CHAPTER 53

Fractures of the Distal Femur

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PATHOLOGY

Relevant Anatomy

The distal end of the femur traditionally encompasses the lower third of this bone. This zone varies greatly in the literature, from the distal 7.6 cm to the distal 15 cm of the femur. This chapter deals only with fractures that involve the supracondylar (metaphyseal) or intercondylar (epiphyseal) areas of the distal end of the femur. Distal femoral fractures that are purely diaphyseal are discussed in Chapter 52.

BONE

The supracondylar (metaphyseal) area of the distal portion of the femur is the transition zone between the distal diaphysis and the femoral articular condyles (Fig. 53–1*A*). At the diaphyseal-metaphyseal junction, the metaphysis flares, especially on the medial side, to provide a platform for the broad condylar weight-bearing surface of the knee joint. Anteriorly between these two condyles is a smooth articular depression for the patella, the trochlear groove. Posteriorly between the two condyles is the intercondyloid notch. Medially, a readily identifiable landmark is the adductor tubercle at the maximal point of flare of the metaphysis. Both condyles have epicondyles on their outer surfaces.

Of surgical importance, the shaft of the femur in the sagittal view is aligned with the anterior half of the condyles, whereas the posterior half of both condyles is in a posterior position relative to the proximal femoral shaft. In addition, the condyles are wider posteriorly than anteriorly. A transverse cut through the condyles shows a trapezoid with a 25° posterior-to-anterior decrease in width on the medial side.

MUSCLE

Anteriorly, the extensor compartment contains the quadriceps femoris, the single largest muscle in the body. It consists of four heads: the rectus femoris more superficially and, in the deeper layer from lateral to medial, the vastus lateralis, vastus intermedius, and vastus medialis. The anterior extensor compartment is separated from the posterior compartment by the lateral and medial intermuscular septa. These partitions provide important landmarks for both the lateral and medial approaches to the knee joint. Of major significance on the medial side is the superficial femoral artery, which runs down the thigh between the extensor and adductor compartments. The artery passes into the popliteal fossa approximately 10 cm above the knee joint by passing through the adductor magnus muscle. It obviously must be identified and avoided in medial approaches to the distal end of the femur.

The powerful muscles of the distal part of the thigh produce characteristic bony deformities with fractures. The muscle pull of the quadriceps and posterior hamstrings produces shortening of the femur. As the shaft overrides anteriorly and the gastrocnemius muscles pull posteriorly, the condyles are displaced and angulated posteriorly (see Fig. 53–1*B*). When the condyles are separated by a fracture, rotational malalignment is common because of the unrestrained pull of the gastrocnemius muscles and the anterior overriding of the shaft.

ALIGNMENT

The anatomic axis of the shaft of the femur is different from the weight-bearing, or mechanical, axis (Fig. 53–2). The latter passes through the head of the femur and the middle of the knee joint. Generally, the weight-bearing femoral axis subtends an angle of 3° from the vertical. The anatomic femoral axis has a valgus angulation of 7°

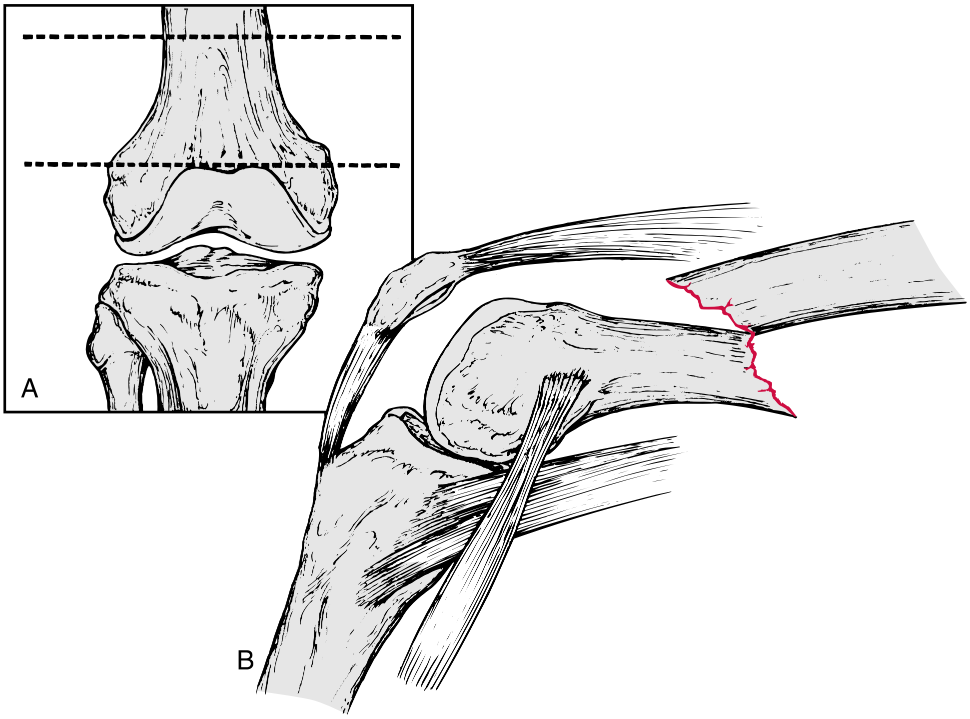

FIGURE 53–1. Anatomic representation of the distal end of the femur. *A,* Sketch of an anteroposterior radiograph of the metaphysis. The segment between the *dashed lines* is the supracondylar zone. *B,* Sketch of a lateral radiograph demonstrating muscle attachments and bone displacement.

(average, 9°) relative to the vertical axis. Normally, the knee joint axis is parallel to the ground, and the anatomic femoral axis subtends an 81° lateral distal femoral angle relative to the knee joint axis. For each patient it is important to confirm this angle from the opposite femur. Then, at the time of surgical reconstruction, the correct femoral valgus angulation (anatomic axis) can be recreated and the knee joint kept parallel to the ground.

Incidence

Distal femoral fractures have been reported to account for between 4%[57] and 7%[95] of all femoral fractures, which in Sweden corresponds to an annual incidence of 51 per million inhabitants older than 16 years.[57] If fractures of the hip are excluded, 31% of femoral fractures involve the distal end.[1] With the modern trends of high-energy lifestyles combined with increased longevity, this incidence is probably increasing.

Distal femoral fractures occur predominantly in two patient populations: young persons, especially young men, after high-energy trauma, and elderly persons, especially elderly women, after low-energy injuries. In one series from Sweden, up to 84% of distal femoral fractures occurred in patients older than 50 years.[57] In a Rochester, Minnesota, study of patients aged 65 years or older, 84% of the femoral fractures occurred in women. The conclusion of this epidemiologic study was that the "incidence rates for distal femoral fractures do indeed rise exponentially with age and are greater among elderly women than men."[1]

In the older group, most of the injuries occur after moderate trauma, such as a fall on a flexed knee. Two thirds of the fractures caused by moderate trauma were "preceded by prior age-related fractures (hip, proximal humerus, distal forearm, pelvis or vertebra) or with roentgenographic evidence of generalized osteopenia."[1]

In the younger group, distal femoral fractures occur after high-energy trauma. These fractures are often open, comminuted, and most probably the result of direct application of load to a flexed knee. Most are caused by vehicular accidents, including motorcycle accidents, but they can also result from industrial accidents or falls from heights. Most of these patients are younger than 35 years, with a definite male preponderance.

Surprisingly, the degree of comminution in the supracondylar region is often equivalent in both these groups. However, younger patients experiencing high-energy trauma have a greater incidence of additional intra-articular disruption or segmental or more proximal shaft comminution.[104]

Anatomic and Functional Consequences of the Injury

Fractures in the supracondylar area characteristically deform with femoral shortening and posterior angulation and displacement of the distal fragment. In more severe fractures with intercondylar involvement, one often sees rotational malalignment of the condyles relative to each other in the frontal plane, a result of their muscle attachments.

Even with significant supracondylar comminution and displacement of the distal fragment, axial alignment can often be regained with traction, but the alignment is hard to maintain. Conversely, with intercondylar involvement and malrotation of the condyles, reduction is almost impossible by traction alone and is often difficult even with surgery. The aims of treatment must be restoration of length, rotation, and axial alignment and anatomic reconstitution of articular surface to avoid long-term morbidity. Length and rotation can usually be restored by traction alone, but restoration of axial alignment of the knee joint relative to the femoral anatomic axis often requires additional measures, including surgical intervention. Disruption of the articular surface also requires anatomic reduction and usually mandates an operative procedure.

Commonly Associated Injuries

High-energy distal femoral fractures, especially in young patients, are often only one of several injuries sustained by the individual. The whole patient must be carefully evaluated by a multidisciplinary team approach (see Chapter 5). This section addresses only commonly associated injuries in the involved lower extremity.

The most common mechanism of distal femoral fracture is direct trauma to a flexed knee, typically impact against the dashboard of a moving vehicle. The position of the leg at the time of the injury determines the presence and type of injury. Care must be taken to exclude concomitant acetabular fractures, hip dislocations, femoral neck fractures, and associated femoral shaft fractures.

