46 Osteotomies about the Knee

Jeremy M. Burnham, Jonathan D. Hughes, Jason P. Zlotnicki, and Volker Musahl

INTRODUCTION

Before total knee arthroplasty (TKA) became a successful technique in the 1970s, osteotomies were the main treatment option for unicompartmental arthritis, especially in the older population (1). As techniques improved, TKA became the definitive surgical option for an aging patient with symptomatic osteoarthritis (OA), while osteotomies were performed less frequently due to unpredictable outcomes and the demanding nature of the procedure. However, osteotomies reemerged in the early 1990s as a treatment option for young patients with unicompartmental arthritis after various studies showed good results from high tibial osteotomy (HTO) (2,3).

The knee joint experiences two to four times body weight when ambulating. Approximately 75% of this load is on the medial compartment in the single leg stance phase of gait, and this is exacerbated with varus deformity. On the other hand, with 6 degrees of mechanical valgus, only 40% of this load is transmitted through the medial compartment. Thus, the goal of the osteotomy is to correct the angular deformity of the knee (whether valgus or varus deformity) and decrease the abnormal load on the affected tibiofemoral compartment, thereby allowing the young patient to return to activities, while hopefully avoiding or at least delaying TKA. Even minimal angular deformities in the coronal and sagittal planes can cause a significant increase in forces to the tibiofemoral compartments (4,5). It has been shown that offloading the affected compartment leads to articular cartilage recovery and a decrease in symptoms (6). In this chapter, HTO and distal femur osteotomy (DFO) for treatment of varus and valgus knee conditions, respectively, are discussed.

HIGH TIBIAL OSTEOTOMY

Indications

The primary indication for HTO is symptomatic isolated medial compartment OA in a young, physically active patient with varus knee malalignment (7–9), and a successful outcome depends on proper patient selection. Important factors to consider when considering HTO are age, smoking status, knee range of motion, degree of deformity, body mass index (BMI), and quality of the menisci and cartilage. Classic indications for HTO include patients aged 40 to 60 years, at least 10 degrees of proximal tibial varus, good knee range of motion with <10 degrees flexion contracture, BMI of <30, nonsmokers, and relatively well-preserved lateral compartment cartilage and menisci. In 2005, the International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine (ISAKOS) created guidelines for patient selection when considering an HTO (Table 46-1) (10). Since that time, guidelines have evolved and expanded to include patients <40 years of age or >60 years of age, patients with flexion contractures up to 25 degrees, and overweight patients (13,14). Additionally, studies have demonstrated that a tibial bone varus angle (TBVA) > 5 degrees is a good prognostic factor for success (15). HTO can be performed concomitantly with ligamentous reconstruction, cartilage restoration, and meniscal transplant (16–19).

TABLE 46-1 Patient Selection Criteria for High Tibial Osteotomy (HTO)

Indications (10)	Relative Indications (11)	Contraindications (10–12)
Young age (40–60 y)	ACL, PCL, or PLC insufficiency	Obesity (BMI > 30)[a]
Isolated medial joint line pain	Age (60–70 y or <40 y)	Bi- or tricompartmental osteoarthritis
Body mass index (BMI) < 30	Moderate patellofemoral arthritis	Flexion contracture >25 degrees
High activity level	Flexion contracture of 15–25 degrees	Prior lateral meniscectomy
Tibial mechanical axis deformity >5 degrees		Knee arc of motion <120 degrees
Nonsmoker		Inflammatory osteoarthritis
No lateral or patellofemoral pain		
Flexion contracture <15 degrees		

A chart demonstrating the indications, relative indications, and contradictions for osteotomy set forth by the International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine (ISAKOS), as well as various recent studies (10–12).

[a]Relative contraindication.

Contraindications

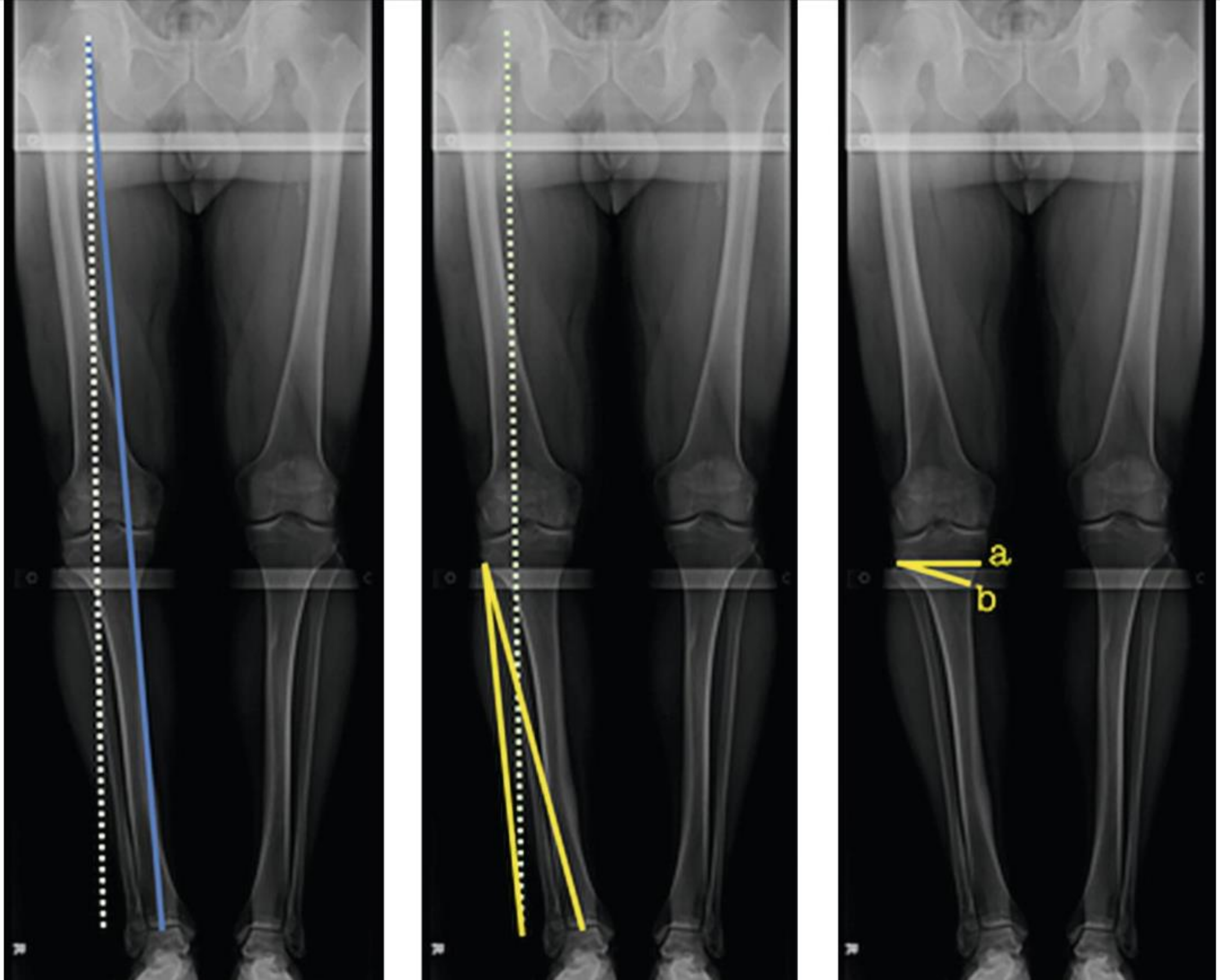
There are strict criteria when selecting the ideal patient for an HTO. The contraindications are listed in Table 46-1. Although indications continue to expand, age >65 to 70 years is a relative contraindication. Smoking cessation should be encouraged before surgery due to risk of nonunion and wound breakdown (20). An arc of motion <120 degrees is a risk factor for early failure, especially flexion contractures >10 degrees (21), as well as inflammatory arthritis. BMI remains a controversial contraindication, as some studies have indicated greater failure rates in heavier patients, while others have reported higher failure rates in lean patients (1,21–23). However, since obesity has a negative effect on orthopedic surgery in general, a BMI > 30 is considered a relative contraindication, and other aspects of the patient's health should be taken into consideration. Lastly, arthritis or prior total meniscectomy in the lateral compartment is a contraindication, since the procedure will offload the medial compartment and place more stress on the lateral compartment (21).

