins are placed and tips are broken away.

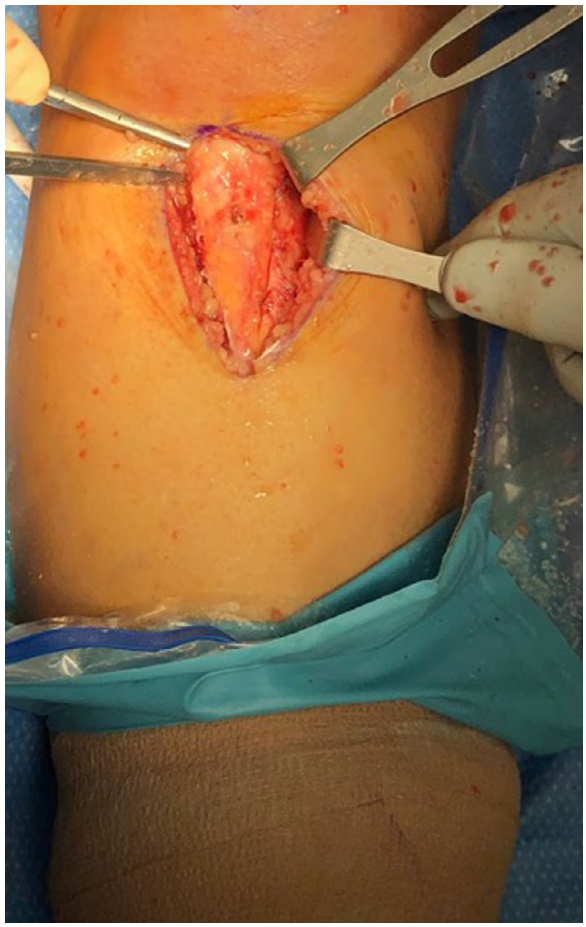

Figure 6 The saw cut is made and completed with an osteotome distally completing the osteotomy.

the CDI to 1.0. A chevron osteotomy is made using a marking pen as the tibial tubercle tapers (Fig. 7). A ruler is used to measure and verify the proposed amount of bone to be resected for the distalization (Fig. 8). An oscillating saw is then used to make the distal most cut first which should be oblique to increase cortical healing surface area (Fig. 9). This is followed by the horizontal cut with retractors in place to protect the neurovascular structures (Figs. 10 and 11). The proximal of the 2 distal marks are then cut (Fig. 12). The cuts are made in this manner so that the horizontal cut is flush and the osteotomized piece does not inadvertently fall from the sterile field. An osteotome may be necessary to complete free of the osteotomy. The osteotomy is then released of all soft tissues attachments medially and laterally (Fig. 13). The free piece is held on the back table during this (Fig. 14). The piece is then place proximally within the osteotomy site (Fig. 15). This effectively anteriorizes the osteotomy offloading the patellofemoral joint. The osteotomy is then placed down and ready for fixation (Fig. 16).

Tibial Tubercle Fixation

In both AMZ and distalization, the tibial tubercle requires adequate fixation. The key to fixation in both osteotomies is maintenance of the new tubercle position by maintaining a