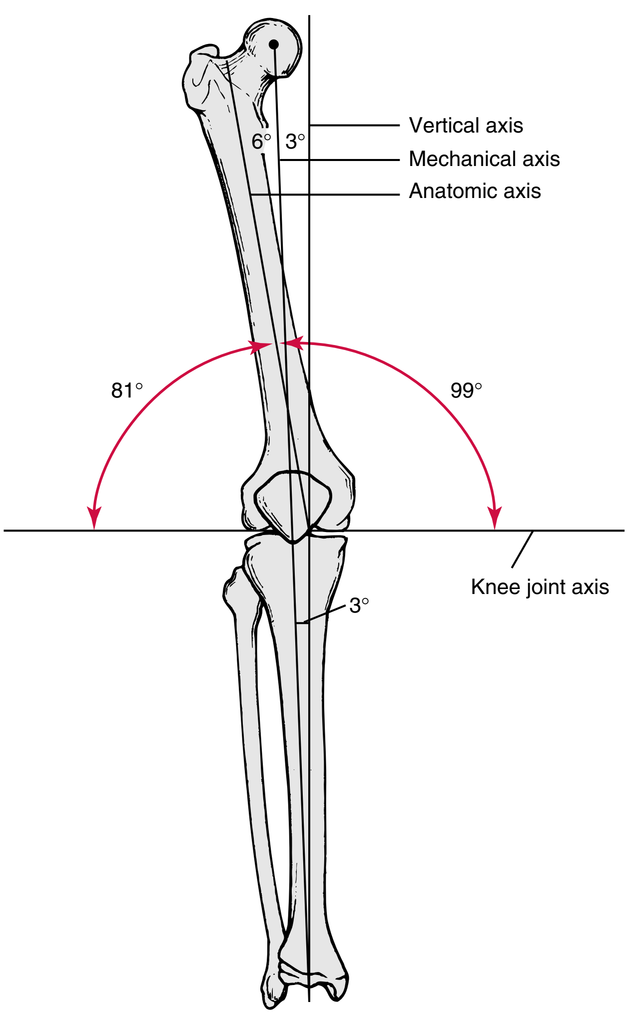

Figure 53–2. Lower extremity axes.

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SOFT TISSUE INJURIES

Significant soft tissue injuries of the knee are often associated with distal femoral fractures. Associated ligamentous disruptions of the knee joint have been reported in approximately 20% of these fractures.[125] They are hard to diagnose until the distal part of the femur has been stabilized because both clinical examination and stress radiographs require stability above the knee.

In a polytraumatized patient, distal femoral fractures commonly occur with associated injuries to the tibia. Associated tibial plateau fractures occur after a predominantly varus or valgus force. Careful evaluation of the plateau is needed and often requires tomograms. Associated tibial shaft fractures, often comminuted or open, mandate aggressive treatment of both injuries to avoid the morbidity associated with the "floating knee" syndrome.

VASCULAR INJURIES

The femoral artery in the adductor canal is in close proximity to the medial cortex of the distal end of the femur as it passes through to the posterior compartment only 10 cm above the knee joint. With high-energy or open distal femoral injuries, the artery is at significant risk of injury. With associated ligament disruptions of the knee (especially a posterior dislocation), the popliteal artery is at great risk of injury—up to 40% in some series.[32, 54, 79, 113] Arterial injuries must be aggressively sought. Arteriography or immediate surgical exploration is mandatory in patients with evidence of ischemia or diminished pulse pressure. In these instances, the information gained must justify the time needed to perform the angiography in an angiography suite. For example, in cases in which surgical exploration of the vascular bundle is needed anyway or in patients in whom amputation is being planned, an "on-table angiogram" is another option to be considered. In delayed cases, deep venous thrombosis should be considered.

COMPLEX TRAUMA OF THE KNEE

For severe accompanying local injuries around the knee, the term "complex trauma of the knee" has been defined and includes (1) a distal supracondylar or intercondylar femoral fracture combined with a proximal tibial fracture ("floating knee"), (2) a supracondylar or intercondylar femoral fracture with a second- or third-degree closed or open soft tissue injury, and (3) complete knee joint dislocation. The thin soft tissue coverage on the anterior aspect of the distal end of the femur is a frequent problem. Neurovascular injuries are mostly observed in the type 3 "distal femur complex trauma." Because of the need for interdisciplinary management (vascular surgery, plastic surgery), the high technical demands (joint reconstruction, alignment, ligamentous instability, soft tissue coverage), and the risk of complications (nonunion, infection, malalignment), we recommend that "complex knee trauma"

TABLE 53–1

Definition of "Complex Knee Trauma"

Complex Knee Trauma	Soft Tissue Injury	Fracture Pattern
Type 1		Supracondylar-intercondylar fracture of distal end of femur **and** proximal end of tibia (floating knee)
Type 2	2nd- or 3rd-degree closed or open soft tissue damage	Supracondylar-intercondylar fracture of distal end of femur **or** proximal end of tibia
Type 3	Complete knee dislocation	

Source: Krettek, C.; Tscherne, H. In: Fu, F.H.; et al., eds. Knee Surgery. Baltimore, Williams & Wilkins, 1994, pp. 1027–1035.

be treated in trauma centers with a high case load and extended experience (Table 53–1).

Classification

One of the original and simpler classification schemes of supracondylar-intracondylar femoral fractures was that of Neer and associates.[89] They subdivided intracondylar fractures into the following categories: minimal displacement (grade I); displacement of the condyles (grade II), including medial (A) and lateral (B) displacement; and concomitant supracondylar and shaft fractures (grade III). This classification system is very basic and does not provide the surgeon with much clinical and prognostic information.

Seinsheimer[106] classified fractures of the distal 3.5 inches of the femur into four basic types: nondisplaced fractures—any fracture with less than 2-mm displacement of the fractured fragments (grade I); fractures involving only the distal metaphysis, without extension into the intracondylar region (type IIA: two-part fractures; type IIB: comminuted fractures); fractures involving the intercondylar notch in which one or both condyles are separate fragments (type IIIA to IIIC); and fractures extending through the articular surface of the femoral condyles (type IVA or IVB: a fracture through the medial [A] or lateral [B] condyle, with two parts comminuted; type IVC: more complex and comminuted fractures involving one femoral condyle and the intercondylar notch, both femoral condyles, or all three; it usually involves a comminuted fracture across the metaphysis as well). Seinsheimer[106] found that patients with type I nondisplaced fractures and type II simple, two-part supracondylar fractures all had preexisting pathologic osteoporosis before their injury. At the other end of the spectrum, patients with type IV fractures involving the articular surface were the youngest patients, and all fractures resulted from high-energy trauma.

The "Schweizer Arbeitsgemeinschaft für Osteosynthesesfragen" (SWISS AO) Group, through the AO Documentation Center in Davos, has collated its vast experience and has documentation on thousands of these fractures. Müller and colleagues,[86] in an updated AO classification system for distal femoral fractures, separated these fractures into three main groups[87] (Fig. 53–3): type A (extra-articular), type B (unicondylar), and type C (bicondylar). The three groups are each further divided into three subgroups. Type A (extra-articular) fractures are divided into simple, two-part supracondylar fractures (type A1), metaphyseal wedge fractures (type A2), and comminuted supracondylar fractures (type A3). Type B (unicondylar) fractures are divided into lateral condyle sagittal fractures (type B1), medial condyle sagittal fractures (type B2), and coronal fractures (type B3). Type C (bicondylar) fractures are divided into noncomminuted supracondylar (T or Y) fractures (type C1), supracondylar comminuted fractures (type C2), and supracondylar or intercondylar comminuted fractures (type C3). In progressing from A to C, the severity of the fracture increases, whereas the prognosis for a good result decreases. This relationship is also true for the progression from 1 to 3 within each group.

For a classification system to have clinical significance, it must be able to do the following: (1) allow for adequate documentation of all fractures so that a common language is possible when discussing these injuries, (2) be simple enough that it is "user friendly," (3) help the surgeon in clinical decision making so that the correct treatment option can be selected for a particular fracture, and (4) provide prognostic information detailing the results that can be expected for a particular fracture, depending on the treatment option selected. The Müller updated classification system meets these criteria and is used for classifying and describing fractures in the remainder of this chapter.

DIAGNOSIS

History and Physical Examination

A careful evaluation of the whole patient as well as the involved lower extremity is mandatory, especially in a polytraumatized patient. Assessment must include careful scrutiny of the hip joint above the fracture and the knee and leg below it. If vascularity to the lower extremity is a concern, Doppler pulse pressure readings can be obtained. If vascularity is still a concern after these procedures, an urgent arteriogram may be indicated. Rarely, if tense swelling of the thigh is noted, a thigh compartment syndrome must also be ruled out by examination and possibly compartment pressure monitoring.

Grossly open and contaminated wounds are easily identifiable. However, when the injury results from direct trauma, skin abrasions are frequently present and must be differentiated from open fracture wounds of the soft tissues. The examination usually reveals swelling of the knee and supracondylar area, often obvious deformity, and marked tenderness on palpation. Manipulation of the extremity, if tolerated by the patient, demonstrates motion and crepitance at the fracture site. However, such manipulation is cruel and unnecessary if immediate radiographs are available.

Radiographic Evaluation

Routine anteroposterior (AP) and lateral radiographs of the knee and supracondylar region are standard. When fractures are comminuted or displaced, an exact classification of the fracture is often difficult to make. AP and lateral radiographs, both with manual traction applied to the lower extremity, frequently demonstrate the fracture morphology more clearly. These studies can be performed in the emergency department or operating room. In patients with intracondylar involvement, 45° oblique radiographs also help delineate the extent of the injury, especially if comminution or additional tibial plateau injuries are present. Stress radiographs to identify ligamentous disruptions of the knee or associated tibial plateau fractures are not usually indicated until the distal femoral injury is stabilized. If in doubt about intra-articular involvement, computed tomography (CT) scans help in planning the surgical approach, especially in minimally invasive techniques. CT scans may also be useful for isolated chondral or osteochondral lesions or for the identification of impression zones.