Preoperative Planning

Precise preoperative planning is crucial to obtain satisfactory outcomes and avoid undercorrection or overcorrection. The degree of correction will rely on the amount of mechanical axis deviation in the lower extremity, as determined preoperatively via full-length standing radiographs. This includes selecting a specific wedge angle to match the angular deformity and adding this specific angle to the desired overcorrection or undercorrection (24). Additionally, the condition of the three compartments, as well as the bony morphology of the patient, will help determine whether an opening-wedge or closing-wedge osteotomy is performed. Magnetic resonance imaging can be very helpful to determine the extent of cartilage damage, as well as concomitant ligamentous injuries.

A complete radiographic evaluation should be obtained, including weight-bearing anteroposterior or posteroanterior views, sunrise view, lateral radiograph of the involved knee, intercondylar notch view, and full-length hip-to-ankle standing views of both lower extremities. All three compartments must be checked for signs of OA. The patella height needs to be assessed preoperatively on the lateral view, as patella baja can occur after both medial opening-wedge and lateral closing-wedge HTO (25). Additionally, tibial slope must be measured on this view to ensure that a biplanar osteotomy does not need to be performed, especially in combination with anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL) injuries. Lateral tibial plateau slope has been found to average between 5 and 7 degrees (26), and a recent study demonstrated that increasing the tibial slope causes an anterior shift in the tibial resting position under axial loads (27,28). Thus, an ACL-deficient knee would benefit from a decreased tibial slope, while increasing tibial slope would help protect a PCL-deficient knee.

The full-length standing radiographs will assist with calculating the mechanical axis (24). Many methods have been described, but most aim to correct the mechanical femorotibial axis to 3 to 6 degrees of valgus, or the anatomic femorotibial axis to 6 to 15 degrees of valgus. The authors' preferred technique is to use the weight-bearing line (WBL) method to correct the angular deformity, as described by Noyes et al. and Miniaci et al. This technique appropriately accounts for the tibial and femoral length using full-length weight-bearing films (29). To use this method, the mechanical axis WBL is first drawn, which goes from the center of the femoral head to the center of the talus. In a normally aligned knee, this line passes through the medial aspect of the lateral tibial spine, although in patients with varus deformity, the WBL will pass through or medial to the medial compartment. Next, the WBL is adjusted such that it passes through the tibial plateau at approximately 62% to 66% of the medial to lateral width of the plateau. This usually corresponds with the lateral aspect of the lateral tibial spine (29), which approximates a desired 3 to 5 degrees valgus mechanical axis. A line is then drawn from the distal point of that line, at the level of the tibiotalar joint, up to the proximal tibial hinge point of the planned osteotomy, and back down to the center of the talus. The angle subtended by these lines represents the degree of correction needed to correct the angular deformity (Fig. 46-1). This degree of correction is then templated on the proximal tibia, and the distance of wedge opening (or closing) is measured. Several authors have suggested slight overcorrection into valgus due to reports of loss of reduction into varus with undercorrection (1,24,30). However, it is important to consider the anatomic alignment of the contralateral limb. Overcorrection without addressing the contralateral knee could result in a windswept deformity, which is poorly tolerated by patients. If biplanar correction is warranted, the sagittal plane correction should be taken into consideration with the final wedge angle to address both deformities with one corrective surgery.


a
b

A B C

FIGURE 46-1 Preoperative planning for opening-wedge high tibial osteotomy. Full-length, weight-bearing alignment films show varus malalignment of the right knee. **A:** The weight-bearing line is shown in *blue* and passes through the medial compartment, consistent with this patient's varus deformity. The *dashed line* shows the preferred weight-bearing line passing through the lateral aspect of the lateral tibial spine, or about 62% to 66% of the medial to lateral distance of the proximal tibia. **B:** Lines are drawn from the modified weight-bearing line at the level of the tibiotalar joint, to the planned hinge point at the lateral proximal tibia, and back down to the center of the tibiotalar joint. The angle formed by these lines (shown in *yellow*) is the correction angle needed to restore ideal knee alignment. **C:** The correction angle is superimposed over the osteotomy site, and the needed distraction distance of the medial tibia can be calculated as the distance from point "*a*" to point "*b*."

Surgical Technique

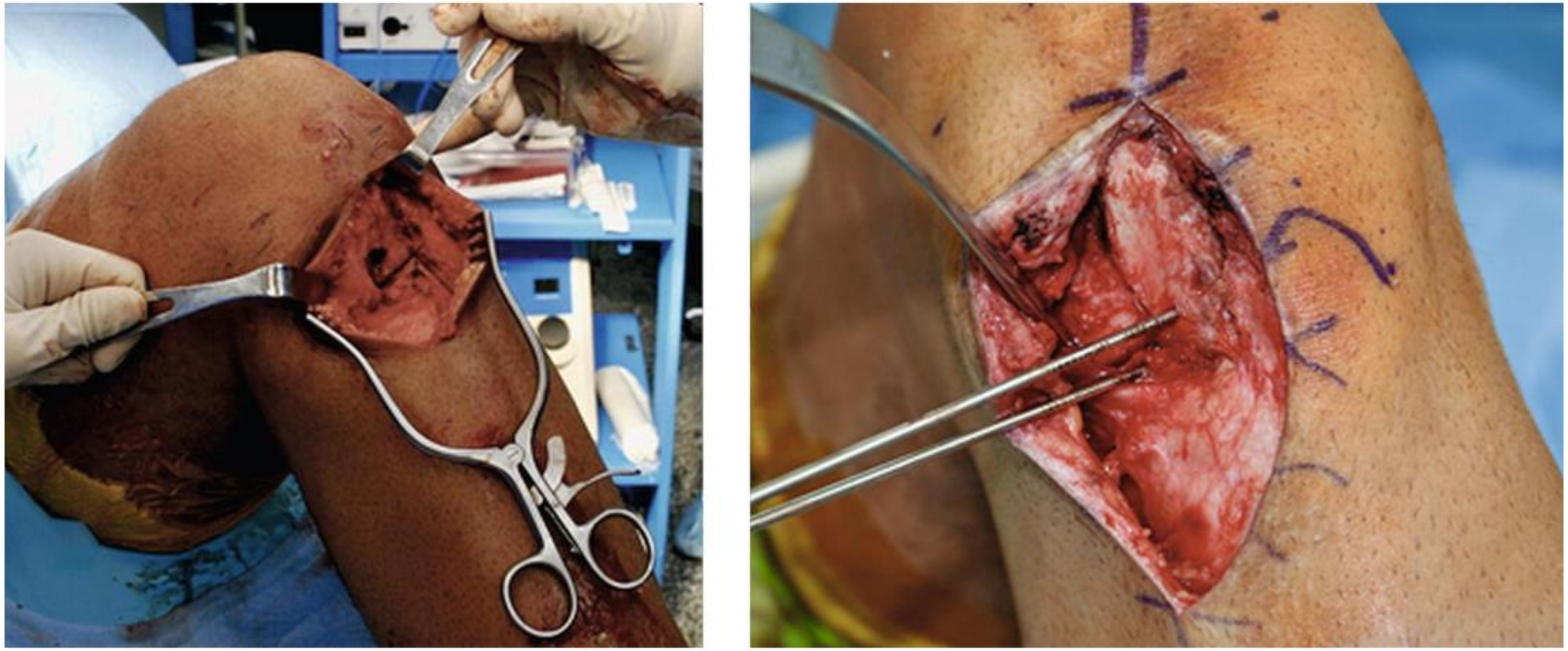
The medial opening-wedge and lateral closing-wedge HTO are ideal for valgization of proximal tibia varus. Diagnostic arthroscopy can be utilized to verify meniscal, chondral, and ligamentous structures prior to initiating the osteotomy.

