Malalignment can affect any of the three compartments of the knee. An osteotomy performed on the proximal tibia, the distal femur, or the tibial tubercle can alter the knee's biomechanical alignment and unload the affected compartment. Osteotomy can also be very useful when done in conjunction with cartilage restoration procedures. Multiple procedures have been proposed for each level of osteotomy, with varying degrees of clinical success. This chapter discusses the indications, surgical techniques, and results of opening wedge high tibial osteotomy, opening wedge distal femoral osteotomy, and tibial tubercle osteotomy.

Before a patient can be considered for any of these osteotomies, a detailed history and physical examination must be performed. The history should determine the patient's occupation and activity level, and all previous surgical and nonsurgical interventions. It is important to note the patient's body habitus and overall alignment, and any coronal, sagittal, or rotational instability. All arthroscopic and radiographic images obtained previously should be reviewed with the patient. New radiographs should be obtained, including a Merchant view and weight-bearing AP, lateral, and 45° flexion PA views. Bilateral weight-bearing long-cassette views also should be obtained to measure the mechanical axis and degree of correction needed. MRIs are useful when cartilage or ligament damage is suspected.

High Tibial Osteotomy

Patient Selection

High tibial osteotomy is indicated for younger patients with symptomatic, isolated, medial compartment arthritis in whom a unicondylar arthroplasty is likely to fail. Patients with osteonecrosis or osteochondral defects with varus malalignment can benefit from an osteotomy once their cartilage defects have been addressed.

The procedure is contraindicated in patients with tricompartmental arthritis, a deformity greater than 15°, a flexion contracture greater than 15°, knee flexion less than 90°, medial or lateral tibial subluxation greater than 1 cm, excessive bone loss (more than 3 mm), inflammatory arthritis, morbid obesity, or any medical comorbidities that might interfere with bony healing. Patellofemoral arthritis and patient age over 60 years are considered relative contraindications.

Calculating the Degree of Correction

Coronal Plane

For medial compartment arthritis, overcorrection to the 62% lateral weight-bearing line (roughly two thirds the width of the tibial plateau) is usually needed. For unloading cartilage restoration procedures, correction of the mechanical axis to neutral (center of plateau) is sufficient. The point of the desired mechanical axis is marked on the tibial plateau. A line is drawn from the center of the femoral head to the desired point on the...
plateau. Another line is drawn from the point on the plateau to the center of the tibial plafond. The angle formed by the two lines is the degree of correction needed (Figure 1). Generally, 1 mm of opening corresponds to 1° of correction.

Sagittal Plane
Increasing the tibial slope will worsen symptoms in patients with anterior cruciate ligament (ACL) instability and improve symptoms in those with posterior cruciate ligament (PCL) instability. On the other hand, decreasing the tibial slope will improve symptoms in patients with ACL instability and worsen symptoms in those with PCL instability.

Surgical Technique
All osteotomy procedures are performed on a radio-lucent table. If iliac crest autograft is planned, the ipsilateral pelvis can be prepared and draped as well. Arthroscopy is routinely performed to verify the status of the articular cartilage and to perform any required cartilage restoration procedure.

The tibial osteotomy incision extends along a line that runs from the distal aspect of the anteromedial arthroscopic portal distally to the level of the pes. The portion of the line below the joint surface can be used to perform the actual incision. The incision falls roughly between the tibial crest and the posteromedial tibial border. Dissection is made down to the anteromedial tibia and the sartorius fascia. A transverse cut is made along the superior aspect of the hamstring tendons, extending from the posteromedial tibia to the level of the patellar tendon. This cut is curved inferiorly along the medial side of the patellar tendon. A sleeve is elevated subperiosteally to the posteromedial tibia. Two blunt retractors are put in place, one behind the tibia to protect the neurovascular bundle, and the other under the patellar tendon.