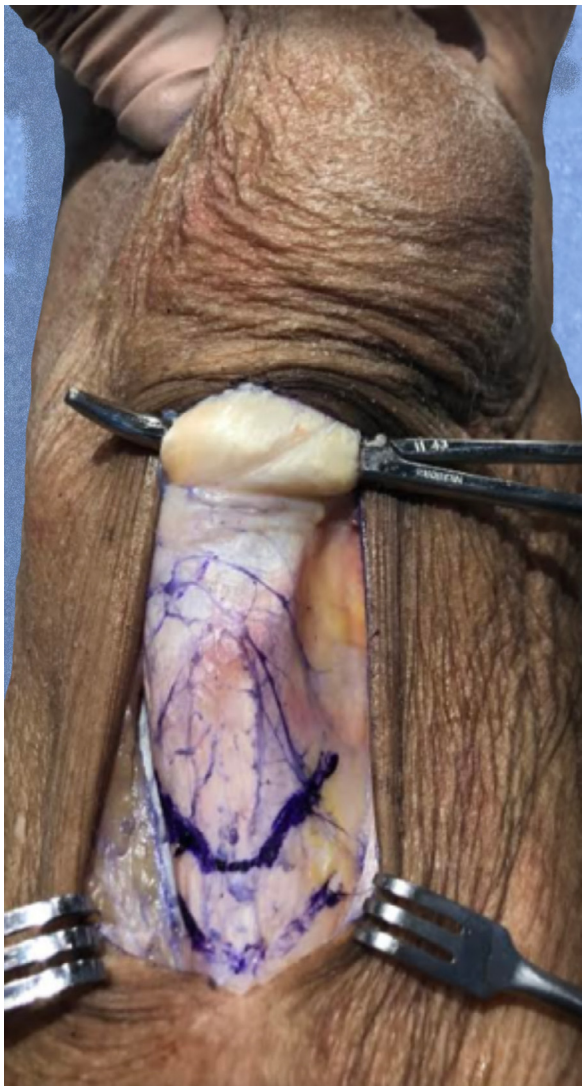

Figure 7 A marking pen is used to mark out the chevron osteotomy both distally and proximally.

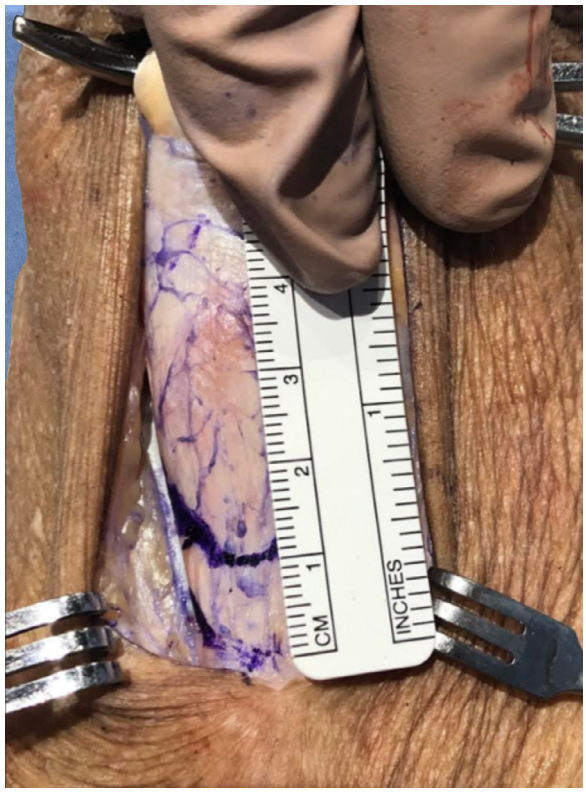

Figure 8 A ruler is used to verify the amount of bone to be resected for the distalization.

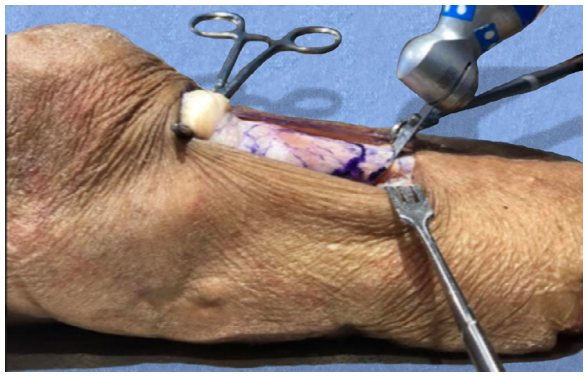

Figure 9 An oscillating saw is used to make the most distal cut first.

perpendicular position to the osteotomy during screw fixation. This is crucial for AMZ as any misdirected screw will preferentially force the tubercle back to its native position. After establishing the final position for the tibial tubercle, 4.5 mm screws are countersunk and affixed in a lag by technique fashion. This occurs by first drilling bicortically with a 3.2 mm drill, leaving one in place for rotational control, followed by using a 4.5 mm drill unicortically. A countersink is then used before placing the screw (Fig. 17). Countersinking the screws decreases the chance of prominent hardware. One should be mindful of positioning and the potential for cracking the osteotomy during fixation.

Closure

Closure occurs in the standard fashion paying close attention to tissue layers. The anterior compartment fascia is closed loosely back to its fascial attachment. Keep in mind medialization may disallow this and one should be mindful of overtightening the anterior compartment. Retinacular rents may be closed both medially and laterally. The deep subcutaneous tissues are closed followed by the subcutaneous tissues. The skin is closed with a subcuticular monofilament followed by steri strips. If the portal incision is left out of the incision, this too may be closed by a buried monofilament suture with steri strips.

