Prior to the development of total knee arthroplasty (TKA) as a reliable procedure in the 1980s, high tibial osteotomy (HTO) was the most common surgical treatment for varus gonarthrosis. The surgical technique was primarily a closing wedge osteotomy, often with only a staple for fixation along with a cast. A “dome” sliding osteotomy also was used by some surgeons. More rigid fixation with large plates became the dominant mode of fixation in the 1990s.

As TKA became more reliable, HTO was less widely used in the United States. However, HTO has remained more popular outside the United States, partially for economic reasons and partially because of a greater interest in knee repair in other countries.

Whereas HTO was initially performed almost exclusively as a closing wedge procedure, in the past two decades it has come to be performed primarily using opening wedge techniques. Initially, external fixation opening wedge procedures were widely used, but more recently, internal fixation with limited or large plates has become more popular and external fixation less common.

**Indications**

**Medial Pain and Pathology**

There is consensus that candidates for HTO are patients with pain located primarily on the medial aspect of the knee and radiographic evidence of medial arthrosis demonstrated by less than 4 mm of medial joint space on a standing knee film along with mechanical overload associated with a varus deformity. Young patients undergoing articular cartilage restoration procedures or...
medial meniscal transplantation who have the mechanical axis lying within that compartment also are candidates for an unloading osteotomy. It is generally agreed that no lateral pain should exist preoperatively.

Preoperative Varus
For HTO to be indicated, some degree of preoperative varus must exist. It is essential to measure alignment on long, hip-knee-ankle mechanical axis radiographs (orthoradiograms) (Figure 1). There is no consensus on the minimum amount of varus that indicates the need for HTO. Patients with as little as 4° of varus of the mechanical axis and unicompartmental medial disease can benefit from HTO.

Contraindications
Stiffness
A markedly decreased range of motion predisposes patients to poor results. This is usually considered flexion of less than 90°, although less than 100° and less than 120° also have been reported as showing fewer good results. One of this chapter’s authors (RPJ) found that stiffness in younger patients is caused by posterior condylar osteophytes; good outcomes are possible if the osteophytes are removed concurrently.

Symptomatic Patellofemoral Disease
The presence of patellofemoral pain and arthritis is often a concern when deciding on whether to perform an osteotomy; however, in the experience of this chapter’s authors, it is not a contraindication. Patellofemoral pathology (articular cartilage attrition in the absence of substantial patellofemoral symptoms) is common and consistent with a good result if the patient clearly identifies his or her medial knee as the overriding problem.

Relative Contraindications and Indications
Obesity
Coventry et al. reported poorer results in patients who were 1.32 times heavier than their ideal body weight. Although this does not directly translate to the more commonly used body mass index, this in general translates to a body mass index of 30 or greater. To varying degrees, outcomes have been worse in patients who are obese. Not only are success rates lower, but complications are higher. However, some surgeons have achieved good results in patients who are obese. One of this chapter’s authors (CCP) has found obesity to be an important relative contraindication to HTO, whereas another author (AA) believes that patients who are obese may be better served by osteotomy than arthroplasty. The other author (RPJ) has found that HTO may be preferable to TKA in a young patient who is obese. However, care is needed to ensure fixation stability using techniques such as a small lateral plate to fix the hinge, in addition to a medial plate (Figure 2).

Smoking
Many authors have reported higher nonunion rates in patients who smoke; this is an even greater concern when performing opening wedge techniques. Among opening wedge osteotomy procedures, the risk of nonunion is particularly high when external fixators are used and the procedure is performed below the tibial tubercle. Many surgeons decline to perform HTO on a patient who smokes. If HTO is
believed to be indicated in a patient who smokes, a closing wedge osteotomy performed above the tubercle with a plate may be the best option. Alternatively, a cancellous graft can be used in an opening wedge HTO if the opening exceeds 8 to 9 mm.

**Age**
Younger patient age is a relative indication and one of the key factors in the decision to perform HTO. In the United States, the generally accepted maximum age of a patient considered for HTO is 60 years, with TKA preferred in older patients. Outside the United States, HTO is often performed in older patients who are physically fit and have been informed that their pain will be diminished but likely not eliminated.