As with all orthopaedic injuries, it is necessary to rule out additional injuries to the joint above and the joint

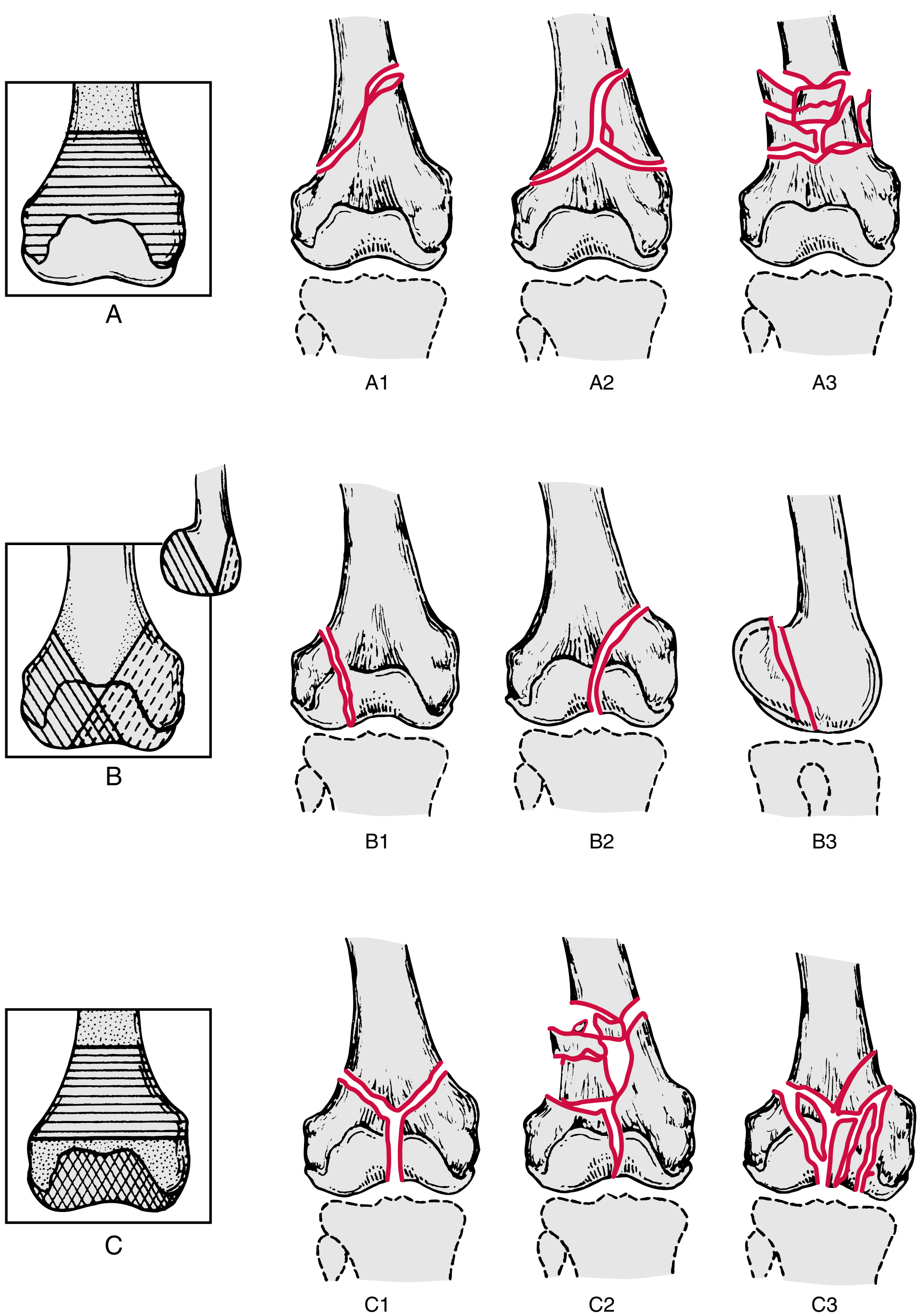

FIGURE 53–3. The Müller classification.

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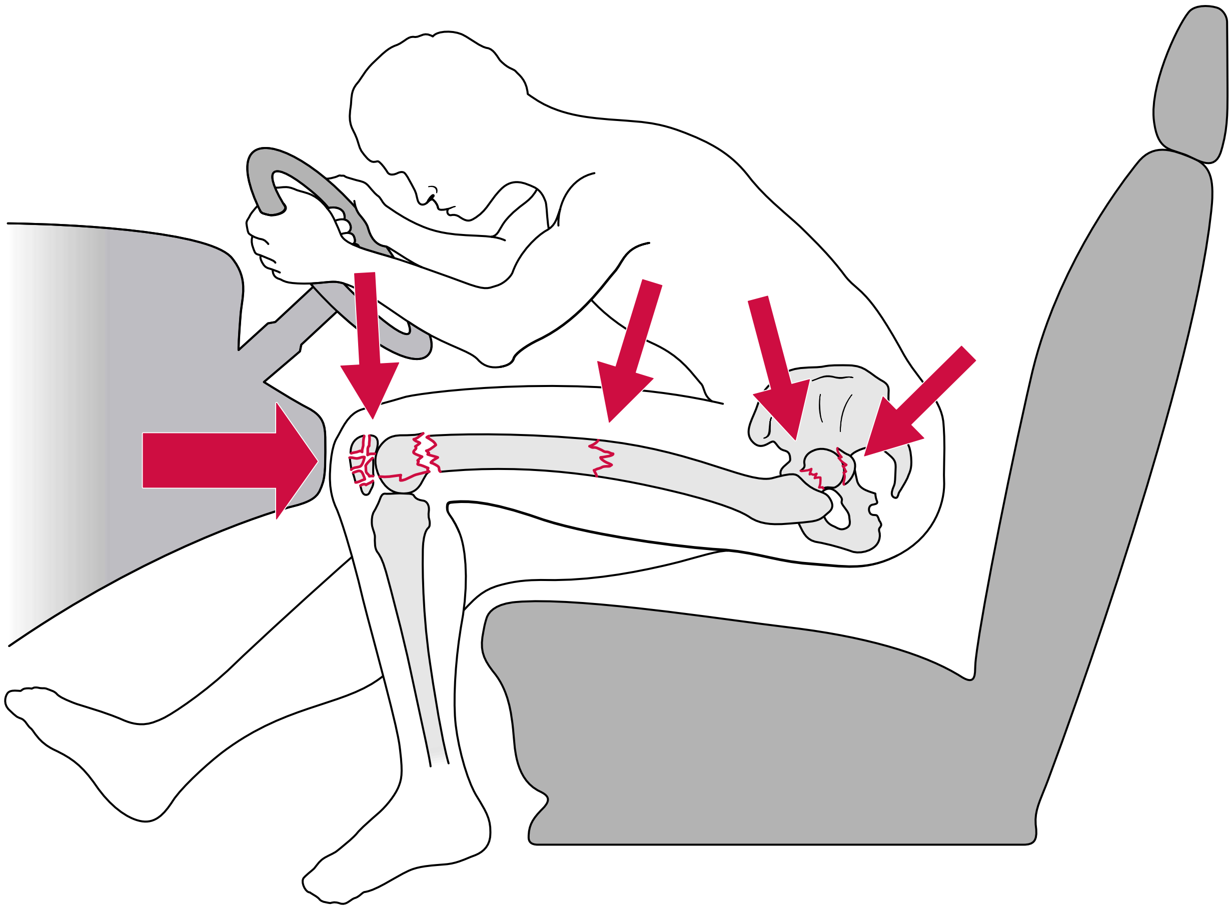

FIGURE 53–4. Transmission of energy results in typical concomitant injury patterns.

below because of a significant incidence of ipsilateral fractures of the femur (shaft, neck), patella, and acetabulum, especially after high-energy vehicular trauma (Fig. 53–4). An adequate AP view of the pelvis and AP and lateral views of the hip and whole femur are indicated for all these fractures.

Unless a frank dislocation of the knee joint is associated with the distal femoral fracture, radiographic evaluation of the knee joint has not proved to be as reliable as a careful examination in assessing the extent of ligamentous and soft tissue injury. If such lesions are clinically suspected, magnetic resonance imaging may be effective preoperatively to confirm injuries to the knee joint ligamentous or meniscal tissue.

Comparison radiographs of the normal or uninvolved opposite extremity help the surgeon with preoperative planning. Radiographs should include an AP view of the whole femur to determine valgus alignment and AP and lateral views of the distal end of the femur to allow superimposition of the fracture fragments on the normal template (see the section on preoperative planning).

Unless a thorough vascular examination (pulses, Doppler pulse pressure, sensation, and motor strength) is normal and unless frequent, skillful repeat examinations are feasible, arteriography is indicated in patients with an associated frank dislocation of the knee joint because of the 40% incidence of arterial injuries reported with knee dislocations.[32, 54, 79, 113] An absent or diminished pulse (determined clinically or by Doppler pressure measurement) compared with that of the normal lower extremity is also an indication for immediate arteriography or vascular exploration if the limb is frankly ischemic. Arteriography is contraindicated if it will delay surgical treatment of limb-threatening ischemia.

MANAGEMENT

Objectives

It is essential to appreciate the following goals of operative management of periarticular fractures: (1) anatomic reconstitution of the articular surface; (2) reduction of the metaphyseal component of the fracture to the diaphysis and restoration of normal axial alignment, length, and rotation; (3) stable internal fixation; (4) undisturbed fracture healing; and (5) early motion and functional rehabilitation of the limb.

Conservative and Operative Treatment

Previously, the treatment of choice for management of femoral fractures, including supracondylar fractures, was traction and subsequent mobilization in cast braces. The traction technique used was either a single pin in the proximal end of the tibia[56, 73, 115] or a two-pin system with an additional pin through the supracondylar fragment.[34, 82, 127]

Neer and associates[89] in 1967 reported on 110 supracondylar fractures treated at New York Orthopaedic Hospital over a 24-year period. They proposed a three-part classification system as well as a rating system for evaluation based on a functional and anatomic assessment. Ninety percent of those treated by closed methods had satisfactory results versus only 52% of those treated by open procedures. However, they considered patients to be "satisfied" in this rating system as long as they had strong extensor power and could flex the knee 70°! These criteria are no longer acceptable. In their summary, Neer and associates stated that "no category of fracture at this level seemed well suited for internal fixation, and sufficient fixation to eliminate the need for external support or to shorten convalescence was rarely attained." In fact, almost all their surgically treated patients had prolonged postoperative immobilization because of the inadequacy of the fixation techniques used at that time. In conclusion, these authors believed that operative intervention should be limited to débridement of open fractures or internal fixation of a fracture with an associated problem such as an arterial injury.