Rehabilitation

The authors preference for rehabilitation protocol is based largely on need for concomitant procedures, specifically cartilage restoration. In situations of isolated TTO without cartilage restoration the patient will remain in their hinged knee brace at all times during the first 2 weeks with heel touch

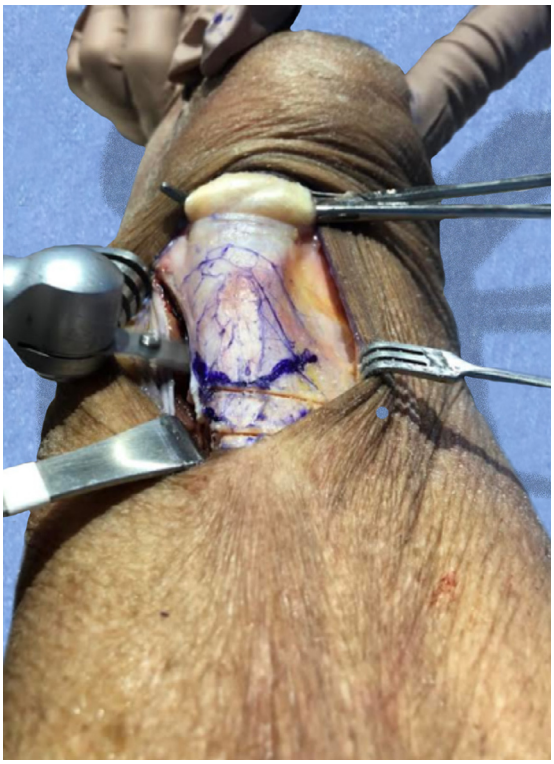

Figure 10 Anterior view demonstrating horizontal cut for distalization.

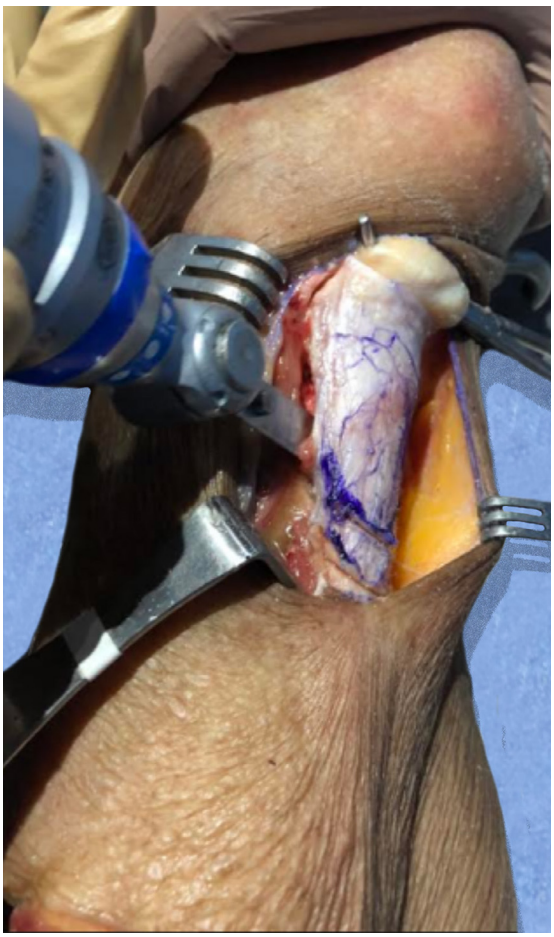

Figure 11 Oblique view demonstrating horizontal cut for distalization.