Osteotomy-specific instruments needed:

- Oscillating saw with wide saw blade and a blade length of approximately 9 cm
- Several flat osteotomes from 10 to 20 mm in width
- 2.3-mm guidewires
- Caliper
- Lamina spreader
- Osteotomy spreader (optional)
- Allograft bone wedges (optional)

Medial Opening-Wedge High Tibial Osteotomy

The patient is positioned supine with a tourniquet, and a lateral leg holder and footrest. The authors prefer performing the procedure without tourniquet inflated. The knee is positioned at 70 to 90 degrees of flexion during portions of the case. After optional diagnostic arthroscopy, anatomic landmarks are drawn: medial joint line, pes anserinus, and tibial tuberosity. The incision is made longitudinally approximately 6 to 8 cm in length between the medial edge of the tibial tuberosity and posteromedial edge of the tibia, inferior to the joint surface (Fig. 46-2A). The superior border of the pes anserinus is dissected and retracted distally to expose the superficial fibers of the MCL. Blunt dissection allows placement of a Hohmann retractor under the superficial MCL and behind the posterior tibial ridge, safely retracting the MCL and protecting the neurovascular structures. Limited release of the distal portion of the superficial MCL helps to relieve joint tension and improve medial compartment unloading (29). The superior edge of the patellar insertion at the tubercle should also be identified and bluntly exposed. This can be marked with a curved hemostat placed between the tibia and tendon at the insertion.



A B

FIGURE 46-2 Opening-wedge high tibial osteotomy. Intraoperative picture of a right knee during high tibial osteotomy. **A:** The exposure has provided adequate access to the tibia, and the planned bone cuts of a biplanar osteotomy are sketched with a surgical marker. **B:** Two parallel pins provide a cutting template for the saw blade. The pins are placed parallel and 2 to 3 cm apart.

With the knee in full extension, two 2.3-mm guidewires are inserted into the medial tibia 3.5 to 4.0 cm below the medial joint line and aimed obliquely toward the most superior aspect of the fibular head (the planned hinge point). The posterior wire is placed first, and a second wire is placed parallel in the coronal plane, with a 2- to 3-cm anteroposterior distance between them (Fig. 46-2B). The starting points and trajectory are checked on intraoperative fluoroscopy. It is paramount that the fluoroscopy image is a true AP of the knee, with the knee in full extension, and overlap of the tib-fib joint such that one third of the fibular head is overlapped by the tibia. Each wire should be docked in the far cortex but not protruding through it. The wires and planned saw cut should be positioned such that there is adequate room proximally for the proximal row of locking screws and the most proximal shaft screw of the plate. The approximate distance of the osteotomy cut can be measured using a third guide pin, which is placed adjacent to one or both of the existing guide pins, just touching the near cortex. The distance between the exposed ends, <1 cm, is marked on the saw blade.

The knee should now be placed in 90 degrees of flexion, and the planned cut line should be marked out with a Bovie or surgical marker on the medial tibia prior to initiating the cut. The anterior ascending osteotomy should be marked at an angle of approximately 110 degrees and should exit the anterior tibia just proximal to the patellar insertion. This anterior ascending cut should intersect the main cut line 1.5 to 2 cm posterior to the anterior border.

The osteotomy is started with an oscillating saw directly below the guidewires, using the wires as a saw guide to direct the blade. It is important to stop the cut 1 cm medial to the lateral cortex, as breach of this cortex leads to instability and higher nonunion rates. Judicious use of irrigation with sterile saline can prevent heat osteonecrosis from the saw. The posterior two thirds of the tibia is cut first, with Hohmann retractors protecting the posterior neurovascular structures. When the posterior cortical cut is complete, there will be noticeable loss of resistance to the saw blade. The anterior ascending cut is then completed. To avoid excessive opening or fracture of the lateral cortex, osteotomes should be added in a stepwise fashion to distract and open the osteotomy. Most osteotomy systems provide instrumentation that allows for precise opening of the osteotomy to correspond with the preoperative templating. If the tibial slope is to remain unchanged, it is important to distract the osteotomy equally in the anterior and posterior sections of the cut. In cases of biplanar correction, the degree of distraction can be varied to achieve the desired level of tibial slope adjustment. For instance, in the ACL-injured knees with increased tibial slope, the osteotomy can be distracted more posteriorly than anteriorly, effectively decreasing the tibial slope. Bone graft can be contoured accordingly or placed only in the posterior portion of the osteotomy. The opposite approach can be used in patients with PCL deficiency and decreased tibial slope. The knee is once again placed into full extension, and intraoperative fluoroscopy or radiographs are used to evaluate the alignment. Fine adjustments are made as needed.

Once correction is achieved, internal plate fixation is performed. A pin is placed through the middle proximal hole, and position of the plate is confirmed under C-arm. A bicortical screw is placed through the first hole distal to the osteotomy to reduce the plate to the bone. The proximal screws are placed under fluoroscopy to avoid violation of the plateau. Often, plates will include a spacer component that provides rigid distraction at the cortical region of the osteotomy, though selection of hardware is based on surgeon preference. Bone grafting is then performed in cases of large defects (>8–10 mm). The authors' preferred method of fixation is a large fragment proximal tibial plate with a row of locking screws proximally and locking and cortical screw options in the shaft portion of the plate (Fig. 46-3). These larger plates have shown improved performance in biomechanical testing than the shorter "spacer" plates, as they provide a long, rigid lever arm with angle-stable locking screws (29). The locking screws should not protrude past the lateral cortex to prevent hardware irritation (Fig. 46-4).