We use one of the commercially available opening wedge osteotomy systems to fix our osteotomies. A breakaway osteotomy guide pin is inserted into the tibia in an inferomedial-to-superolateral direction. The starting point is about 3 cm distal to the medial joint line. The tip of the guide pin should end on the lateral cortex at least 1 cm distal to the lateral tibial joint line, near the tip of the fibular head. Another pin is inserted parallel to the first, taking into account the proximal slope of the tibia. The pins are bent and broken at their breakaway point and the osteotomy cutting guide is placed over the two pins. An oscillating saw is used to cut the tibia to within 1 cm of the lateral cortex (Figure 2, A). Thin osteotomes are used to complete the osteotomy. To avoid violating the lateral cortex, the tibial cut should be made—and the osteotomes should be placed—inferior to the cutting guide and pins.

The guide pins are removed, and the calibrated wedges are gently tapped through the medial tibia to distract the osteotomy (Figure 2, B and C). The markings on the side of the wedges correspond to the size of the opening in millimeters. The wedges should be inserted slowly because rapid insertion can lead to a lateral fracture. Once the appropriate osteotomy angle is achieved, the...
handle is removed and the wedges are left in place. If the wedges do not open the bone, the wedges are removed and the osteotomes are used again. If the osteotomy extends to the opposite cortex, it can be fixed by making a small incision over the lateral cortex and inserting two bone staples. If the osteotomy extends proximally to the tibial plateau, it can be fixed using two partially threaded AO screws or a periarticular plate.

A plate with the same sized opening is placed in the space between the two wedges (Figure 2, D). Two 6.5-mm unicortical cancellous screws are used to fix the plate proximally. The calibrated wedges are removed to allow the osteotomy to close down on the plate. Two 4.5-mm bicortical screws are used to fix the plate distally (Figure 2, E).

Allograft or autograft tricortical bone is inserted in the osteotomy site on both sides of the plate (Figure 2, F). The elevated tissue on the medial side of the tibia is repaired, and the rest of the incision is closed in layers. A knee brace locked in extension is applied. Anticoagulation medication—low-molecular-weight heparin or warfarin—is prescribed for 4 weeks.
Rehabilitation Protocol
The principal goals of a rehabilitation program following a high tibial osteotomy include pain relief and improvement in the ability to walk. After any type of osteotomy, bone healing must occur before full weight bearing or vigorous physical activity can be initiated. A detailed description of the rehabilitation protocol prescribed after high tibial osteotomy can be found in Table 1.

Distal Femoral Osteotomy

Patient Selection
A distal femoral osteotomy is indicated for patients with valgus deformity in the knee. The procedure should be performed with cartilage restoration procedures in the lateral compartment when valgus malalignment coexists. The indications and contraindications for distal femoral osteotomy are similar to those for high tibial osteotomy.

TABLE 1
Rehabilitation Protocol After High Tibial Osteotomy

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I (first 4 weeks):</td>
<td>Touch-down weight bearing with crutches is allowed for at least 4 weeks. The knee brace is worn at all times, except during continuous passive motion machine (CPM) use. The CPM should be used for 4 hours a day, with a goal of achieving 90° of flexion. Physical therapy includes quadriceps sets, ankle pumps, straight-leg raises with the brace locked in extension, and non–weight-bearing calf/hamstring stretches.</td>
</tr>
<tr>
<td>Phase II (4 to 6 weeks):</td>
<td>Weight bearing is advanced without crutches. The brace is unlocked for ambulation and the CPM is discontinued. Physical therapy continues with gentle stationary bike use and straight-leg raises without the brace.</td>
</tr>
<tr>
<td>Phase III (6 weeks to 3 months):</td>
<td>The brace can be discontinued if the patient is pain free. Mini-squats (0° to 45°), leg-presses (0° to 60°), closed-chain terminal knee extensions, balance activities, and toe raises may be started.</td>
</tr>
<tr>
<td>Phase IV (3 to 9 months):</td>
<td>Progress closed-chain exercises as tolerated. Treadmill walking may begin; progress as tolerated by the patient. Return to sports and work typically occurs around 9 to 12 months.</td>
</tr>
</tbody>
</table>