Such papers definitely prejudiced the North American orthopaedic community against internal fixation during the 1960s and 1970s. As a result, more advanced techniques of closed treatment were proposed in the early 1970s by Connolly and Dehne[16] and by Mooney.[84] To shorten traction time and allow earlier ambulation and knee motion, they recommended the use of early cast bracing for femoral shaft and supracondylar fractures.

In 1958 the Swiss AO Group was formed, thus commencing a new era in fracture care. Their desire was to restore full function to the limb and the patient and to avoid the so-called fracture disease associated with prolonged immobilization.[86] They recommended the principles of anatomic reduction of the fracture fragments, preservation of the blood supply, stable internal fixation, and early, active, pain-free mobilization. It was not until 1970 that the AO published its first results on the treatment of supracondylar femoral fractures according to these principles. Wenzl and colleagues[126] reported on 112 patients, 73.5% of whom had good or excellent results. For open reduction, these results were far superior to the 52% satisfactory results reported by Neer and associates, even though the criteria used by Wenzl and colleagues were much more stringent.

Schatzker and co-workers[102] reported on 71 distal femoral fractures, 32 of which were treated by open reduction and internal fixation (ORIF). They were able to achieve good or excellent results in 75% of fractures treated with the AO method as compared with only 32% in the conservatively treated group. They concluded that "if normal function or near normal function is to be achieved, . . . then unquestionably, if correctly employed, open reduction internal fixation ensures a very high rate of success." However, they did emphasize that ORIF is not appropriate for all patients. For fractures that are not displaced or are easily reduced, especially in elderly persons, immediate mobilization in weight-bearing functional braces is the treatment of choice. They also cautioned against internal fixation in severely osteoporotic patients. In 1979, Schatzker and Lambert reviewed an additional 35 patients with supracondylar distal femoral fractures treated by ORIF; only 49% had good or excellent results.[103] When they analyzed the 17 cases treated in accordance with the principles of rigid internal fixation as promoted by the AO Group, 71% had good to excellent results. Among the 18 patients treated with AO implants but not AO technique, only 21% had a good to excellent outcome. Critical review of these 18 patients revealed that most were elderly with severely comminuted fractures; however, surgical technical error was the common denominator contributing to the poor results. The most common errors included (1) incomplete reduction, (2) failure to achieve interfragmentary compression with lag screws, (3) failure to use autogenous cancellous bone graft to fill defects or comminution, (4) ineffective use of acrylic cement to supplement screw fixation in osteoporotic bone, and (5) use of blade plates that were either too long or too far from the joint.

Schatzker and co-workers recommended that elderly patients with thin, osteoporotic bone and comminuted fractures "are better treated by such methods as closed reduction and early cast bracing, than an attempt at operative reduction."[102] In such patients, the only clear indication for ORIF is an intra-articular fracture in which adequate joint congruity cannot be restored by manipulation. In conclusion, these authors stated:

> *"Rigid fixation is difficult to achieve with osteoporotic bone because of the degree of comminution and the poor holding power of the bone. The mere use of the appropriate implant does not assure rigid fixation. Failure to meticulously observe all the details of the method of rigid fixation resulted in a high complication rate with failures. These factors must be considered in evaluating criteria for surgical treatment."*

Slatis and associates[114] in 1971 reported on 21 "severe" fractures of the lower end of the femur that were treated by open reduction according to the AO method. Among the 16 patients available for follow-up longer than 1 year, 83% had good to excellent results. These authors recommended the technique as "reliable" but stated that it "should be restricted to fractures of considerable severity and to selected cases among patients with multiple injuries." Olerud,[91] in 1972, reviewed 15 patients with complex articular fractures of the distal end of the femur. He reported 92% good to excellent results with use of the angled blade plate but concluded that satisfactory osteosynthesis of fractures of this type is a difficult procedure and should not be attempted without experience with the technique.

In 1974, Chiron and Casey[13] reviewed 137 patients with distal femoral fractures who underwent stable internal fixation with the 95° condylar blade plate (CBP). Seventy-two percent of patients fulfilled their criteria for good to excellent results (i.e., 135° of motion and only mild swelling on prolonged weight bearing). In 1982, Mize and colleagues[81] reported on 30 supracondylar and intracondylar fractures of the femur that were reduced and stabilized with the AO technique. They reported good to excellent results in 80% of patients and also recommended the use of an extensile surgical exposure with elevation of the tibial tuberosity to facilitate exposure of the condyles in more complex fractures with intra-articular comminution. Healy and Brooker[36] in 1983 reviewed 98 distal femoral fractures to compare open and closed treatment methods; 38 of the 47 fractures treated by open methods but only 18 of 51 treated by closed methods had good functional results. Of significance in this review was that age, with an increasing degree of osteoporosis, did not adversely affect the operative results. The authors concluded that fractures of the distal part of the femur, except in more simple cases, are best managed by open methods.

From all recent reports, it would appear that better functional results can be obtained with ORIF in all but the most simple fracture types.[107] However, the superior outcome seems to depend on the use of improved fixation devices, meticulous surgical technique, and adherence to principles of the AO Group: anatomic reduction, stable internal fixation, preservation of tissue vascularity, and early mobilization.

Although AO techniques initially relied on plates and screws, intramedullary (IM) nailing has also found an important and enlarging role in the treatment of distal femoral fractures, particularly extra-articular type A and, increasingly, total articular (type C) injuries. Given the appropriate fracture patterns, Leung and co-workers[71] and Butler and associates[10] demonstrated that antegrade interlocking IM nailing is an acceptable treatment of supracondylar and intercondylar femoral fractures. Leung and co-workers included in their study only fractures 9 cm or less from the knee and found the technique of antegrade femoral nailing applicable to ASIF (Association for the Study of Internal Fixation) type A fractures and to selected type C (C1 and C2) fractures. Variables that determined the applicability of distal femoral fractures for closed nailing were the pattern and reducibility of the intercondylar fracture and the extent of metaphyseal and condylar comminution. The condylar fragment had to be reducible by closed traction and manipulation, and it had to be sufficiently large to permit stable fixation with supplementary percutaneously inserted lag screws placed under fluoroscopic guidance. The authors found that type B and type C3 fractures were not amenable to this form of treatment. Given these limitations, they had 95% good to excellent results, and normal healing was achieved in all but 1 of their 37 cases.[71] Butler and associates used a similar method to specifically treat ipsilateral femoral shaft and supracondylar-intercondylar distal femoral fractures. Fractures of the femoral condyle in the coronal plane (type B3) and type C3 injuries were relative contraindications to this technique. In their series, no patients had loss of fixation or alignment or implant failure. The authors warned, however, that the rigidity of fixation of distal femoral fractures achieved with interlocking nails must be regarded with caution, and weight bearing must be restricted.[10] The advantage of treating ipsilateral femoral shaft and supracondylar femoral fractures with this method of antegrade interlocking femoral nailing is the ability to treat both fractures with one device.[8]

Several recent series have investigated the treatment of supracondylar-intercondylar distal femoral fractures with the GSH supracondylar IM nail (Smith and Nephew, Richards, Memphis, TN). Henry and associates reported in 1991 that "by virtue of the intramedullary position, the GSH nail has a biomechanical advantage over the laterally placed conventional devices. The intramedullary position decreases the lever arm, reducing varus/valgus angulation."[39] In 1995, Firoozbakhsh and colleagues[28] mechanically tested the retrograde IM nail and the 95° angled screw and side plate in composite bone with an intercondylar split and a medial segmental shaft defect. They found that the bending stiffness of both constructs was not significantly different in varus compression and in flexion. The plate-and-screw device was three times stiffer in lateral bending and 1.6 times stiffer with torsion than the retrograde supracondylar nail. Clinically, medial comminution or a defect with varus collapse is the most common cause of failure of implant fixation in a supracondylar femoral fracture. The authors concluded that the supracondylar nail has biomechanical rigidity comparable to that of the screw and side plate with varus loading, thus making it a reasonable alternative to plate fixation for the treatment of these fractures.

Lucas and co-workers[72] in 1993 reported follow-up on 25 AO type A and type C distal femoral fractures treated with the GSH nail. All the fractures healed, but 4 of the 19 type C fractures eventually required a bone graft. Danziger and associates[18] in 1995 found similar success with the GSH nail: 15 of 16 patients with supracondylar-intercondylar distal femoral fractures had union with good to excellent results. They also found that postoperative alignment was maintained in this group.

Not all investigators have had similar success with the GSH nail, however. Iannacone and colleagues[45] in 1994 reported on 41 complex distal femoral fractures treated with the GSH nail; they had 4 nonunions, 5 delayed unions (2 of which required revision of the fixation), and 4 fatigue fractures. The authors stated that fatigue fractures occurred only with the 11- and 12-mm nails and 6.4-mm interlocking screws. They had no nail failures when the rod system was modified to use 12- and 13-mm-diameter nails with 5.0-mm interlocking screws. Aside from the theoretical biomechanical advantage of this IM locked nail over plating techniques, both Lucas and co-workers[72] and Danziger and associates[18] reported that treatment of complex distal femoral fractures with this system was also associated with decreased blood loss, operative time, and periosteal stripping and allowed the IM reaming debris to be used as bone graft. In addition, use of the median parapatellar approach for surgical exposure and nail insertion permitted direct visualization of the articular surface, thus facilitating anatomic reduction.

Giles and associates[30] reported in 1982 on the use of a supracondylar lag screw and side plate for fixation of 26 supracondylar-intercondylar fractures of the distal end of the femur. They stated that "the advantages of this device over others are that the lag screw supplies not only interfragmentary compression across the intracondylar fractured surfaces, but also better purchase in osteopenic bone," thereby allowing earlier aggressive restoration of knee motion and muscle power. In their series, they did not have any nonunions or infections, and the average postoperative range of motion was 120°, which compares very favorably with other reported series of similar fractures. These authors concluded that "meticulous open reduction and stable internal fixation of supracondylar fractures with supracondylar plate and lag screw, combined with autogenous bone grafting in patients with severe comminution, provide an excellent opportunity to secure bone union and restore limb alignment, joint congruity and range of motion." Similar excellent results with the use of this device have been reported by Hall,[33] Pritchett,[94] Regazzoni and colleagues,[95] Sanders and associates,[99] and Shewring and Meggitt.[110]

Brown and D'Arcy[7] reported on the use of a nail plate with an additional adapted medial compression plate to provide stable fixation on both sides of the femoral condyles. They recommended this technique to obtain better fixation in elderly, osteoporotic patients; in their series, all but one patient obtained knee flexion better than 55°, and the average time to walking was only 4 weeks.