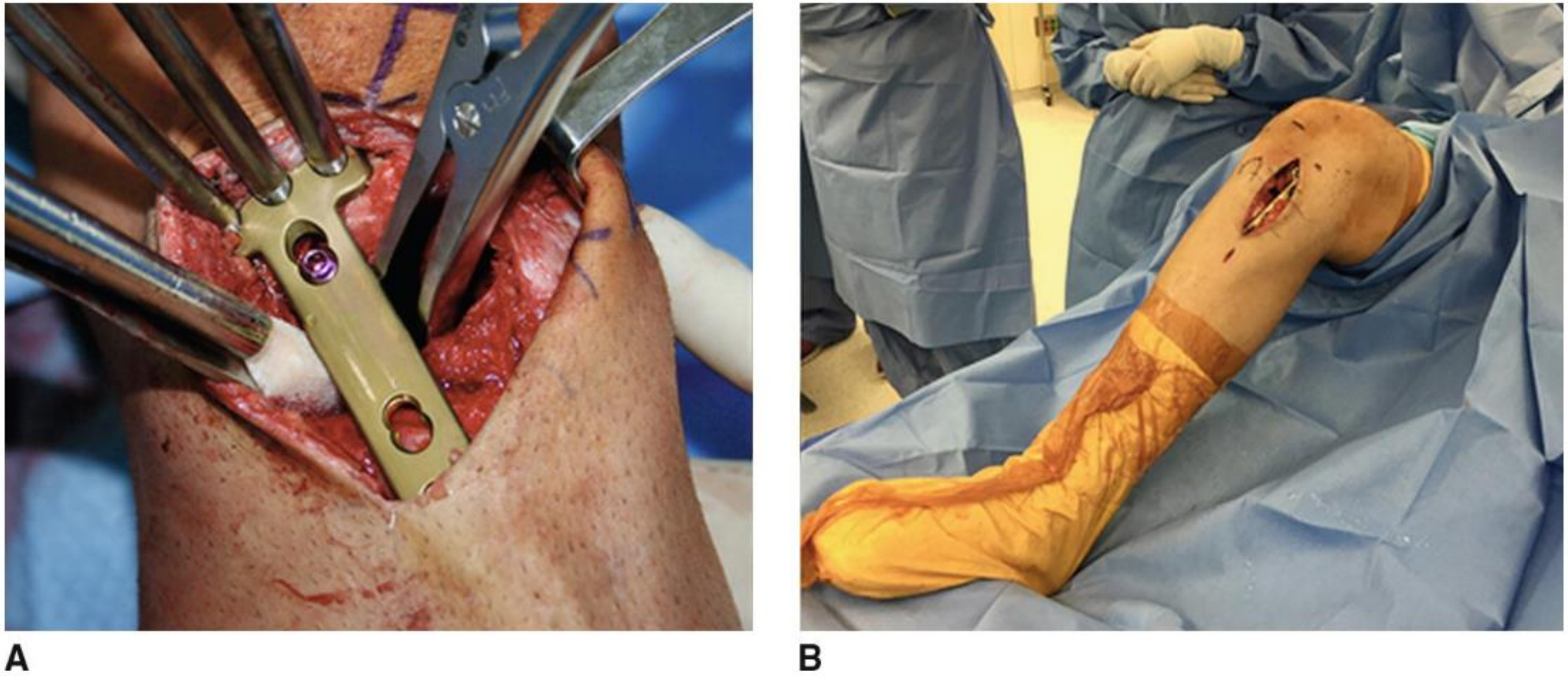
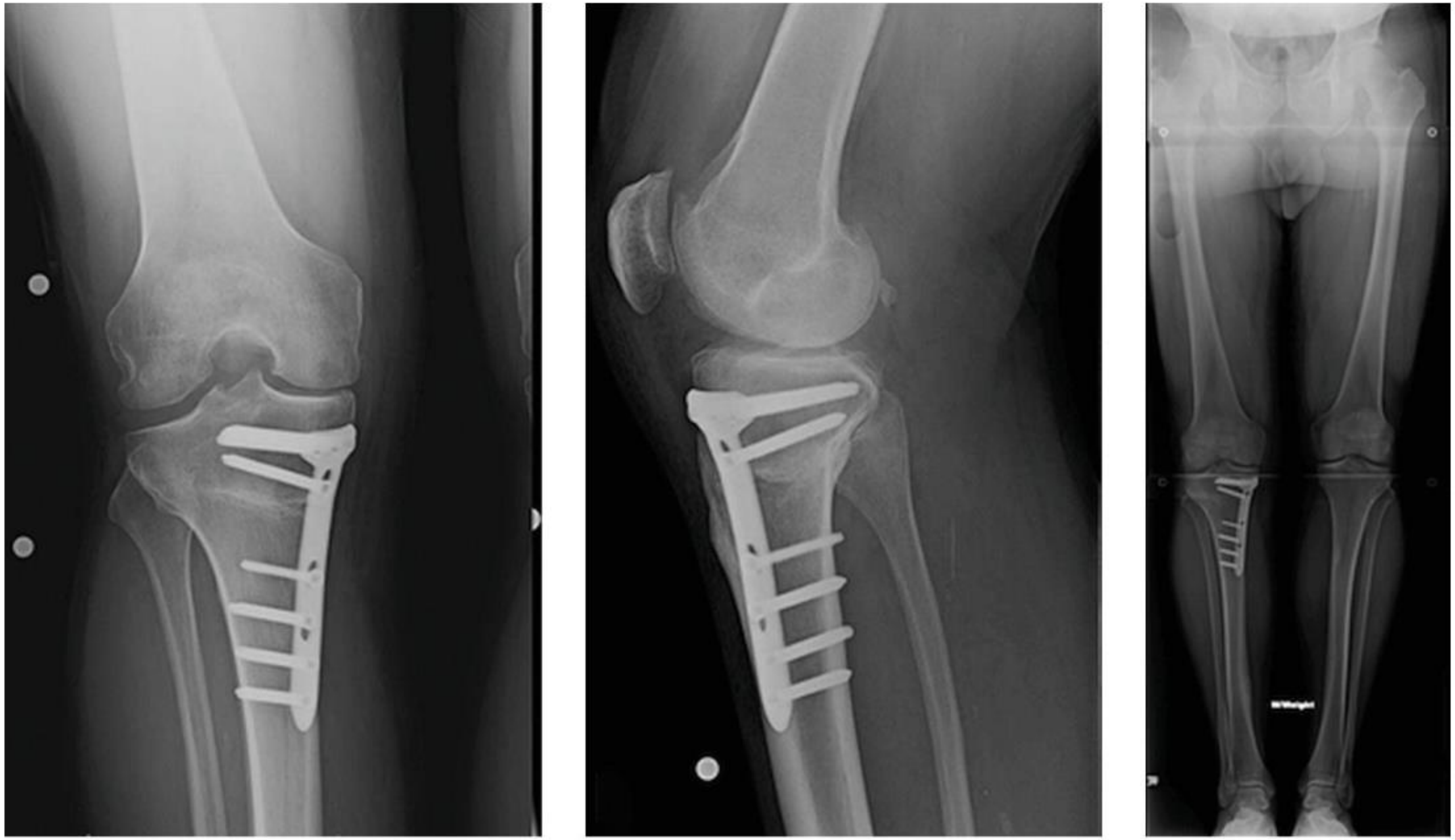


FIGURE 46-3 Opening-wedge high tibial osteotomy. **A:** Insertion of bone graft into posterior aspect of the left knee high tibial osteotomy. An osteotomy spreader is located anterior to the plate and maintaining adequate distraction for graft placement. **B:** Final result after graft placement and hardware fixation of right knee high tibial osteotomy.



A B C

FIGURE 46-4 Postoperative images from opening-wedge high tibial osteotomy. Anteroposterior **(A)** and lateral **(B)** radiographs 9 months after high tibial osteotomy demonstrating complete healing of the osteotomy and incorporation of bone graft. **C:** Full-length alignment films demonstrate correction of preoperative varus and symmetry with the contralateral knee.

Lateral Closing-Wedge High Tibial Osteotomy

An anterolateral L-shaped incision is made centered over Gerdy tubercle; the vertical aspect runs distally along the tibia, and the horizontal aspect runs parallel to, and approximately 1 cm distal to, the joint line toward the fibular head. Exposure of the lateral edge of the tibia is performed with subperiosteal elevation of the proximal anterior leg musculature, ensuring adequate hemostasis throughout the dissection. The peroneal nerve is identified and protected throughout the duration of the case. To further expose the osteotomy site, the proximal tibiofibular joint must be addressed. Various options exist, including producing an oblique osteotomy of the fibular head with a curved osteotome, fibular shaft osteotomy (~10 cm distal to the fibular head), excising the tibiofibular joint, or fibular head excision. Under fluoroscopic guidance, a guidewire is placed transversely from lateral to medial, 2 cm distal to the joint line, until the medial cortex is reached. A second guidewire is then placed at a predetermined distance distal to the first guidewire on the lateral cortex (this distance will correlate with the overall correction required). It is driven medially in an oblique direction and connected with the prior guidewire approximately 1 cm lateral to the medial cortex. This will allow a wedge of bone to be removed while leaving the medial cortex intact during cutting. Cuts are then made with an oscillating saw and osteotomes along these guidewires, while protecting the soft tissues anteriorly and posteriorly. Once the bone wedge is removed, mild valgus stress should be applied to the site resulting in deformation of the medial cortex and closing of the osteotomy site. If resistance is met, a 2.0 drill can be used to perforate and increase the plasticity of the medial cortex without causing overt fracture. The plate is then applied in submuscular fashion and secured into place.

DISTAL FEMUR OSTEOTOMY

Indications

The primary indication for opening- or closing-wedge DFO is a patient with considerable valgus and isolated lateral compartment arthritis (12). The goals of this varus-producing procedure are to correct the knee to within 0 to 2 degrees difference between the mechanical and anatomic alignment without overcorrecting into varus, minimizing pain and restoring function (12,31). Similar to HTO, proper patient selection is crucial for optimal success (Table 46-2). Although older age is often cited as a contraindication, the patient's lifestyle, overall health, and goals must be taken into consideration. Overall, most studies suggest that a DFO should be utilized to treat lateral unicompartmental OA in relatively young patients with well-maintained range of motion and early stages of OA with a valgus knee deformity (33). Similar to an HTO, ligamentous reconstruction and DFO can be performed concomitantly.

TABLE 46-2 Patient Selection Criteria for Distal Femur Osteotomy (DFO)

Indications (10,12,32)	Relative Indications	Contraindications (10,12,32)
Young age (40–60 y)	Moderate patellofemoral arthritis	Extension deficit >10 degrees
Isolated lateral joint line pain	Age (60–70 y or <40 y)	Loss of significant portion of medial meniscus
Body mass index (BMI) < 30	ACL, PCL, or PLC insufficiency	Medial compartment degenerative joint disease
High activity level		Bi- or tricompartmental osteoarthritis
Valgus deformity >10 degrees		Inflammatory osteoarthritis
Unicompartmental gonarthrosis		Valgus deformity >20 degrees with subluxation of the tibia
Reconstructive cartilage procedure in lateral compartment		Osteonecrosis of lateral femoral condyle
Nonsmoker		Obesity (BMI > 30)[a]

A chart demonstrating the indications, relative indications, and contradictions for osteotomy set forth by the International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine (ISAKOS), as well as various recent studies (10,12,32).