**Female Sex**
It was believed that female sex is a relative contraindication for HTO because of the possibility of unsightly excessive postoperative valgus alignment for which women may have a lower tolerance. It is, however, important to discuss this possibility with all patients to avoid dissatisfaction because of poor cosmesis in an otherwise relatively painless knee. With current techniques that make substantial overcorrection unlikely, the sex of the patient is less of an issue.

**Other**
Patients younger than 50 years who have better preoperative knee function and range of motion usually have the best outcomes. Ligamentous instability and more severe articular cartilage destruction in the medial compartment (Ahlback or Outerbridge grade 3 or higher) have been associated with poorer outcomes in some studies. Overall, if the main indications for HTO are met, most patients can be expected to benefit from the procedure, although it is important to take all these factors into consideration when discussing options with a patient.

HTO is generally believed to be contraindicated in patients with an inflammatory arthropathy.

**Surgical Technique**

**Preoperative Planning**
Obtaining full-length, weight-bearing, mechanical axis hip-knee-ankle radiographs is mandatory (Figure 1). Lines are drawn on the radiograph from the center of the knee to the center of the head of the femur and from the center of the knee to the center of the ankle joint. The angle between these two lines is measured. The lower extremities must be equally rotated. Valgus and varus stress views may be used to show the thickness of the medial and lateral compartment of the articular cartilage and provide an index of the amount of ligamentous stretching (Figure 3). This often adds an additional 2° to 3° to the actual deformity, which can be subtracted from the total angular correction or overcorrection results. The size of the opening wedge should be calculated from the preoperative radiographs, and magnification should be taken into account. An example of this preoperative planning technique and the final results are shown in Figures 4, 5, and 6. This information is used during surgery to check the osteotomy. Meticulous preoperative planning is of paramount importance. Although information on relevant techniques is beyond the scope of this chapter, such information is available in the...
the work of Coventry suggests that correction to some degree of valgus is the chief goal; this avoids residual varus. This chapter’s authors recommend correction to 1° to 2° of mechanical axis valgus.

**External Fixation of an Opening Wedge Osteotomy Below the Tubercle**

One of this chapter’s authors (CCP) uses an external fixation opening wedge hemicallotasis exclusively for HTO. This original technique first defines the lateral bony hinge. A Gigli saw is then used to complete the osteotomy in a lateral to medial direction (Figures 7, 8, and 9). A video of this technique is available. There are several advantages to this technique, including the use of 2-inch incisions to accomplish the osteotomy. The cut is made from the lateral hinge medially, ensuring the proper hinge thickness and minimizing the risks of tibial plateau and hinge fracture. The external fixator and pins are removed after healing has progressed sufficiently, resulting in no retained hardware. Detailed presurgical planning is unnecessary because the correction takes place after surgery as the fixator is opened slowly until the desired correction is reached. This technique allows precise correction, with the final alignment radiographically checked before the fixator is locked and healing occurs. The achievement of 1° to 2° of mechanical axis valgus is recommended. The experience of one of this chapter’s authors (CCP) has shown that this is sufficient to produce positive clinical outcomes while preventing unsightly and unnecessary overcorrection. The main disadvantage of using an external fixator is the possibility of pin tract infection, which is common but easily treatable. In addition, this technique has a longer recovery time. Patients can return to seated work in 1 week after the surgery; however, return to heavy labor generally requires approximately 9 months.

**Opening Wedge Osteotomy With Plate Fixation**

An opening wedge osteotomy with plate fixation can be performed with a variety of plates. The open space can be filled with autograft, allograft, or synthetic bone substitutes or can remain empty. There is no good evidence favoring one option over another, and different surgeons have different preferences. Most authors, however, recommend some form of grafting for an opening wedge osteotomy. One of this chapter’s authors (RPJ) believes that the use of bone substitutes may increase the risk of infection. There is a tendency toward more stable implants with angular screws, which lower the risk of loss of...
Coronal correction or overcorrection and allow for more rapid weight bearing. Regardless of the technique used, arthroscopy can be performed to manage and assess associated pathologies. An anteromedial longitudinal incision is made 1 cm distal to the joint line between the tibial tubercle and the posterior medial border of the tibia. Wound healing seems to favor a longitudinal incision over a transverse incision. Sharp dissection is made down to the fascial layer. The exposed sartorial fascia is then incised, ending at the superior portion of the pes anserinus. The proximal aspect is extended medially. The medial border of the patellar tendon is identified and retracted. A Cobb elevator is used to dissect subperiosteally the medial tibia, allowing a retractor to be placed posteriorly around the tibia. This allows release of the medial collateral ligament distally. Under fluoroscopic control, a guidewire is placed at the level of the superior aspect of the tibial tubercle, approximately 4 cm anteromedially distal from the joint line. On insertion, the guidewire is aimed to the fibular head, approximately 1 cm below the lateral articular margin of the tibia. The tibial osteotomy is performed immediately distal to the guidewire by cutting the cortex with a thin oscillating saw. It is then continued with a thin osteotome under fluoroscopic control.