Surgical Technique
A lateral approach is used to perform a distal femoral osteotomy. The iliotibial band is split along its fibers and the vastus lateralis is elevated off the femur to expose the femoral shaft and metaphysis. A breakaway osteotomy guide pin is inserted about 4 cm proximal to the lateral epicondyle (Figure 3, A). The pin is placed from lateral to medial at an oblique angle to end near the medial epicondyle. It is important not to make the osteotomy cut too distal because it can violate the...
trochlea and enter the joint. The osteotomy is performed in a way that is similar to that of a high tibial osteotomy; however, the cut should be made perpendicular to the femur in the sagittal plane to prevent flexing or extending the femur. An opening wedge instrument set similar to that used for a high tibial osteotomy, but with longer plates, is available for this procedure.

Once the appropriate angle of correction is achieved, the plate is fixed distally with 6.5-mm unicortical cancellous screws and proximally with at least three 4.5-mm bicortical screws (Figure 3, B). Bone graft is then inserted. The incision is closed in layers. A drain can be used for 24 hours if needed.

A rehabilitation protocol similar to that used for high tibial osteotomy (see Table 1) should be initiated.

**TIBIAL TUBERCLE OSTEOTOMY**

**Patient Selection**

Tibial tubercle osteotomy with medialization is indicated in symptomatic patients with a tibial–tubercle–to–trochlear groove (TT-TG) distance greater than 20 mm, with or without signs of patellar instability.\(^2,3\) It can be performed on patients who are also undergoing a medial patellofemoral ligament (MPFL) repair or reconstruction and lateral release. In general, the patellofemoral compartment should exhibit no signs of chondrosis.

Tibial tubercle osteotomy with anteromedialization should be reserved for patients who have an abnormal TT-TG distance with lateral distal chondrosis or who are undergoing a cartilage restoration procedure in the patellofemoral compartment. In patients with Outerbridge grade I or II lesions, an anteromedialization may be sufficient. In patients who have grade III or IV lesions, the osteotomy should be combined with a cartilage procedure.\(^2,3\)

A tibial tubercle osteotomy is contraindicated in patients who have a normal TT-TG distance or who have complete loss of joint space and advanced diffuse arthritis. Medical issues that could interfere with bony healing (smoking, infection, and osteoporosis) also are considered contraindications to an osteotomy.

**Evaluation**

Chondral defects in the patellofemoral compartment are commonly seen in knee arthroscopies. These chondral defects sometimes present with alignment and mechanical abnormalities, which also may benefit from a tibial tubercle osteotomy.

Affected patients often describe an insidious onset of pain. The location of the anterior knee pain should be documented. Patients with patellar defects present with pain on the back or sides of the patella, and patients with trochlear defects often present with posterior knee pain. All previous interventions, both nonsurgical and surgical, also should be documented. The physical examination should include testing for some of the entities often seen in patellofemoral pain (excessive femoral antversion, knee valgus malalignment, hip abductor weakness, and iliotibial band contracture). Patients should be observed in a standing position, and the Q angle should be measured. It is important to make sure the patella is not subluxated when measuring the Q angle because a subluxated patella may falsely decrease the value of the angle. Joint effusion and patellar subluxation, mobility, and tilt should be assessed and compared with that of the opposite knee. An exaggerated J-sign may suggest medial
retinacular laxity and possibly a tear in the MPFL. Finally, it is important to document limb rotation through the hip and any signs of femoral or tibial malrotation.

In addition to the standard radiographic imaging described earlier, a CT scan should be taken to more accurately evaluate patellar subluxation and tilt and to diagnose any trochlear dysplasia. The TT-TG distance can be determined by superimposing two radiographs, one taken through the patellofemoral articulation and the second through the tibial tubercle, and measuring the medial-to-lateral distance from the center of the trochlear groove to the highest point of the tibial tubercle (Figure 4). A TT-TG distance less than 15 mm is considered normal; a distance greater than 20 mm is usually deemed abnormal and should be considered for a tibial tubercle osteotomy.\(^3\) Sagittal and coronal reconstructions can help diagnose patella alta or patella infera. An MRI is useful if a cartilage defect is suspected.