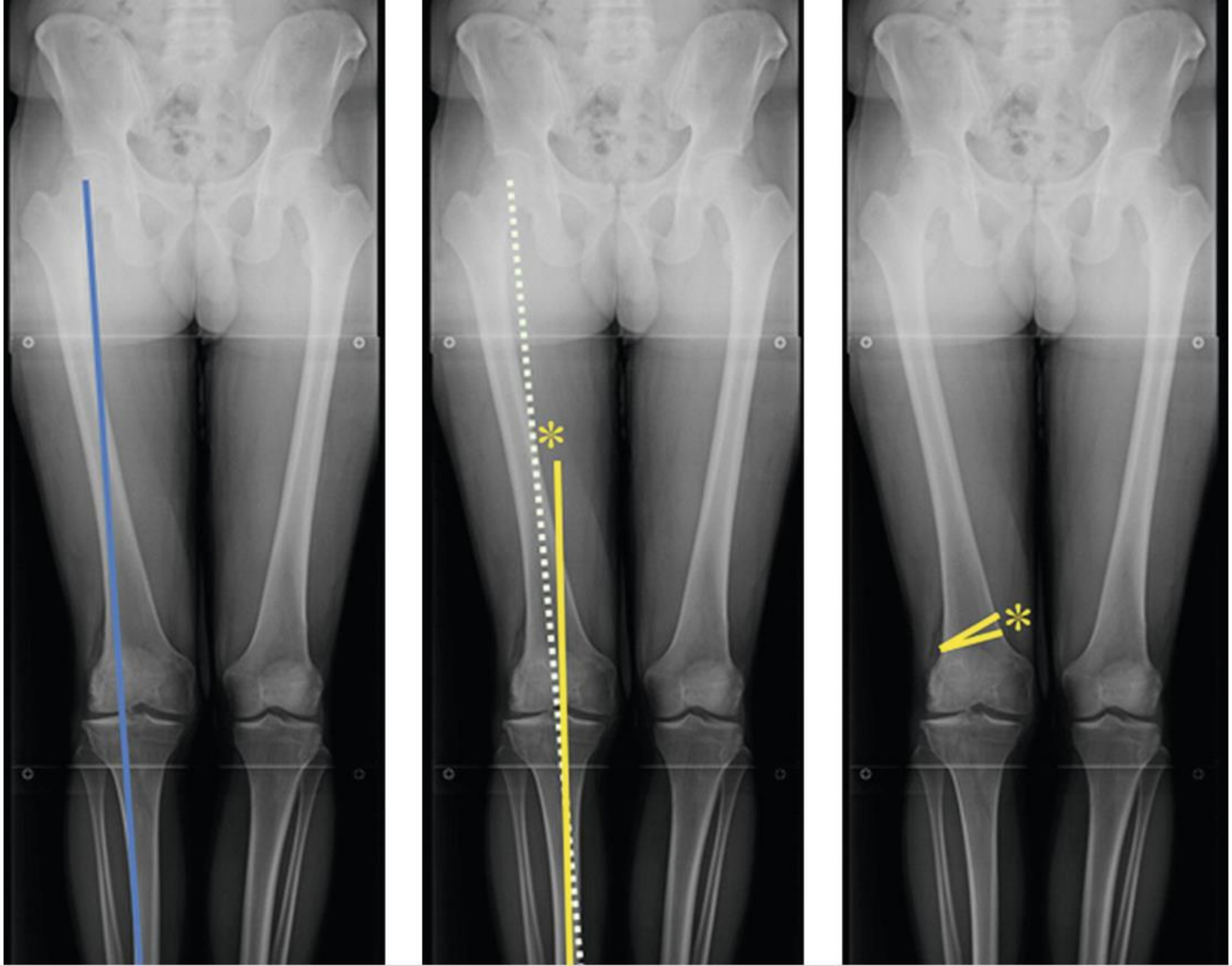
[a]Relative contraindication.

Contraindications

As with an HTO, the strict criteria for a DFO allow for improved long-term outcomes and implant survival. Contraindications are listed in Table 46-2. When planning this procedure, the most crucial factors to consider are age, smoking status, degree of deformity, and condition of cartilage and meniscus in the medial compartment. There is no definite age at which an osteotomy cannot be performed; however, numerous studies have demonstrated that age >70 years is associated with early failure after osteotomy (12,21,31–33). Severe valgus deformity >20 degrees can be associated with subluxation of the tibia and, when present, is an absolute contraindication to DFO (12,31,33). Lateral femoral condyle osteonecrosis will continue to cause the patient pain after a DFO, even with the resultant balanced load distribution, and hence is an absolute contraindication (12,31). Since the goal of a DFO is to offload the lateral compartment and improve pain, the meniscus and cartilage in the medial compartment must be relatively preserved in order to bear a greater load.

Preoperative Planning

Careful and meticulous preoperative planning are paramount for successful outcomes after DFO. The valgus extremity should not be overcorrected into varus, with a goal of 0 to 2 degrees difference between the mechanical and anatomic axes (31). A full radiographic evaluation, as described in the section above, should be performed. Full-length standing radiographs are needed to fully assess the deformity. The mechanical axis line, or WBL, is first drawn, which indicates where the majority of the load is concentrated in the knee. Then, as described previously, a reference point is chosen on the tibial plateau that approximates neutral alignment (24). This reference point is 48% to 50% the width of the tibial plateau as measured from the medial aspect. Two lines are drawn, one from the center of the femoral head to the reference point and the second one from the reference point to the center of the talus. The angle at which these two lines intersect represents the degree of fixation needed without overcorrecting into varus (Fig. 46-5). The size of the wedge can then be determined by measuring the width of the femur at the site of the proposed osteotomy. Both a lateral opening-wedge and medial closing-wedge osteotomy can be performed, although the lateral opening-wedge is more common. However, one study demonstrated that a medial closing-wedge osteotomy decreases the risk of nonunion in smokers and obese patients (34). Fixation of femoral deformities in the sagittal plane have yet to be described.



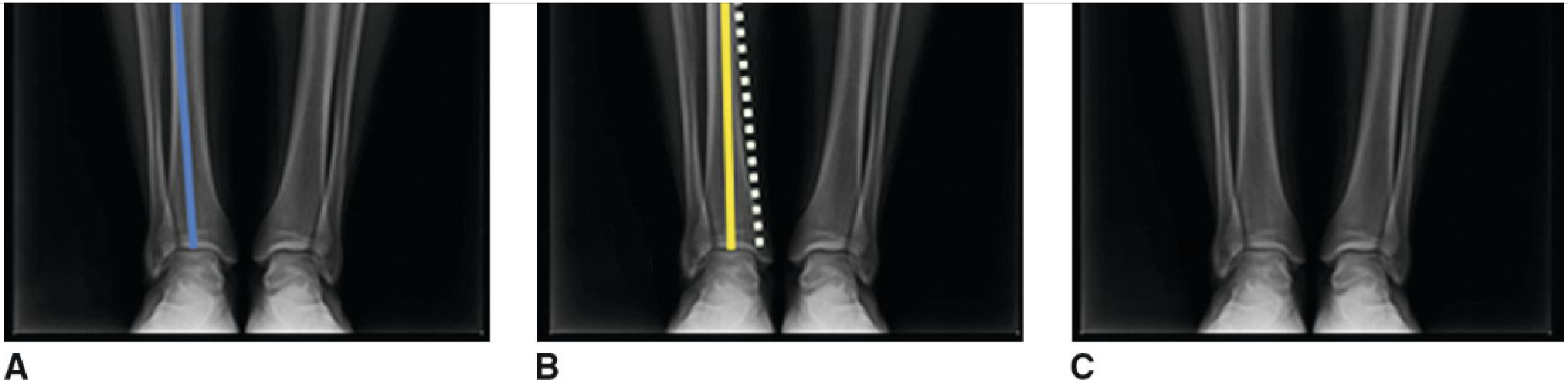


FIGURE 46-5 Preoperative planning for closing-wedge distal femoral osteotomy. **A:** The weight-bearing line (*blue line*) passes through the lateral compartment in this patient with valgus malalignment and symptomatic isolated lateral compartment arthritis. **B:** The correction angle is calculated by drawing a line (*dotted line*) from the center of the femoral head that passes through a point located at 50% of the medial to lateral width of the tibial articular surface. A separate line (*yellow line*) is drawn from the center of the tibial talar joint and passing through 50% of the tibial articular surface width at the knee. The angle (*) subtended by these lines can then be measured out on the planned osteotomy site **(C)** to identify the planned bone cuts.