Calibrated wedges are then impacted into the osteotomy and slowly advanced until the desired opening is achieved. The position of the wedge is very important to correct the deformity on the sagittal plane: a wedge placed anteriorly causes an increase in posterior tibial slope, whereas a posterior wedge tends to slightly decrease the posterior tibial slope. Anterior and posterior gaps of the osteotomy can be measured with a ruler to calculate the amount of increase of the posterior slope. If the anteromedial gap is half of the postero-medial gap, the slope will not change; for each millimeter of increase of the anterior gap, the posterior tibial slope will increase 2°.

An image intensifier and an alignment rod are used to control coronal and sagittal alignment of the joint. A modified tibial tubercle osteotomy can be performed if the anterior gap is greater than 1 cm to avoid patella baja. After the desired correction has been achieved, plating is performed, and the wedges are removed. Generally, bone graft (autograft, allograft, or synthetic bone substitute) is used to fill the osteotomy gap. The final result and fixation is checked under fluoroscopic control before the tourniquet is deflated; he-mostasis is then confirmed, and skin suturing is performed.

This technique can be modified to perform a biplanar osteotomy by making a transverse osteotomy cut, plus a more vertical anterior cut to the proximal end of the tibial tuberosity to avoid damage.

**Distal Fibular Osteotomy**

Although a distal fibular osteotomy is unnecessary with plate fixation as performed by two of this chapter’s authors (AA and RPJ), if correction greater than 10° is desired with an opening wedge hemicallotasis procedure below the tubercle, a distal fibular osteotomy is necessary to prevent the fibula from acting as a strut that blocks opening of the tibia. An oblique sliding osteotomy through a small incision just above the fibular metaphysis is performed with an oscillating saw.

**Postoperative Alignment**

It has been shown that undercorrection of varus during a tibial osteotomy is associated with inferior clinical results. However, precise intraoperative measurements of correction are difficult to achieve, even with navigational assistance, and are subject to a reported...
error rate that varies from 1° (with navigation) to 8.6° (without navigation), with most surgeons planning on a variability of 2° to 3°. In addition to this expected variability, significant outliers to this range are reported with nonnavigational techniques, with approximately 23% of the results falling into the expected range, and 85% when navigation is used. Because of this variability, most surgeons attempt to achieve intraoperative mechanical axis valgus of approximately 1° to 2° to ensure against undercorrection. However, this means that some patients will have postoperative valgus of 5° or possibly more. Although this degree of valgus is beneficial regarding knee pain outcomes, it also produces a visually obvious valgus alignment. As previously mentioned, a patient who is pain free may still be dissatisfied with the procedure if cosmesis is unsatisfactory. The patient should be counseled preoperatively concerning this possible outcome.

The mechanical axis can be estimated intraoperatively using a Bovie cord or an alignment rod to span the distance between the femoral head and the center of the ankle. The location of the joint center can be radiographically confirmed; however, substantial error can result from rotation. One of this chapter’s authors (RPJ) believes that such methods should be used with great caution because of their inherent inaccuracies. To achieve excellent results, RPJ recommends relying on meticulous preoperative planning and a perfect orthoradiogram. The goal is to position the weight-bearing axis slightly lateral to the center of the knee to varying degrees, depending on the patient.

When external fixation opening wedge hemicallotasis techniques are used, precise intraoperative alignment measurements are unnecessary. The only requirement is that the osteotomy opens sufficiently to allow an adequate opening postoperatively. This generally does not need to be precisely measured; rather, the surgeon can measure the size of the opening between the medial tibial cortices, and this can be compared with the preoperatively calculated opening necessary to achieve sufficient correction. This technique uses cutouts preoperatively to determine the amount of osteotomy opening that correlates approximately with the desired amount of angular correction. The general estimate of 1° of opening per degree of correction is usually close, but it should not be relied on.