The use of bone cement as an adjunct to stable internal fixation for supracondylar fractures in osteoporotic femurs was advocated by Benum in 1977.[3] He reviewed 14 patients with an average age of 75 years. Eighty-six percent (12 patients) healed uneventfully despite early mobilization. The two failures were the result of technical error in application of the plate and not loosening of the screw from the bone cement. Although all fractures in this study were extra-articular, Struhl and colleagues[117] in 1990 reviewed 17 supracondylar femoral fractures in osteoporotic patients, 8 of which were of the T-intercondylar type. Using a modification of Benum's bone cement technique, they achieved bony union in all cases and overall 79% satisfactory to excellent results. They concluded that the use of bone cement for adjunctive fixation was effective in restoring patient and joint mobility while avoiding the complication of implant failure in osteoporotic patients.

Sanders and co-workers[100] reported on the use of double-plate fixation for complicated, comminuted, intra-articular fractures of the distal part of the femur; union was obtained in all patients.

Assessment for Surgery

In assessing any patient for surgery, it is important to evaluate not only the "personality" of the fracture but also the personality of the patient.

Patient factors to consider in deciding between operative and nonoperative treatment must include age, activity level, medical condition, hemodynamic status, the presence of infection, the presence of implants, ipsilateral or contralateral injuries, the cause of the injury (high- or low-velocity trauma), and the personality of the distal femoral fracture itself. However, deciding that both the patient and the fracture are candidates for surgery is not sufficient. It is important that potential surgeons honestly assess their own expertise in the management of these difficult problems, including a clear understanding of the pathomechanics and morphology of the fracture, and have the necessary practical experience, equipment, and knowledgeable operating personnel and assistants.

Schatzker and Lambert[103] showed that the mere use of an optimal implant alone is not sufficient to guarantee a good result with these difficult fractures. If the preceding objectives cannot be achieved by surgical intervention, either because of the complexity of the fracture or because of the lack of equipment or skill of the surgical team, conservative treatment is preferable to the complications of poor surgery followed by prolonged immobilization.

Indications for Surgery

DISPLACED INTRA-ARTICULAR FRACTURES

In displaced intra-articular fractures, joint congruity cannot be restored by closed methods. These fractures include unicondylar and bicondylar fractures.

Unicondylar Fractures (Type B). Because of the pull of the gastrocnemius muscle, most unicondylar fractures are displaced by posterior rotation of the condyle relative to the knee joint axis. As a result, joint incongruity occurs, and anatomic reduction is mandatory to prevent long-term axial malalignment and post-traumatic arthritis. These fractures almost always require open reduction to achieve anatomic reconstitution. Of particular importance is a B3 or coronal fracture (the so-called Hoffa fracture), in which the only soft tissue attachment is the posterior capsule. Such a fracture behaves like a large loose fragment in the joint. Traction and closed means do not reduce this fracture. Internal fixation is required to maintain stability, and surgical intervention is thus necessary. Impression zones are often present, and the shape of the condylar fragments makes judgment of anatomic reduction difficult. Recently, a significant frequency of bicondylar involvement with coronal-plane type B distal femoral fractures has been recognized. A CT scan is helpful to clarify this pathology.

Bicondylar Fractures (Type C). The predominant deforming force on the condyles is the gastrocnemius muscle, whose medial and lateral origins cause posterior angulation and rotation. This deformity is compounded by shortening and anterior displacement of the shaft by unrestrained pull of the quadriceps and hamstring muscles. Traction, if applied early, usually corrects the shortening but rarely affects the rotational displacement of the condyles in relation to each other. If joint congruity cannot be restored by closed means, surgery is required to gain anatomic reduction of the articular surface.

OPEN FRACTURES

All open fractures require aggressive surgical débridement. Most would agree that joint congruity should be restored immediately, which can be accomplished in most cases by limited internal fixation of the condyles. Whether stable internal fixation of the condyles to the shaft should be performed primarily, however, is still questioned by some surgeons. Experimental and clinical evidence suggests that the rate of sepsis can be decreased by stabilizing the bony skeleton and hence the surrounding soft tissues.[75] Experience and clinical judgment are required because each of these fractures must be individually evaluated by assessing the whole patient, any associated injuries, the energy and type of fracture involved, the degree of contamination of the soft tissue injury, the adequacy of débridement, and the ability of the surgery to stabilize the bony skeleton without further devascularization of the already compromised bone and soft tissue.

In grade I and most grade II soft tissue injuries, after adequate débridement of all contaminated and devitalized bone and soft tissue, stabilization of the reduced condyles to the shaft can be performed in standard fashion. However, it is essential to leave the injury wound open and return the patient to the operating room within 48 hours for reassessment and repeat débridement until the soft tissues can be safely closed. The most difficult problems are grade III fractures, which are often associated with high-energy bone and soft tissue injury and significant contamination. Absolute and aggressive débridement of all contaminated and devitalized soft tissue and bone is mandatory. Copious irrigation should be performed with 9 to 12 L of irrigating solution, followed by repair of the articular condyles with minimal internal fixation. At this stage, the treating surgeon has two options: (1) stable internal fixation of the condyles to the shaft or (2) stabilization of the bony skeleton and soft tissues by the application of an external fixator across the knee joint (probably the safer option). The latter choice allows immediate stabilization of bone and soft tissue and permits adequate access for débridement and care of the wounds. Eventual control of the soft tissues is obtained by either delayed primary closure of the wound or tissue transfer for wound coverage. Once adequate soft tissue control has been achieved, delayed internal fixation with reattachment of the condyles to the shaft can be performed.

ASSOCIATED VASCULAR COMPROMISE

Injury to the superficial femoral artery in the adductor canal or to the popliteal artery in the popliteal fossa associated with a distal femoral fracture is a limb-threatening emergency. If reinstitution of blood flow to the distal end of the extremity is not accomplished within 6 hours of injury, the chance for successful limb salvage decreases exponentially with greater delay. The timing of vascular repair in relation to stable fixation of the fracture is critical. Optimally, the wound should be débrided, if open, and rapid but stable skeletal fixation should be performed before the vascular repair. If the vascular repair is done before bony stabilization is accomplished, length is hard to determine and manipulation may disrupt the repair. If débridement and skeletal stabilization require a delay of more than 6 hours after injury, Johansen and colleagues[50] recommended the use of a temporary arterial shunt to restore flow. They reported an average time of only 35 minutes to shunt and restore arterial blood flow to an ischemic limb. This technique allows sufficient time for adequate débridement and skeletal stabilization without compromising salvage of the extremity.

IPSILATERAL FRACTURES OF THE TIBIAL SHAFT

An ipsilateral fracture of the tibia associated with a femoral fracture is a well-described injury complex: the floating knee. The best method of restoring knee motion and function in these severe injuries is by surgical fixation of both sides of the knee joint. Such fixation may be done definitively in the initial procedure (often by intramedullary fixation of both fractures with a retrograde femoral and an antegrade tibial nail through the same anterior knee incision). However, patients with this injury complex are frequently severely injured, so complex extremity surgery should be deferred. Depending on the patient's condition, both the distal femoral and tibial fracture sites may be temporarily spanned by external fixation ("orthopaedic damage control surgery"). Alternatively, definitive fixation might be carried out for one bone while the other is externally fixed, or otherwise immobilized, and definitive repair deferred until after the acute period.

IPSILATERAL FRACTURES OF THE TIBIAL PLATEAU

Ipsilateral fractures of the tibial plateau in association with a distal femoral fracture should be addressed like any complex intra-articular fracture (i.e., anatomic reduction of the articular surface, stable internal fixation, and early functional mobilization).

BILATERAL FEMORAL FRACTURES

Patients with bilateral femoral fractures do not tolerate traction well. Nursing care is extremely difficult, and functional rehabilitation is decidedly impaired. As a result, ORIF is indicated to allow patient mobilization, as well as for reasons enumerated later. If the patient is not a candidate for immediate internal fixation, temporary external fixation is a very good alternative because these patients are usually severely injured and need adequate fracture immobilization even if definitive repair must be delayed.

POLYTRAUMATIZED PATIENTS

A severely injured patient with multisystem involvement and an associated femoral fracture has a significant risk of mortality and prolonged morbidity. Bone[6] demonstrated the value of femoral shaft fixation within the first 24 hours. The incidence of multisystem organ failure and adult respiratory distress syndrome, the number of respirator and intensive care unit days, and the incidence of sepsis were all decreased by immediate stabilization of the femoral shaft fracture. Conversely, traction and prolonged bedrest in patients with high Injury Severity Scores and multisystem trauma had a significant detrimental effect on mortality rate and long-term morbidity. In a polytraumatized patient, the same indications for early stabilization of femoral shaft fractures and patient mobilization also apply to distal femoral fractures.

Patients with distal femoral fractures and associated head injuries represent a group of the polytrauma patient population with complex management issues. Impaired consciousness, often with associated spasticity, makes reduction difficult to maintain by traction or closed means. In addition, avoidance of skin breakdown and joint contractures is particularly difficult. Early ORIF facilitates nursing care and allows easier maintenance of skeletal alignment.

Patients with significant burns in addition to their femoral fractures require skilled nursing, frequent immersion in tubs, and multiple dressing changes. Treatment by closed methods and traction severely compromises the management of burns that are potentially life-threatening. Operative stabilization before burn colonization is the treatment of choice.