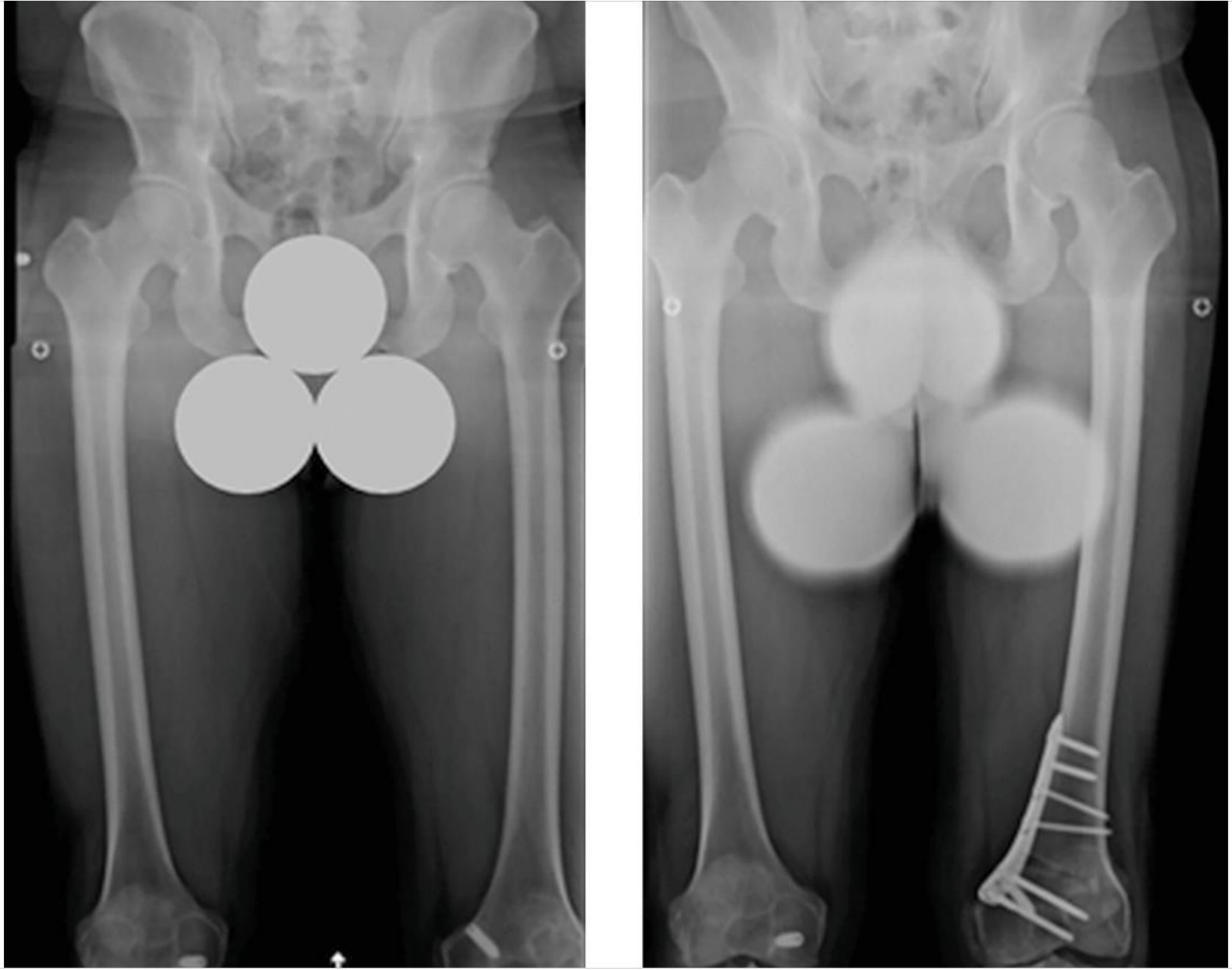
Surgical Technique

Optimal surgical technique starts with thorough preoperative planning, including review of full-length weight-bearing films and plan for amount of surgical correction, as well as reversal of any patient-modifiable risk factors. A preoperative decision should also be made regarding the intended fixation strategy; whether a T-shaped tooth plate, a more robust locking plate, or a fixed angle blade plate is used will depend upon surgeon preference, whether the patient has sufficient soft tissue coverage such that a higher profile plate will not be symptomatic, and/or whether earlier weight bearing will be allowed.

Medial Closing-Wedge Distal Femur Osteotomy

The patient is placed in the supine position. A longitudinal incision of approximately 10 cm is made just medial to the anterior midline of the knee. A large medial flap of skin and soft tissue superficial to the fascia is created with blunt dissection and electrocautery, isolating the vastus medialis muscle. Once isolated, the fascia is opened in longitudinal fashion. Utilizing this approach, the medial patellofemoral ligament must be split and subsequently repaired at the conclusion of the case, prior to layered closure. The vastus medialis is elevated, and a Hohmann retractor is placed across the anterior aspect of the femur. A key to this procedure is to dissect in a precise, layered fashion as the muscles are elevated to avoid aberrant bleeding from deep perforating arteries of the muscle. Once the distal femur is exposed, a guide pin is inserted under fluoroscopic guidance. The pin should be aiming at the metaphyseal corner of the lateral condyle and reach, but not perforate, the far cortex. A second pin is inserted parallel and just posterior to the first pin. These pins provide the plane for the oscillating saw to create the osteotomy. Before making the osteotomy cut, rotation needs to be established and marked on the bone to avoid malrotation. This can be done by using the Bovie and making a vertical line along the bone, crossing the osteotomy site, allowing the lines to be realigned after the cut. The cut should stop 1 cm short of the far cortex. The second cut is made at a predetermined distance proximal to the original cut (this distance will correlate with the overall correction required). The saw should connect with the original osteotomy cut, so that a wedge of bone can be removed while leaving the lateral cortex intact. This conversion point should be approximately 1 cm medial to the lateral cortex. Once the bone wedge is removed, mild varus stress should be applied to the site resulting in deformation of the lateral cortex and closing of the osteotomy site. If resistance is met, a 2.0 drill can be used to perforate and increase the plasticity of the lateral cortex without causing overt fracture. The plate is then applied in submuscular fashion, and a smooth k-wire used to hold the plate in place. Typically, a cortical screw is applied to a proximal hole in the plate permitting for the plate to sit flush along the femoral shaft. Then, locking screws are inserted in the distal segment, securing the plate. Remaining holes are filled with locking or cortical screws as indicated (Figs. 46-6 and 46-7). Final screw length and location is confirmed on fluoroscopy at the conclusion of the case.

FIGURE 46-6 Postoperative radiographs after closing-wedge distal femoral osteotomy. **(A)** Anteroposterior and **(B)** lateral radiographs after a medial closing-wedge distal femoral osteotomy, demonstrating correction of the valgus malalignment. The distal screws are locking screws to increase pullout strength in soft metaphyseal bone. The most distal shaft screw is a cortical screw used to reduce the plate to the bone. The proximal shaft screws can be locking or nonlocking screws.