**Surgical Technique**

In preparation for surgery, the patient is positioned supine on a radiolucent table with a gel roll under the ipsilateral buttock. A tourniquet is applied and used during the osteotomy portion of the case; it is deflated before closure to achieve hemostasis.

If the surgeon is not certain of the extent of the damage to the cartilage, a quick diagnostic arthroscopy can be performed. A chondroplasty, microfracture, or lateral release also can be performed arthroscopically at this time. In addition to the standard portals, a proximal portal can be used to examine patellar tracking in the trochlea. If an MPFL repair or reconstruction is
planned, it should be done after the osteotomy is completed. If a cartilage reconstruction procedure is planned, it should be performed after the osteotomy cut is made but before it is fixed.

A tibial tubercle medialization can be performed through a small, 6-cm incision centered on the lateral aspect of the tubercle. The soft tissue of the anterior compartment is elevated, and the patellar tendon is protected. The osteotomy cut is V-shaped and centered posterior to the patellar tendon insertion. The cut is 5-cm long and is about 1.5 cm posterior to the tibial crest. The osteotomy is rotated over the intact hinge on the distal tibial tubercle to the desired location and fixed with two 4.5-mm fully threaded cortical screws lagged through the tuberosity to achieve interfragmentary fixation.

A tibial tubercle anteromedialization is performed through an approximately 10- to 12-cm incision that extends at an oblique angle from the anterolateral portal proximally to the tibial crest distally. The incision is extended proximally if a cartilage procedure is performed in the same setting (Figure 5, A). Medial and lateral flaps are raised to expose the proximal medial and lateral tibial surfaces. The anterior compartment is elevated subperiosteally, and both edges of the patellar tendon are opened so that a retractor may be placed under it.

We use a commercially available anteromedialization osteotomy guide system to perform this procedure. A broad retractor is placed on the posterolateral edge of the tibia to protect the neurovascular structures. The osteotomy cutting guide is placed on the medial side of the tibia at an angle. The top of the guide should be at the level of, and 1.5 cm posterior to, the proximal patellar tendon insertion. A 2-mm drill bit is used to secure that end of the guide. The distal end of the guide is angled laterally and should terminate on the distal end of the tubercle near the crest. The end of the guide is also secured with a drill bit (Figure 5, B). To verify the angle and accuracy of the osteotomy cut, the C-shaped guide is placed through the cutting guide with the tip of the guide pointing to the end of the osteotomy cut. The cut should end on the lateral tibial surface. The higher the end points on the lateral tibia, the shallower the angle of the anteromedialization.

Once the osteotomy cutting guide is in the desired position, an oscillating saw is used to perform the osteotomy cut. The guide is removed, and the distal end of the cut is finished with the saw. The proximal end of the cut is performed with an osteotome placed on the lateral tibia to connect the saw cut to the anterior tibia. The bone is now rotated up the slope to the desired location. The osteotomy is fixed with two 4.5-mm, fully threaded cortical screws lagged bicortically, and both screws are countersunk (Figure 5, C and Figure 6). The tourniquet is deflated, and a drain is put into place for 24 hours, if necessary. The anterior compartment is reattached, and the incision is closed in layers. A hinged knee brace is applied and locked in extension.

**Rehabilitation Protocol**

The protocol for rehabilitation following a tibial tubercle osteotomy is discussed in Table 2.

**Summary and Conclusions**

**High Tibial and Distal Femoral Osteotomies**

Closing wedge high tibial and distal femoral osteotomies have produced successful short- and long-term results. Recent studies have looked at the efficacy and success of opening wedge osteotomies. Esenkaya and Elmali performed 58 opening wedge high tibial
osteotomies in patients with medial compartment arthrosis. Patient ages ranged from 36 to 66 years and the average follow-up was 21 months. The Hospital for Special Surgery (HSS) score improved from 58 to 89.