**Associated Procedures**

**Arthroscopy With HTO**

Many surgeons perform arthroscopic examination of the knee for débridement of unstable meniscal tears or loose flaps of articular cartilage immediately before performing an HTO. Alternatively, a preoperative MRI can be obtained and, in the absence of substantial pathology, arthroscopy can be avoided.

**Microfracture With HTO**

Although there are few data to guide treatment regarding microfracture with HTO, many surgeons routinely perform microfracture at the time of an HTO. Although HTO by itself has been associated with cartilage regeneration in the medial compartment without microfracture, the minimal added risk and reported good outcomes appear to justify the addition of this quick arthroscopic procedure at the time of HTO. Microfracture should not be performed in asymptomatic patellofemoral or lateral compartments to avoid inciting pain in these areas.

When used as a stand-alone procedure in the presence of varus greater than 4°, microfracture has a lower success rate than if it is performed in cases with less varus. Therefore, HTO may be indicated as an adjunct to a planned microfracture procedure in patients with less severe knee arthritis in whom microfracture is believed to be the indicated primary procedure.

**Anterior Cruciate Ligament Reconstruction and Posterolateral Rotatory Instability**

Suitable patients may benefit from anterior cruciate ligament reconstruction and HTO, which can be accomplished simultaneously or as a staged procedure. Simultaneous HTO and anterior cruciate ligament reconstruction is technically challenging and limits the aggressiveness of passive range-of-motion exercises that may be needed after anterior cruciate ligament reconstruction. Two of this chapter’s authors (AA and RPJ) generally combine these procedures, whereas the other chapter author (CCP) rarely uses that technique. In patients with moderate arthrosis, the anterior cruciate ligament reconstruction can be performed first. If adequate improvement occurs, HTO may be unnecessary. Alternatively, HTO performed first may render an anterior cruciate ligament reconstruction unnecessary. If posterolateral rotatory instability is present, then repair of this instability can be performed with HTO.

**Cartilage Restoration Procedures**

The literature has shown that results of autologous chondrocyte implantation are compromised by angular deformity toward the affected compartment.
(varus for a medial lesion and procedure; valgus for a lateral lesion and procedure). Although the data are less clear for osteochondral allograft or autograft implantation and meniscal allograft implantation, most surgeons believe that a varus deformity of greater than 4° should be corrected for optimal results. Any cartilage restoration procedure can be performed simultaneously with HTO, although such combined surgical procedures are long and difficult. The decision to stage or simultaneously perform the procedures depends on the preference of the patient and the experience of the treating surgeon.

**Postoperative Care**

Patients are allowed partial weight bearing (with or without a brace) for varying periods of time to protect the osteotomy. Patients with an external fixator who also had microfracture performed are kept on partial weight bearing with two crutches for the first 6 weeks to protect the microfracture. Immediate, unlimited range of motion is allowed and encouraged. After 6 weeks, patients progress to full weight bearing as tolerated, first with one crutch or a cane and finally with no assistance. Toleration of each stage is defined as the patient having no pain and no limp and not using pain medications. With internal fixation, 6 to 8 weeks of touch-down or protected weight bearing is usually ordered, with increased loading as radiographic healing is demonstrated.

**Complications**

**Infection**

Deep infections are uncommon after HTO with plates. When deep infections occur, grafts should be removed and the area débrided. However, healing can occur when antibiotics are administered; the plate is removed as soon as radiologic healing is assured.

Superficial pin tract infections are common after HTO with an external fixator. When pin tract infections occur, suppressive antibiotics are used for management until the pins are removed. Early recognition and a high index of suspicion for infection are necessary so that oral antibiotics can be administered at the first sign of a pin tract infection. These infections always manifest with redness and tenderness at the pin tracts, which are several centimeters below the joint line and are easy to distinguish from a knee joint infection. One of this chapter’s authors (CCP) commonly uses postoperative, low-dose, broad-spectrum cephalosporin therapy to suppress infection until the fixator pins are removed.