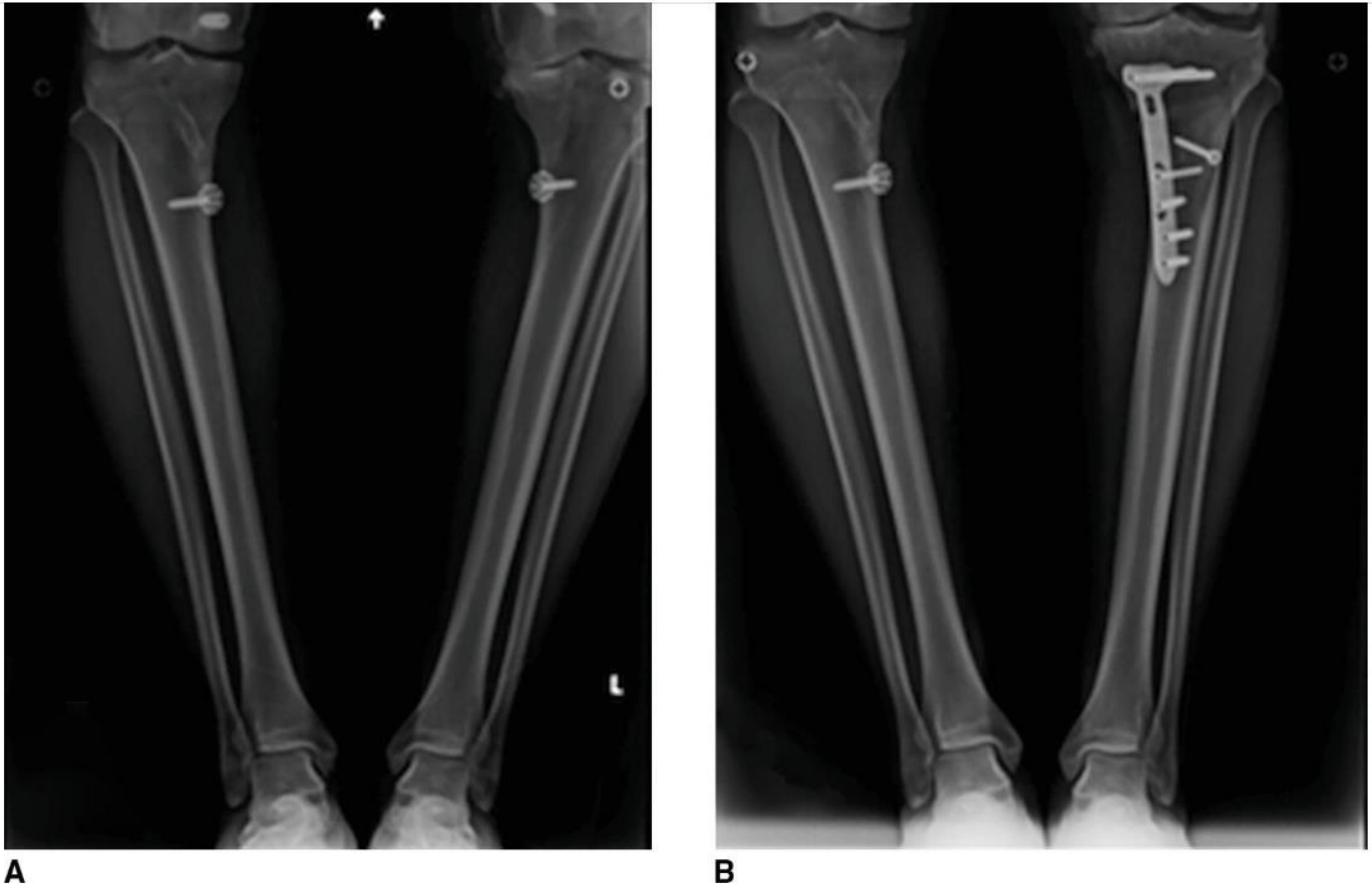


FIGURE 46-7 Pre- and postoperative radiographs after combined femoral and tibial osteotomy. **A:** Preoperative radiographs demonstrate a severe varus deformity that includes the distal femur and the proximal tibia. In these cases of severe deformity, addressing either the femur or tibia in isolation will not adequately correct the alignment. **B:** Postoperative radiographs demonstrating the medial opening-wedge distal femoral osteotomy and the medial opening-wedge high tibial osteotomy. Addressing both the tibial and femoral deformities resulted in correction of the patient's significant varus.

Lateral Opening-Wedge Distal Femur Osteotomy

Surgery is initiated with an approximately 12-cm incision starting from the lateral femoral epicondyle. Once the lateral femoral cortex is located, leaving the joint capsule intact, a freehand guidewire is drilled in a proximal to distal trajectory with the acuity of the angle based on the amount of correction required. Under fluoroscopic guidance, an oscillating saw should be used to start the osteotomy while wedge osteotomes are used in progressive fashion to "open" the osteotomy site. Depending on host factors, approximately 1 cm of medial hinge should be left intact to preserve stability at the osteotomy site and decrease rate of nonunion with a lateral-based plate for final fixation. Postoperative protocols are variable depending upon host factors and surgeon preference, but should generally consist of venous thromboembolism (VTE) prophylaxis, early range of motion and/or continuous passive motion (CPM) device, and non–weight bearing for approximately 6 to 8 weeks with resolution of full weight bearing at 8 to 10 weeks.

POSTOPERATIVE COURSE

Patients are made limited weight bearing for 6 weeks after surgery. Recent studies have suggested improved outcomes with early weight bearing (35), although this should be avoided in cases where the far cortex (hinge point) is breached. Mobilization and range of motion exercises are initiated on postoperative day 1, and sutures are removed after 7 to 10 days. Chemical thromboembolism prophylaxis is prescribed for 3 to 6 weeks. Bone healing can be assessed radiographically, and usually occurs from the bony hinge outward in opening-wedge osteotomies. Some bone resorption may be present around weeks 3 to 4, but approximately 33% of the osteotomy surface area should be healed at 6 weeks, and over 50% at 3 months. Hardware removal is safe after 90% healing, and not prior to 6 months. Nicotine use will significantly prolong these milestones (29).

PEARLS AND PITFALLS

"Pearls" for success with corrective osteotomies center upon use of a repeatable and consistent pre-, intra- and postoperative plan. Firstly, thorough examination and patient selection must be performed prior to surgery. Strict indications (see above) must be adhered to for the optimization of pain relief and functional outcome, and the overall success of the procedure. Once the patient has been carefully selected, all modifiable risk factors (smoking, blood glucose, weight loss, etc.) should be addressed and the patient should be optimized for surgery. Careful preoperative planning should take into account the overall magnitude of deformity, the desired correction, and the location of osteotomy to reduce intraoperative adjustments and operative time. Once this plan has been carefully established, there should be no deviation during the surgery. This may lead to an increased rate of under- or overcorrection, and/or increase the risk of medial cortex disruption. Finally, adherence to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) principles for fracture fixation, including restoration of anatomy, stable fracture fixation, preservation of blood supply, and early mobilization of the limb and patient will improve the repeatability and overall success of this procedure while reducing complication rates.

COMPLICATIONS

With completion of closing- and opening-wedge osteotomies, close attention must be paid to the avoidance and/or correction of any intra- or postoperative complications. As noted in the technique section, it is desirable for the surgeon to maintain a medial/lateral bone bridge or intact cortex to "hinge" the osteotomy—this provides for enhanced rigidity and decreased rates of nonunion. However, fracture of the cortex may occur during the operative cuts or during the opening/closing of the osteotomy site. Addressing this fracture requires close attention to cortical reads on intra-op fluoroscopy, avoiding malreduction and/or rotation by visualizing the osteotomy site and checking the reduction at multiple intervals during plate and screw application. Weight-bearing protocols may vary on a surgeon-to-surgeon basis after disruption of the far cortex. In some cases, a separate incision and fixation of the cortical breach is needed. Under- or overcorrection at the osteotomy site may occur. Close attention must be paid to preoperative planning principles, as well as during intraoperative pin and guidewire placement prior to making final cut and applying lateral-based plates. Iatrogenic injury to the articular surface or lateral-based ligaments is rare but must be addressed intraoperatively and repaired as appropriate. Deep vein thrombosis (DVT) is a significant complication that must be treated in the event of postoperative occurrence. Appropriate mechanical and chemical prophylaxis must be used in the immediate postoperative period, and early mobilization protocols may also reduce the overall risk. Low molecular weight heparin (Lovenox) may be used for 30 days post-op as indicated in patients with increased risk of DVT.

OUTCOMES

Long-term follow-up studies have shown that HTO results in good outcomes and overall survival of >50% at 18 years (9). Furthermore, over 85% of patients return to work and/or sports, and most return to the same or greater level of activity. Of those returning to sports, 78.6% returned at an equal or greater level. Among competitive athletes, 54% returned to competition (36), 90% of patients returning to work or sport did so by 1 year, and 65.5% returned at an equal or greater level (36). However, other studies have suggested excellent early results that deteriorate a 10-year time period, especially when performed with concomitant cartilage procedures (37). A comparison of patients with TKA performed after a previous HTO reported similar results to patients with primary TKA and no history of HTO (38). In young patients with varus deformity and medial compartment arthritis, HTO has been shown to be cost-effective compared to TKA. Similarly, studies have shown good functional outcomes and improvements in patient-reported outcomes at 10 years, with an approximately 25% conversion to TKA at a mean of 6 years (39). A systematic review of both closing- and opening-wedge DFO reported 80% survivorship at 10 years with a low complication rate (40). A systematic review comparing standard HTO to HTO with computer navigation found that navigated HTO resulted in improved mechanical axis correction, although there were no significant differences in clinical outcomes (41).