Lateral tibia plateau fractures were seen in 8.6% of patients, and lateral cortex fractures were noted in 25.8%. Delayed union occurred in 1.7% of patients. Koshino and associates\(^8\) studied the outcomes of 21 opening wedge high tibial osteotomies. The mean patient age was 66.6 years, and the patients were followed for an average of 78.6 months. Two hydroxyapatite wedges were placed in each osteotomy site. The mean American Knee Society knee scores and functional scores improved from 60.2 and 48.1 to 94.3 and 93.1, respectively. No recurrence of varus deformity was noted in any patient. Franco and associates\(^1\) reviewed the outcomes of 30 patients who underwent opening wedge high tibial osteotomy and who were followed for 36 to 48 months. The average patient age was 49 years. The authors used International Knee Documentation Committee and HSS scoring systems for evaluation. All patients improved by at least one category. Using an opening wedge technique, Hernigou and associates\(^9\) treated 93 knees with opening wedge high tibial osteotomy. At 5-year follow-up, 90% of the knees had good or excellent results. These results deteriorated over time, with just 45% of the patients having excellent or good results after 10 years. Finally, Dietrick and Bugbee\(^10\) reported their unpublished results of 18 patients ranging in age from 17 to 58 years who underwent opening wedge distal femoral osteotomy for lateral compartment arthritis or to unload a cartilage restoration reconstruction procedure. Symptoms improved in 15 patients, but 3 patients eventually underwent conversion to a total knee arthroplasty.

**Tibial Tubercle Osteotomies**

Short- and long-term studies of tibial tubercle osteotomies have shown promising, good to excellent results. Fulkerson and associates\(^11\) followed 30 patients who underwent anteromedialization of the tibial tubercle (average follow-up of 35 months) and reported 89% objective and 93% subjective good to excellent results. Similar results were reported in 2000 by Buuck and Fulkerson.\(^12\) Carney and associates\(^13\) published a case series of 18 patients who underwent a combination of lateral release, medial reefing, and tibial tubercle medialization for patellar instability. The patients were followed at least 3 years and at 26 years. Seven percent of the patients had recurrent instability at both 3 and 26 years. Although at 3 years, 73% of the patients reported good to excellent results, the results dropped to 54% good to excellent results at 26 years. Tibial tubercle anteromedialization results in patients with patellofemoral arthritic changes depend on the location of the arthritis. Pidoriano and associates\(^14\) retrospectively reviewed the outcomes of 36 patients who underwent tibial tubercle anteromedialization for arthritis. Of patients who had distal or lateral patellar lesions, 87% had good to excellent results, as did 55% of patients who had medial facet lesions. Only 20% of patients with proximal or diffuse lesions had good to excellent results, however. Interestingly, no correlation existed between the Outerbridge grade of the lesion and the results.

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**TABLE 2**

Rehabilitation Protocol for Tibial Tubercle Osteotomy

| Phase I (first 12 weeks): Touch-down weight bearing is allowed for the first 6 weeks. A radiograph is taken at that point and, if adequate healing is achieved, weight bearing may progress as tolerated by the patient. The hinged brace is locked for the first 2 weeks and can be removed by the patient to perform exercises at home. The patient is allowed immediate full range of motion as tolerated. For the first 6 weeks, the patient works mainly on quadriceps sets and ankle and knee motion. During weeks 6 to 10, the patient may do straight-leg raises and partial wall squats. In weeks 10 to 12, hamstring strengthening is added. The brace should be unlocked during walking by week 6 and discontinued by week 8. |
| Phase II (12 to 16 weeks): Patients should be bearing full weight on their affected legs, and they should have full range of motion. Treadmill walking can begin, along with balance and proprioception exercises. |
| Phase III (16 to 20 weeks): Closed-chain exercises and light plyometric exercises are advanced. |
| Phase IV (20 to 24 weeks): Strengthening exercises continue, progressing to running, single-leg jumping, and loading. |
REFERENCES