**Loss of Alignment**

Initial undercorrection has been associated with recurrent varus and initial overcorrection with progressive valgus. Mild overcorrection to a few degrees of mechanical axis valgus offers the best chance for an enduring and satisfactory alignment. Because late postoperative loss of alignment has not been independently correlated with lower late postoperative knee scores, the original correction may be more important than late changes in alignment.

**Nerve and Vessel Injury**

Nerve injury, specifically peroneal nerve injury, was more common with closing wedge osteotomy and dome procedures than with the opening wedge techniques in current use. These injuries resulted from direct injury to the peroneal nerve at the time of surgery. Popliteal artery injury, in the area of the trifurcation, also is a risk, particularly if substantial rotational correction is performed. Use of a curved, blunt Hohmann retractor posteriorly can protect against popliteal artery injury.

**Hardware Problems**

Painful hardware may require removal. In the absence of infection, however, hardware removal is generally not performed in the United States, although it is routinely performed in Europe and Asia. Advantages of hardware removal are that the surgeon has the opportunity to resurvey the condition of the joint and confirm the state of previously performed microfracture or perform additional microfracture if needed.

**Nonunion**

Nonunion may require bone grafting and hardware replacement. Nonunion is more common with opening wedge procedures than with closing wedge procedures, but it is still uncommon overall. This complication occurs more often in patients who smoke. Patients should be counseled about this risk and preferably required to stop smoking before the surgery is performed.

**Persistent or Recurrent Pain**

A small percentage of patients treated with HTO (4% to 26%) do not have satisfactory pain relief, and this is the primary reason for revision to TKA. It is important for patients to understand that a successful result is a substantial reduction in pain, not necessarily the elimination of pain. Studies commonly report a 4- to 5-point improvement on a 0- to 10-point pain scale. Patients with severe pain may be better candidates for TKA, although many patients who are younger than 60 years will have inadequate pain relief after TKA.
Tibial Plateau Fracture

Tibial plateau fractures have been reported in as many as 11% of patients after opening wedge HTO and are common after closing wedge HTO. The key to avoiding fracture is to complete the osteotomy so only a very thin lateral hinge remains. However, complete propagation of the osteotomy can lead to instability. Lateral hinge fractures have been classified by Takeuchi et al. Type I is a fracture that reaches just proximal to or within the tibiofibular joint. A type II fracture reaches the distal portion of the proximal tibiofibular joint. Type III is a lateral plateau fracture.

Stiffness

Stiffness is uncommon if preoperative motion is satisfactory. Stiffness is a more common complication after a closing wedge osteotomy with staple fixation and postoperative casting. Stiffness is best avoided by beginning early motion. Usually early, unlimited active range of motion is allowed and encouraged.

Deep Vein Thrombosis and Pulmonary Embolism

Some form of prophylaxis is indicated after extensive procedures about the knee. Aspirin (100 mg/d) for up to