SUMMARY

Distal femoral or proximal tibial osteotomy is a good option for knee preservation in patients with unicompartmental gonarthritis with associated tibiofemoral malalignment. While patient selection and technical precision is key, osteotomy of the knee can improve patient function, decrease pain symptoms, facilitate return to work or sport, and provide a meaningful delay (or complete avoidance) of a more complex arthroplasty procedure. Knee osteotomy procedures should be strongly considered in young, active patients with knee arthritis isolated to a single compartment and an accompanying varus or valgus deformity.

REFERENCES

1. Coventry MB. Osteotomy of the upper portion of the tibia for degenerative arthritis of the knee. A preliminary report. *J Bone Joint Surg Am*. 1965;47(5):984–990.
2. Holden DL, James SL, Larson RL, et al. Proximal tibial osteotomy in patients who are fifty years old or less. A long-term follow-up study. *J Bone Joint Surg Am*. 1988;70(7):977–982.
3. Morrey BF. Upper tibial osteotomy for secondary osteoarthritis of the knee. *J Bone Joint Surg Br*. 1989;71(4):554–559.
4. Levine HB, Bosco JA III. Sagittal and coronal biomechanics of the knee: a rationale for corrective measures. *Bull NYU Hosp Jt Dis*. 2007;65(1):87–95.
5. Wu DD, Burr DB, Boyd RD, et al. Bone and cartilage changes following experimental varus or valgus tibial angulation. *J Orthop Res*. 1990;8(4):572–585.
6. Parker DA, Beatty KT, Giuffre B, et al. Articular cartilage changes in patients with osteoarthritis after osteotomy. *Am J Sports Med*. 2011;39(5):1039–1045.
7. Shaw JA, Moulton MJ. High tibial osteotomy: an operation based on a spurious mechanical concept. A theoretic treatise. *Am J Orthop (Belle Mead NJ)*. 1996;25(6):429–436.
8. Jackson JP, Waugh W, Green JP. High tibial osteotomy for osteoarthritis of the knee. *J Bone Joint Surg Br*. 1969;51(1):88–94.
9. Michaela G, Florian P, Michael L, et al. Long-term outcome after high tibial osteotomy. *Arch Orthop Trauma Surg*. 2008;128(1):111–115.
10. Rand J, Neyret P, eds. ISAKOS meeting on the management of osteoarthritis of the knee prior to total knee arthroplasty. ISAKOS Congress; 2005.
11. Lobenhoffer P, Agneskirchner JD. Improvements in surgical technique of valgus high tibial osteotomy. *Knee Surg Sports Traumatol Arthrosc*. 2003;11(3):132–138.
12. Uquillas C, Rossy W, Nathasingh CK, et al. Osteotomies about the knee. *J Bone Joint Surg Am*. 2014;96(24):e199.
13. Seil R, van Heerwaarden R, Lobenhoffer P, et al. The rapid evolution of knee osteotomies. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(1):1–2.
14. Brinkman JM, Lobenhoffer P, Agneskirchner JD, et al. Osteotomies around the knee: patient selection, stability of fixation and bone healing in high tibial osteotomies. *J Bone Joint Surg Br*. 2008;90(12):1548–1557.
15. Bonnin M, Chambat P. Current status of valgus angle, tibial head closing wedge osteotomy in media gonarthrosis. *Orthopade*. 2004;33(2):135–142.
16. Imhoff AB, Linke RD, Agneskirchner J. Corrective osteotomy in primary varus, double varus and triple varus knee instability with cruciate ligament replacement. *Orthopade*. 2004;33(2):201–207.
17. Noyes FR, Barber SD, Simon R. High tibial osteotomy and ligament reconstruction in varus angulated, anterior cruciate ligament-deficient knees. A two- to seven-year follow-up study. *Am J Sports Med*. 1993;21(1):2–12.
18. Dejour D, Khun A, Dejour H. Osteotomie tibiale de déflexion et laxité chronique antérieure à propos de 22 cas. *Rev Chir Orthop Reparatrice Appar Mot*. 1998;84:28.
19. Sonnery-Cottet B, Mogos S, Thaunat M, et al. Proximal tibial anterior closing wedge osteotomy in repeat revision of anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;42(8):1873–1880.
20. van Houten AH, Heesterbeek PJ, van Heerwaarden RJ, et al. Medial open wedge high tibial osteotomy: can delayed or nonunion be predicted? *Clin Orthop Relat Res*. 2014;472(4):1217–1223.
21. Naudie D, Bourne RB, Rorabeck CH, et al. The Install Award. Survivorship of the high tibial valgus osteotomy. A 10- to 22-year followup study. *Clin Orthop Relat Res*. 1999;367(367):18–27.
22. Akizuki S, Shibakawa A, Takizawa T, et al. The long-term outcome of high tibial osteotomy: a ten- to 20-year follow-up. *J Bone Joint Surg Br*. 2008;90(5):592–596.
23. Matthews LS, Goldstein SA, Malvitz TA, et al. Proximal tibial osteotomy: factors that influence the duration of satisfactory function. *Clin Orthop Relat Res*. 1988;229:193–200.
24. Dugdale TW, Noyes FR, Styer D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. *Clin Orthop Relat Res*. 1992;274(274):248–264.
25. El-Azab H, Glabgly P, Paul J, et al. Patellar height and posterior tibial slope after open- and closed-wedge high tibial osteotomy: a radiological study on 100 patients. *Am J Sports Med*. 2010;38(2):323–329.
26. Hashemi J, Chandrashekar N, Gill B, et al. The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. *J Bone Joint Surg Am*. 2008;90(12):2724–2734.
27. Giffin JR, Vogrin TM, Zantop T, et al. Effects of increasing tibial slope on the biomechanics of the knee. *Am J Sports Med*. 2004;32(2):376–382.
28. Neyret P, Zuppi G, Selmi TAS. Tibial deflexion osteotomy. *Oper Tech Sports Med*. 2000;8(1):61–66.
29. Lobenhoffer P, Van Heerwaarden R, Staubi A, et al. *Osteotomies around the Knee*. Switzerland: AO Publishing; 2008.
30. Tjornstrand B, Egund N, Hagstedt B, et al. Tibial osteotomy in medial gonarthrosis. The importance of over-correction of varus deformity. *Arch Orthop Trauma Surg*. 1981;99(2):83–89.
31. Puddu G, Cipolla M, Cerullo G, et al. Osteotomies: the surgical treatment of the valgus knee. *Sports Med Arthrosc*. 2007;15(1):15–22.
32. Van Heerwaarden RJ, Wymenga AB, Freiling D, et al. Supracondylar varization osteotomy of the femur with plate fixation. In: Lobenhoffer P, van Heerwaarden RJ, Staubli AE, Jakob RP, eds. *Osteotomies around the Knee*. Stuttgart, Germany: Thieme. AO Foundation Publishing; 2008:147–166.
33. Puddu G, Cipolla M, Cerullo G, et al. Which osteotomy for a valgus knee? *Int Orthop*. 2010;34(2):239–247.
34. Healy WL, Anglen JO, Wasilewski SA, et al. Distal femoral varus osteotomy. *J Bone Joint Surg Am*. 1988;70(1):102–109.
35. Lee OS, Ahn S, Lee YS. Effect and safety of early weight-bearing on the outcome after open-wedge high tibial osteotomy: a systematic review and meta-analysis. *Arch Orthop Trauma Surg*. 2017;137(7):903–911.
36. Ekhtiari S, Haldane CE, de Sa D, et al. Return to work and sport following high tibial osteotomy: a systematic review. *J Bone Joint Surg Am*. 2016;98(18):1568–1577.
37. Harris JD, McNeilan R, Siston RA, et al. Survival and clinical outcome of isolated high tibial osteotomy and combined biological knee reconstruction. *Knee*. 2013;20(3):154–161.
38. W-Dahl A, Robertsson O. Similar outcome for total knee arthroplasty after previous high tibial osteotomy and for total knee arthroplasty as the first measure. *Acta Orthop*. 2016;87(4):395–400.
39. Ekeland A, Nerhus TK, Dimmen S, et al. Good functional results of distal femoral opening-wedge osteotomy of knees with lateral osteoarthritis. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(5):1702–1709.
40. Chahla J, Mitchell JJ, Liechti DJ, et al. Opening- and closing-wedge distal femoral osteotomy: a systematic review of outcomes for isolated lateral compartment osteoarthritis. *Orthop J Sports Med*. 2016;4(6):2325967116649901.
41. Yan J, Musahl V, Kay J, et al. Outcome reporting following navigated high tibial osteotomy of the knee: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(11):3529–3555.