PATHOLOGIC FRACTURES

In pathologic fractures, especially with bone loss, healing cannot be expected to occur with treatment by closed means and prolonged immobilization. Surgical options depend not only on the type of tumor (primary or metastatic) but also on many patient factors, including medical status, life expectancy, and functional demands. Decision making must be individualized. ORIF of pathologic distal femoral fractures is technically demanding and often requires multiple forms of internal fixation and additional stabilization with methyl methacrylate. Healy and Lane[35] in 1990 reviewed 14 patients with pathologic supracondylar fractures treated by Zickel nailing and augmented with bone cement. In 11 of the 14 patients, their goals of pain relief and functional restoration were achieved. They concluded that intramedullary fracture fixation was the method of choice in treating pathologic fractures of the distal end of the femur because of the presence of bone defects and the rarity of bone healing. However, the authors cautioned that in patients with massive bone destruction of the femoral condyles, an IM device is not indicated; in such cases, they recommended distal femoral knee arthroplasty.

ASSOCIATED LIGAMENTOUS DISRUPTION OF THE KNEE JOINT

Distal femoral fractures with associated knee ligament disruption require a stable distal femoral platform, not only for repair or augmentation of ligaments but also to allow functional aftercare and rehabilitation. This goal can be accomplished only by initial ORIF of the distal femoral fracture.

EXTRA-ARTICULAR FRACTURES IN WHICH REDUCTION CANNOT BE OBTAINED OR MAINTAINED

Supracondylar extra-articular fractures that are displaced or markedly comminuted and in which axial alignment length or rotation cannot be restored or maintained by closed means require surgical reduction and fixation.

RELATIVE INDICATIONS

Patients in whom axial alignment, rotation, and length can be obtained or maintained by closed means are considered relative candidates for operative stabilization if they prefer to avoid the prolonged immobilization associated with closed treatment methods. However, the patient must be made aware of the risks and benefits of all treatment options.

Recent reports also indicate that elderly patients are candidates for operative intervention in the management of distal femoral fractures.[11, 36, 90, 95, 99, 100, 103, 108, 132] However, the decision regarding operative versus closed treatment must be based on the personality of both the patient and the fracture, as discussed previously. Stable fixation can often be obtained, especially if the surgeon is skilled in all available techniques in the armamentarium, including the use of newer implants and methyl methacrylate. Careful assessment of the degree of osteopenia and the amount of comminution is necessary to avoid operative intervention that is inadequate and necessitates prolonged traction or immobilization postoperatively. However, if stable fixation is achieved, the adverse effects of prolonged immobilization, especially in the elderly, can be avoided.

ORTHOPAEDIC DAMAGE CONTROL—STAGED STABILIZATION

"Orthopaedic damage control" refers to provisional skeletal fixation when immediate definitive surgery is contraindicated. The high force required to produce a distal femoral fracture contributes to a high incidence of local and distant associated injuries. In polytraumatized patients, treatment planning must be guided first by the patient's overall clinical status. Orthopaedic "tunnel vision" must be avoided. Consultation with the general surgery team leader is necessary to ensure optimal care of not only the orthopaedic injury but also the patient as a whole. If the patient is hemodynamically labile, acidotic, hypothermic, hypoxic, coagulopathic, or septic or has severely contaminated soft tissues that cannot be débrided or are inadequately débrided, definitive surgical stabilization of the orthopaedic injury is contraindicated until these problems can be resolved. Instead, temporary stabilization with bridging external fixation should be performed. In undisplaced fractures, temporary treatment with a cast is an option. Only patients in a metabolically stable condition should have definitive osteosynthesis in the primary period after admission.

Especially in elderly patients, medical conditions in which the anesthetic and operative risks are potentially life-threatening (e.g., associated myocardial infarction) are obvious contraindications to surgical intervention for return of function to a limb.

Massive comminution of the fracture or very severe osteopenia (e.g., paralyzed limb) should not be considered contraindications but should be addressed by careful selection of the method of treatment and aftertreatment.

It is mandatory that surgeons evaluate the complexity of the injury and make an honest appraisal of their experience, the ability of the team to deal with such technically demanding fractures, and the facilities available. If any of these factors is found to be lacking, the patient is best served by closed treatment or referral.

Principles of Surgical Treatment

Principles of surgical treatment include the following:

1. Careful handling of soft tissues and careful planning of the surgical approach

2. Direct and anatomic reduction of the articular surface
3. Treatment of multifragmentary metaphyseal fractures by indirect reduction techniques to preserve as much of the vascular supply to the fracture fragments as possible
4. Restoration of limb axial alignment, rotation, and length
5. Stable internal fixation
6. Early and active functional rehabilitation of the patient and the limb

PREOPERATIVE PLANNING

Preoperative planning is essential to help the surgeon anticipate the potential problems associated with operative fixation of all fractures, especially the more complex periarticular fractures. It also allows the surgeon to consider the extent of the definitive surgical fixation procedure and to determine the optimal timing for the procedure (discussed further later). Our suggested planning technique is relatively simple and can usually be accomplished within 10 minutes. Tracings of the uninvolved or opposite femur are made on tracing paper in both the AP and the lateral planes. These tracings are then turned over to form templates for the involved extremity. Tracings are made of all the fracture fragments on the involved side, in both the AP and lateral planes. These fragments are individually reduced and drawn in different colors on the tracing of the normal femur to demonstrate the amount of comminution and whether bone defects are present. However, this planning does not reflect the three-dimensional properties of the broken bone, and this technique therefore does not always give satisfying results.

At this stage, the planned internal fixation can be drawn from transparent templates that can be obtained from Synthes, USA (Paoli, PA). With use of the templates, one can determine the need for and position of temporary fixation with K-wires, the optimal locations and angles for lag screws, the types and sizes of any plates required, the angles of the screws in the plates (to avoid fracture lines on the opposite side), the need for bone graft based on comminution or the size of the defect, and the need for adjunctive fixation (e.g., methyl methacrylate). On the final drawing showing the reduction of the fracture lines and the composite fixation, a surgical tactic that lists the steps of the procedure should also be developed.

The advantages of careful preoperative planning cannot be sufficiently stressed. It allows the surgeon to study the fracture more carefully and understand its particular morphology and what will be required to achieve reduction. It ensures that all equipment and implants required for the procedure are available in the operating room, thereby avoiding possible compromise of the fixation. It decreases the delays imposed by intraoperative indecision and waiting for instruments and implants (which often prolongs open wound time) and therefore decreases the infection rate. By comparing the postoperative result with the preoperative plan, the surgeon has a readily available method to assess results and to help with quality control.

Preoperative Planning in the Presence of Preexisting Deformity

In normally aligned knees, 95° implants such as the 95° CBP and the dynamic condylar screw (DCS) are planned for insertion parallel to the distal femoral joint line (Fig. 53–5). In the presence of shaft deformities or a malaligned distal femoral joint line, implant placement parallel to the joint line will lead to malalignment in either varus or valgus or require bending of the plate component (Fig. 53–6). The problem can be solved by separate radiographs of the femur and tibia, including the hip, knee, and ankle joints. These radiographs are transferred to transparent paper: the tibia with the ankle and knee joint (paper 1) and the femoral condyles with the proximal end of the tibia (paper 2). The proximal end of the femur with the shaft and hip joint is transferred to a third paper (paper 3). Papers 1 and 2 are then put together in a way that shows the contours of the proximal end of the tibia of both radiographs to be congruent. Onto these two papers, paper 3 is added in a way that shows the mechanical axis (a line through the center of the femoral head and through the center of the talus) in the middle of the knee joint. The 95° template is now aligned to the lateral side of the drawing of the femoral shaft and taped in that position. If shaft deformities or a malaligned distal femoral joint line (or both) are present, the implant will not be parallel to the distal femoral joint line despite the fact that the mechanical axis is in the middle of the knee joint. This angle between the intraosseous implant and the joint line should be measured and considered when placing the chisel (95° CBP) or guide wire (DCS) (see Fig. 53–6).

TIMING OF SURGERY

Distal femoral fractures, particularly if caused by high-energy forces, are often associated with multiple injuries, systemic decompensation, severe local soft tissue contusions, or any combination of these problems. In elderly, osteoporotic patients with isolated, low-energy injuries, fracture fixation may be challenging, and the patient's underlying medical status may include conditions that should be corrected to reduce the risk of surgery. In either case, definitive surgery should be postponed until it is safest and has the best possible chance of success. It is not usually advisable to carry out definitive osteosynthesis acutely. Primary treatment should consist of closed reduction, wound débridement or fasciotomy (if necessary) only, and temporary transarticular external fixation.