Table 1
Clinical Results of High Tibial Osteotomy Studies

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>No. of Knees/ Patients</th>
<th>Technique</th>
<th>Mean Patient Age in Years (Range)</th>
<th>Males/ Females</th>
<th>Length of Follow-up in Years (Range)</th>
<th>Failure Endpoint</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coventry et al</td>
<td>1993</td>
<td>87/73</td>
<td>Closing wedge with staple fixation</td>
<td>63 (41-79)</td>
<td>48/25</td>
<td>10 (3-14)</td>
<td>Arthroplasty</td>
<td>90% survivorship at 5 years; 65% at 10 years in patients with ≥8° valgus, weight ≤1.32 times normal</td>
</tr>
<tr>
<td>Koshino et al</td>
<td>2004</td>
<td>75/53</td>
<td>Closing wedge above tibial tuberosity</td>
<td>59.6 (46-73)</td>
<td>11/42</td>
<td>19 (15-28)</td>
<td>Looked at Knee Society Scores; Arthroplasty (excluding those who died)</td>
<td>Knee score went from 37 ± 20 to 87 ± 13; function score went from 38 ± 16 to 80 ± 19; survivorship 96% at 10 years, 93% at 15 years</td>
</tr>
<tr>
<td>Hernigou et al</td>
<td>2010</td>
<td>53–all with varus &gt;15° preoperatively</td>
<td>Opening wedge with beta-TCP wedge and buttress plate</td>
<td>60 (43-67)</td>
<td>15/26</td>
<td>10 (8-12)</td>
<td>Arthroplasty</td>
<td>81% survivorship at 10 years</td>
</tr>
<tr>
<td>Efe et al</td>
<td>2011</td>
<td>199</td>
<td>Closing wedge with AO plate</td>
<td>54 (27-72)</td>
<td>110/89</td>
<td>9.6 (1-18)</td>
<td>Arthroplasty</td>
<td>84% survivorship at 9.6 years, 68% at 15 years</td>
</tr>
<tr>
<td>Hui et al</td>
<td>2011</td>
<td>413</td>
<td>Closing wedge with staple and cast or brace</td>
<td>50 (24-70)</td>
<td>326/87</td>
<td>12 (1-19)</td>
<td>Revision HTO or arthroplasty</td>
<td>79% 10-year survivorship; 85% satisfied with procedure</td>
</tr>
<tr>
<td>Saragaglia et al</td>
<td>2011</td>
<td>124/110</td>
<td>Opening wedge with Biosorb wedge (SBM Corp) and plate</td>
<td>53.2 (32-74)</td>
<td>74/36</td>
<td>10.4 (8-14)</td>
<td>Arthroplasty</td>
<td>89% survivorship at 5 years, 74% at 10 years</td>
</tr>
<tr>
<td>Schallberger et al</td>
<td>2011</td>
<td>54</td>
<td>Opening wedge with plate and bone graft and closing wedge with plate</td>
<td>40 (15-69)</td>
<td>37/17</td>
<td>16.5 (13-21)</td>
<td>Arthroplasty</td>
<td>92% survivorship at 10 years; 71% after 15 years; no differences between opening and closing wedge procedures</td>
</tr>
</tbody>
</table>

HTO = high tibial osteotomy, TCP = tricalcium phosphate
14 days or mechanical methods are most commonly used in the United States. Portable foot compression units are available and usually covered by insurance for use in the home for the first week after surgery. If not covered by insurance, they can usually be rented at low cost. In Europe, low-molecular-weight heparin administered by injection or orally is often used for prophylaxis.

Clinical Results
A review of the literature shows that HTO produces excellent intermediate- and long-term survivorship (with conversion to arthroplasty as the end point) and allows patients to resume manual labor and active lifestyles. In 1993, Coventry et al reported a 65% survival rate at 10 years in a subpopulation of patients whose preoperative weight was 1.32 times ideal weight or less and whose postoperative valgus angulation was 8° or more at 1 year after surgery. Since that time, studies have reported 10-year survival rates ranging from 74% to 96% (Table 1). Koshino et al followed 75 knees for 15 to 28 years after osteotomy and found that 94% could walk more than 1 km without pain. In 2011, Hui et al reported that 85% of the patients were satisfied with their HTO procedure. Reports for opening and closing wedge osteotomies have been similar, with a study by Schallberger et al reporting no differences between the two techniques in terms of survivorship and symptom relief.

Results of TKA after HTO
If HTO fails to halt the progression of osteoarthritis, TKA is usually indicated. In general, TKA after an opening wedge HTO has outcomes as good as TKA without prior HTO, however, a prior HTO appears to increase the technical difficulties of performing TKA. Opinion has varied on whether opening or closing wedge HTO is associated with poorer results after TKA. Recent studies have not found any differences in the outcome of TKA after the two procedures.

HTO Versus Arthroplasty
The choice between HTO and unicompartmental knee arthroplasty or TKA is often controversial and may depend on both surgeon training and patient preferences or perceptions. In general, a frank discussion regarding the pros and cons of each procedure is advised. In many instances, consultation with another physician (particularly if the treating surgeon performs either HTO or arthroplasty but not both) can be helpful in educating the patient preoperatively so that an informed decision can be made.

Summary
Properly performed HTO is a safe and effective procedure in appropriately selected patients. These procedures are particularly valuable in avoiding TKA in young patients in whom TKA often results in poor outcomes and implant survivorship and in whom a failed TKA may be difficult to salvage. Osteotomy can usually sustain function in younger and more active patients until a more appropriate age is reached for arthroplasty.

References


**Video Reference**