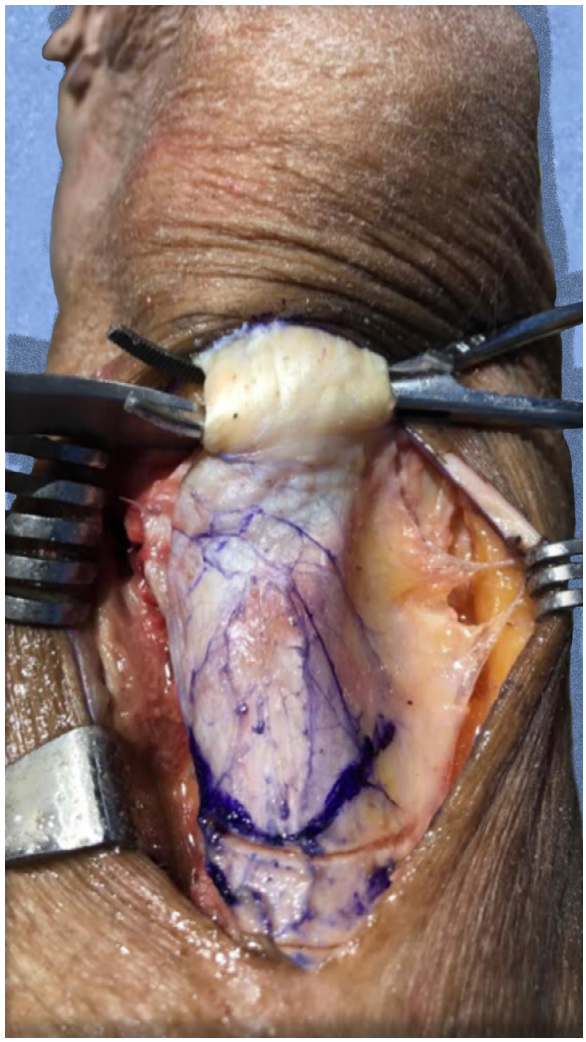

Figure 12 An oscillating saw is used to make the proximal cut.

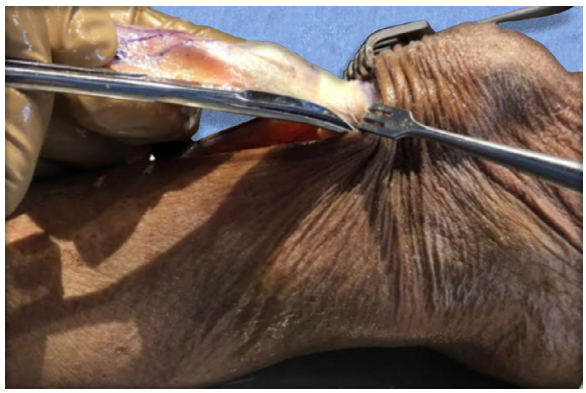

Figure 13 The osteotomy is freed of all soft tissue attachments distally, medially, and laterally.

weight bearing and supine ROM of 0-90° while at home. At 2-6 weeks they will continue heel weight bearing but may remove the brace at night but with continued ROM of 0-90° while out and at home. At 6-8 weeks they should discontinue their brace and advance weight bearing 25% of their weight weekly until full weight bearing. At 8-16 weeks, they are full

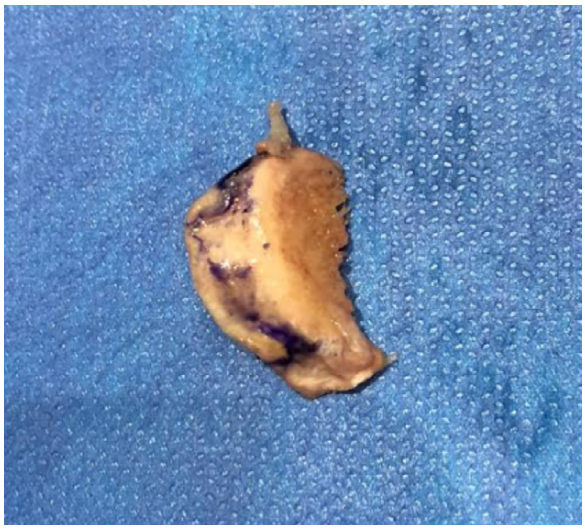

Figure 14 The free distal piece is held on the back table.

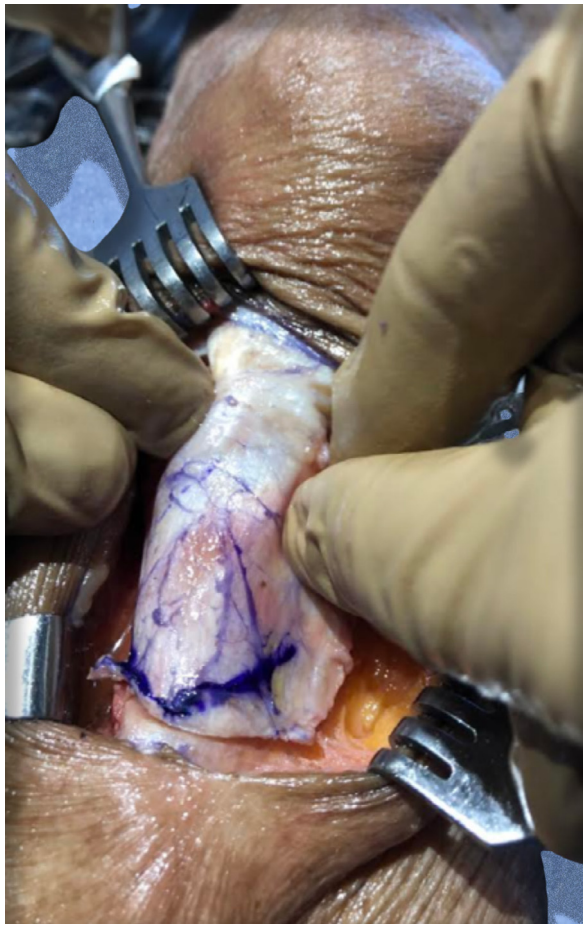

Figure 16 The osteotomy is then placed down and ready for fixation.