The timing of surgery is dependent on the general condition of the patient, additional injuries, the condition of the soft tissues, and the neurovascular status of the limb. Additional important factors are the infrastructure of the hospital and the technical skills of the treating surgeon and surgical team. The extent of surgical intervention is also influenced by several factors: it may range from initial soft tissue débridement and temporary external fixation up to complete definitive osteosynthesis. No hard data have indicated that these fractures need immediate definitive fixation. The situation is similar to that for other intra-articular fractures such as acetabular fractures, proximal tibial fractures, tibial pilon fractures, or calcaneus

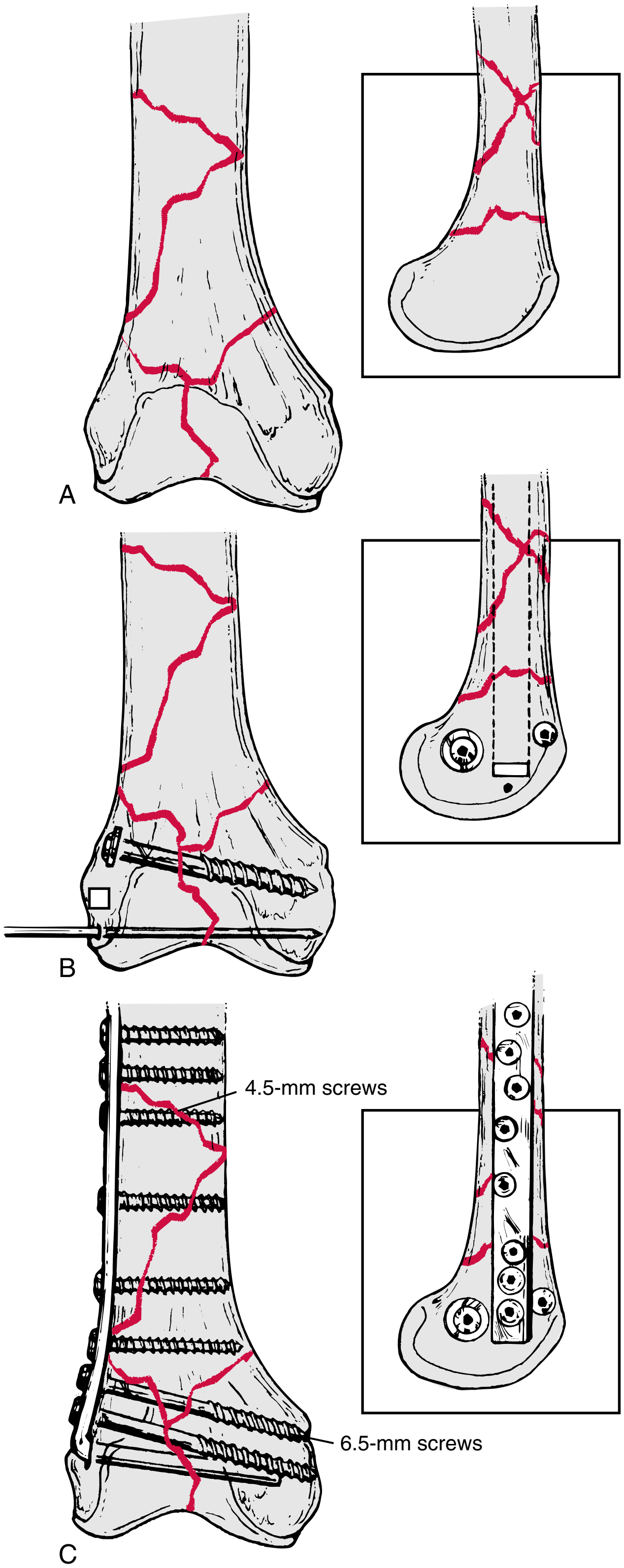

FIGURE 53–5. Preoperative planning. *A,* The fracture lines are reduced. *B,* Position for insertion of lag screws, summation K-wire, and the 95° angled condylar blade. *C,* Final plan with the fracture reduced and positioning and fixation of all hardware.

fractures, which are all difficult to treat. Temporary external fixation with later, well-prepared, and properly planned elective and definitive fixation by an experienced team is much more preferable. Definitive surgery should not be undertaken without adequate preoperative evaluation and the availability of all necessary resources. In certain situations, however, immediate emergency surgery is indicated; examples include open fractures and fractures with vascular impairment. For such injuries, discretion is necessary regarding fixation. Only completely stable patients in perfect circumstances should have definitive osteosynthesis in the primary period after admission. Unstable patients and those with questionable soft tissue should have delayed treatment. Their primary treatment should consist of closed reduction, wound débridement or fasciotomy (if necessary) only, and then temporary transarticular external fixation. Definitive ORIF, as well as complex soft tissue reconstruction, free flaps, or extensive bone grafting in large defects, is performed at the second operation after stabilization of the patient and soft tissue.

In the case of open fractures, discretion is necessary regarding the type of fixation indicated at the time of initial débridement.

Successful management of the soft tissue envelope is the key to avoiding the major complications associated with surgical intervention and internal fixation. Decision making regarding the timing of definitive internal fixation and optimal management of the soft tissue injury is one of the hardest aspects to learn. Surgeons must use their own experience and judgment, in consultation with others if necessary, to choose the best time for surgery. Delay of definitive stabilization for 3 weeks or longer makes the surgery much more difficult. The limb often remains malreduced and shortened, early callus forms, and the fracture lines lose their clear demarcation, especially in cancellous bone. These factors make exposure and reduction technically more demanding.

If surgery is to be delayed more than a few hours, the limb should be stabilized with an external fixator. If not possible, skeletal traction offers a less satisfactory alternative: traction is applied through a tibial pin inserted at least 10 cm inferior to the tibial tubercle to avoid the potential operative field. The patient is then placed in balanced suspension in a Thomas splint with a Pearson attachment flexed at approximately 20° (Fig. 53–7). The weight of the traction should be sufficient to correct length (usually between 15 and 30 lb). Such management stabilizes the fracture and greatly facilitates future manipulation of the fracture fragments at the time of surgical reduction so that indirect techniques with less exposure and soft tissue stripping can be used at the time of stable internal fixation.

CONSERVATIVE TREATMENT

Traction

Traction can be used for the treatment of Müller type A2 and A3 supracondylar femoral fractures as long as it is possible to restore limb axial alignment, rotation, and length. Commonly, such treatment involves skeletal traction with one pin placed 10 cm below the tibial tubercle and the leg maintained in a Thomas splint with a Pearson attachment at the level of the fracture and flexed about

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Presentation

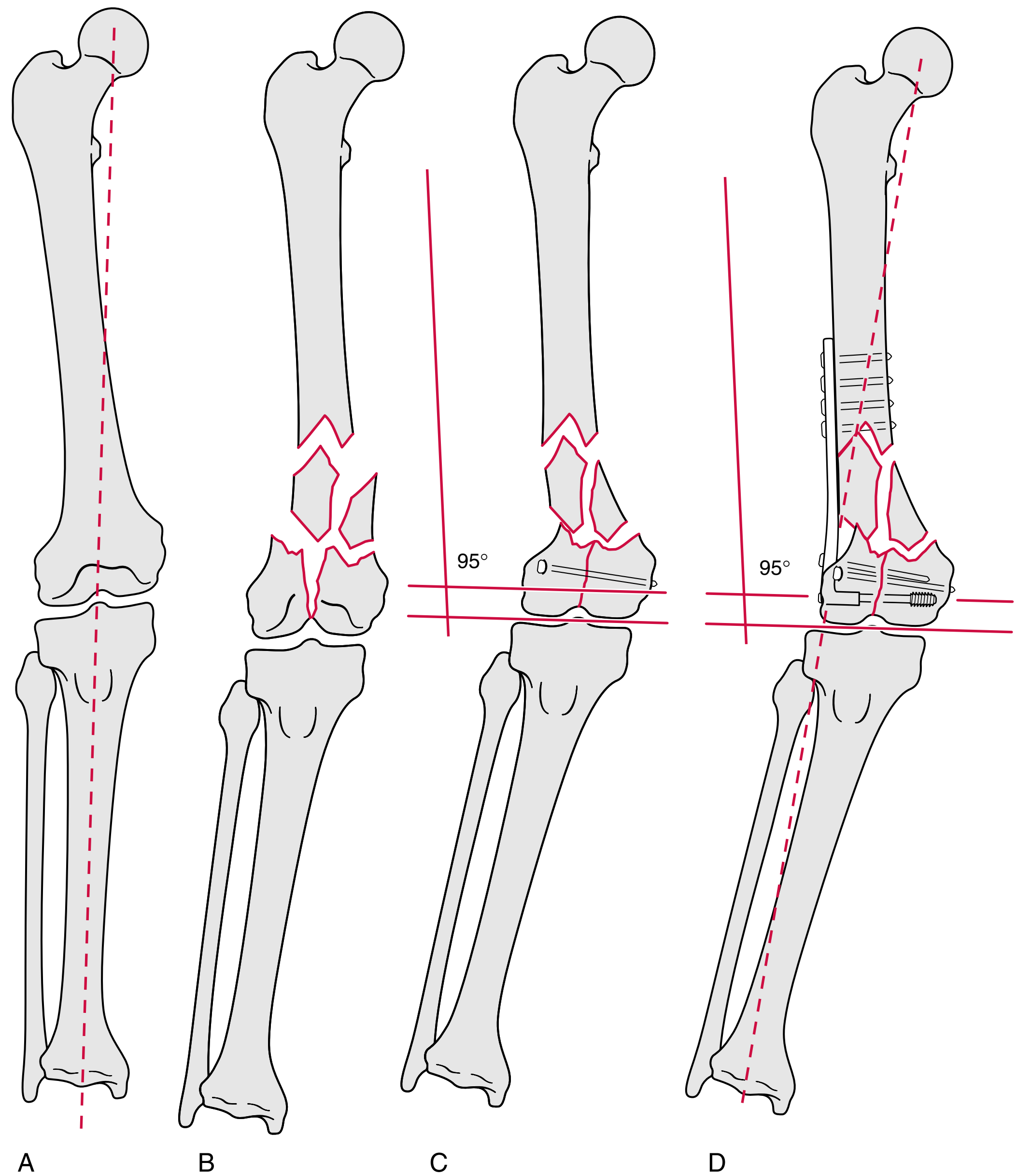

FIGURE 53–6. Preoperative planning (preexisting deformity). See text.

20°. The patient must remain bed bound with maintenance of traction for 2 to 12 weeks, depending on the fracture. Manipulation can be performed under anesthesia to obtain reduction if traction alone is not successful. In the present era of managed care, low-risk anesthesia, and better surgical implants and techniques, most surgeons would opt for surgical stabilization and early active mobilization. However, medical complications, the age and functional demands of the patient, and local factors such as excessive comminution or an inability to manage the soft tissues adequately may make the option of traction more favorable. Rarely, the use of two-pin traction, with the second pin through the femoral condyles, may provide better reduction.[115] However, this technique adds significant risk to traction treatment (i.e., the potential for vascular impairment from pin insertion and also intra-articular and fracture sepsis if a pin tract infection develops around the condylar pin).