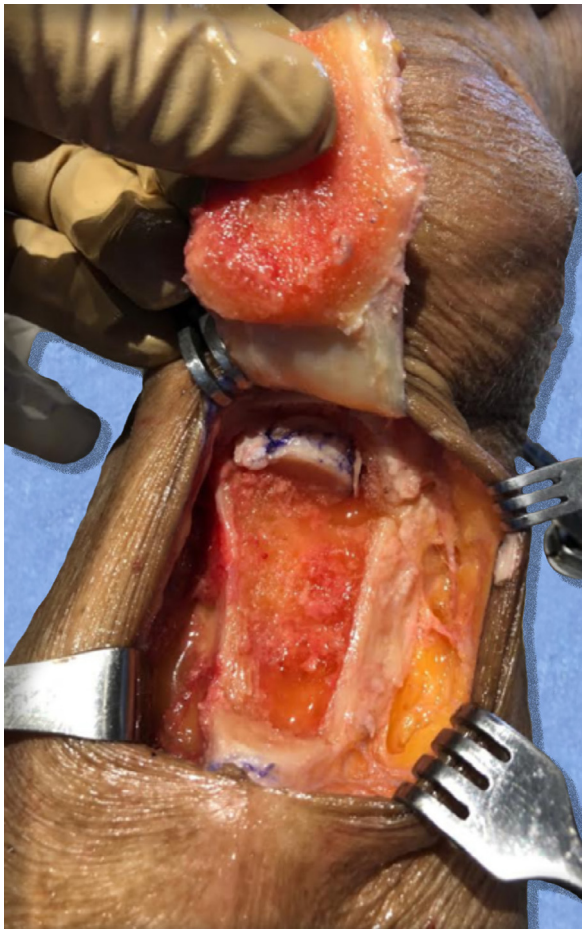

Figure 15 The free piece is placed proximally within the osteotomy site.

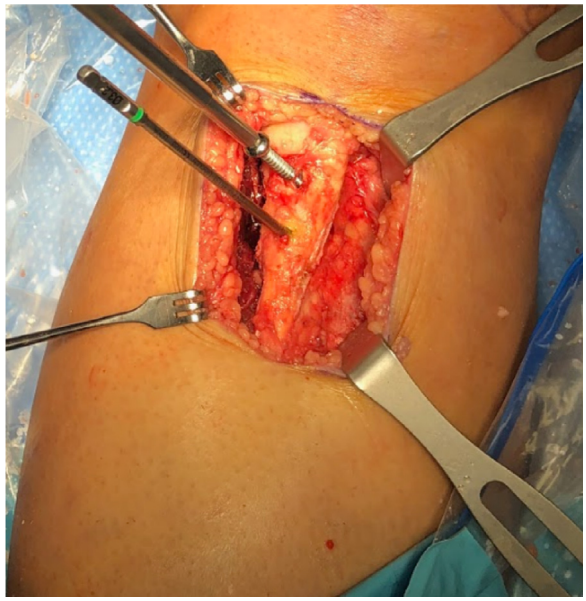

Figure 17 A 4.5 mm screw is placed proximally after being countersunk and affixed in a lag by technique fashion. The 3.2mm drill bit is held in place distally as to not rotate the osteotomy during screw fixation.

weight bearing and progressing their flexibility and strengthening. By 16-24 weeks they will maximize core to extremity movements in their lower extremities and transition to sport specific activities.

Conclusion

TTO - provide an additional surgical procedure which can help improve outcomes in patients with patellofemoral instability or pain. There are a multitude of indications for anteriorization, medialization, distalization, or any combination of the 3. Thorough history taking, physical examination, and advanced imaging in selected cases can help determine which procedures are necessary for each individual patient. The management of initial patellar subluxation events is controversial, but for those with chronic patellofemoral pain and instability, TT osteotomies with proper patient and procedure selection allow patients to return to an active and pain-free lifestyle.

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