Prolonged joint immobilization with traction results in intra-articular adhesions and fibrosis and scarring of the quadriceps musculature. Therefore, active flexion and extension of the knee, even in traction, must be encouraged as soon as pain tolerance allows. Excessive or prolonged traction is detrimental to functional rehabilitation of the patient and the extremity. Connolly,[15] Mooney,[84] and others[83, 97] have advocated the use of early cast bracing for the management of femoral and supracondylar fractures. In most cases, traction can be converted to cast brace treatment 3 to 8 weeks after fracture consolidation, but before radiographic evidence of significant callus.

Early Fracture Bracing or Cast Bracing

Impacted supracondylar fractures that do not have intracondylar extension can, in most cases, be reliably stabilized immediately in a knee immobilizer, which is replaced with a fracture brace or cast brace once the pain and swelling have decreased. Care must be taken to monitor progress until union occurs because the powerful muscles of the thigh can easily cause angulation or displacement. It may be wiser to start treatment with the patient in skeletal traction to allow the swelling and pain to decrease and the fracture to become "sticky" before the application of a cast or brace.

Delayed Cast Bracing

The main indication for cast bracing is at a subsequent stage of treatment. After the patient is treated by traction, traditionally for 6 to 12 weeks, and after sufficient signs of early healing have appeared, a cast brace is applied. Connolly,[15] Mooney,[84] and others have reported that earlier progression from traction to cast bracing (i.e., at 2 to 3 weeks) prevents the sequelae of prolonged traction immobilization and gives good results. Such management requires experience and not only an understanding of the pathomechanics of the fracture but also knowledge of the technique of successful cast brace application. Optimally, patients should be given a general anesthetic or an intravenous sedative. When the cast brace is being applied, the patient's knee should be extended with 20° of external rotation and slight valgus angulation of the leg. Knee extension counteracts the posterior displacement and angulation of the condyles. The external rotation and valgus force counteract the varus deformity commonly seen after prolonged traction. The stability of the cast brace is greatly enhanced by careful molding around the femoral condyles distally and by sufficient proximal control above the fracture site. A longer thigh and a more slender habitus improve the control provided by a long leg fracture brace. Modern fiberglass casting material has become as easy to mold as plaster and is significantly lighter.

OPERATIVE TREATMENT

Temporary External Fixation

An external fixator is used in the management of distal femoral fractures not to treat the bony injury but rather to treat the soft tissues and avoid shortening and gross malalignment. In patients with severe open wounds and in those who are septic or whose medical condition precludes definitive distal femoral fracture fixation, the use of a temporary external fixator across the knee joint allows for adequate access and management of the soft tissues. It also reduces pain and facilitates nursing care and patient mobilization.

Proximally, two 4.5-mm half pins are placed anteriorly (or laterally) in the femoral shaft. A connecting rod is clamped to them. Distally, two shorter 4.5-mm half pins are placed anteromedially in the tibial shaft. Care must be taken to ensure that the pins are sufficiently proximal and distal so that even if they become infected, they will not compromise later open fixation of the distal end of the femur. A similar rod joins the two tibial pins. A third connecting rod, attached with adjustable clamps, links the femoral and tibial rods and permits adjustment of limb alignment in all planes.

This simple fixator provides adequate temporary stabilization of the supracondylar component and the knee joint. However, articular condyle displacement is not reduced and stabilized with such a construct. In cases in which a long time interval between initial temporary and definitive fixation cannot be excluded, gross reduction of the femoral condyles and temporary fixation with two crossed K-wires prevents shortening of the gastrocnemius and makes definitive reduction much easier (Fig. 53–8).

If the condyles are readily exposed through an open fracture wound, they may be fixed immediately after

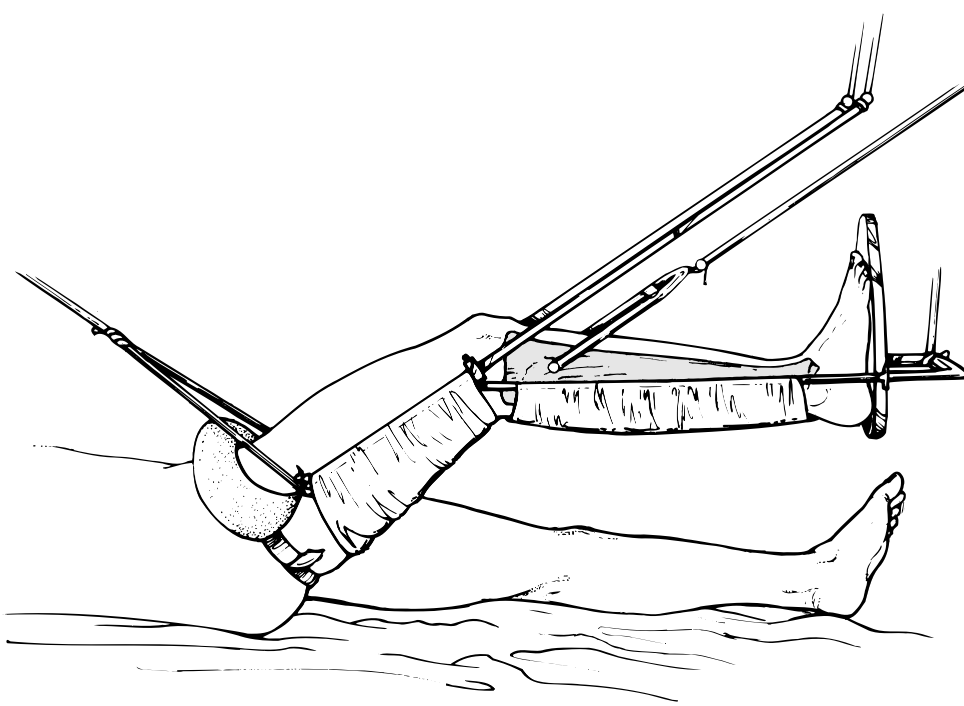

FIGURE 53–7. Single-pin proximal tibial skeletal traction.

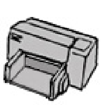

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FIGURE 53–8. Temporary external fixation and provisional K-wire fixation.

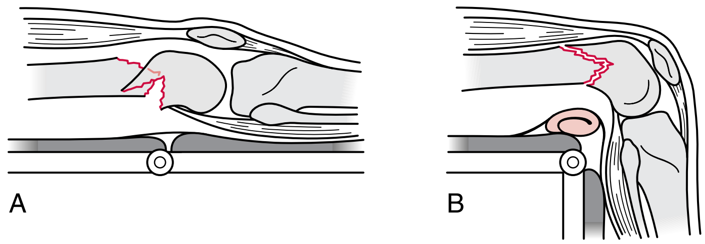

Figure 53–9. Positioning for distal femoral fractures. Patients are placed on a standard radiolucent table with the knee joint line of the injured knee slightly distal to the mechanical hinge of the table to reduce the pull from the gastrocnemius muscles. Gravity on the lower part of the leg results in gross rotational alignment. (From Krettek, C.; et al. Tech Orthop 14:247–256, 1999.)

adequate débridement, and the next step of fixing the condyles to the shaft can be delayed.

In the event of undisplaced C1 or C2 intra-articular fractures, percutaneous screw fixation secures the position until definitive fracture fixation. Later, exact anatomic reduction should be checked by CT because it has consequences for the approach when minimally invasive techniques are used: anatomic intra-articular reduction will allow a small lateral approach without joint exposure. A nonanatomic position will require joint reconstruction and therefore preferably a lateral parapatellar approach.

Screws for articular fixation should be placed in such a way that they will not interfere with future definitive internal fixation.

SURGICAL EXPOSURE

Positioning

The patient is placed supine on a fluoroscopy table, and a tourniquet is not usually applied to the proximal part of the thigh. If necessary, a sterile tourniquet may be used. The ipsilateral iliac crest and the whole lower extremity are prepared in sterile fashion, but the foot can remain unsterile and is draped in a boot-type bag (Fig. 53–9).

Conventional Lateral Approach

Many distal femoral fractures can be approached through a single lateral incision (Fig. 53–10). The incision is made directly laterally in the thigh and through the midpoint of the lateral condyle distally while staying anterior to the proximal insertion of the lateral collateral ligament.[44] Proximally, the incision is extended as necessary for diaphyseal involvement of the supracondylar fracture. The distal incision can be extended so that it gently curves from the knee joint axis anteriorly to the lateral border of the tibial tubercle when the fracture involves the articular condyles. The fascia lata is incised in line with the skin incision, and its fibers are split. Distally, it is often necessary to incise the anterior fibers of the iliotibial tract, and the incision is then carried down through the capsule and synovium on the lateral aspect of the lateral femoral condyle. Care must be taken to identify the superior lateral geniculate artery, which must often be ligated, and to avoid damage distally to the lateral meniscus. To expose the articular surface, a blunt Hohmann retractor is placed across the joint and over the medial femoral condyle. Visualization of the articular surfaces of the lateral condyle is usually adequate. The medial condyle, especially its posteromedial aspect, is difficult to visualize. The more comminuted the metaphysis, the easier the visualization. In extra-articular type A supracondylar femoral fractures, joint visualization is not necessary because the extraosseous guide wires can be inserted under fluoroscopic control. To expose the distal femoral shaft, the vastus lateralis muscle must be reflected off the lateral intermuscular septum. Care must be taken to identify and ligate the perforating vessels. It is only necessary to expose enough of the lateral cortex to apply the plate. Any additional unnecessary soft tissue stripping or the careless insertion of anterior or posterior retractors should be avoided.

Tibial Tubercle Osteotomy

Occasionally in type C3 distal femoral fractures, if intercondylar comminution is present, more extensive dissection is necessary to increase intra-articular exposure. Mize and colleagues[81] recommended that such exposure be accomplished with a tibial tubercle osteotomy. The distal incision is extended inferiorly and medially to expose the tibial tuberosity. A 3.2-mm hole is drilled in the middle of the tibial tuberosity from the anterior to the posterior tibial cortex. The depth is measured, and the near cortex is tapped with a 6.5-mm tap. The tibial tuberosity is osteotomized with a fine oscillating saw to release a piece of bone approximately 2 cm long and at least 0.5 cm thick. Because the tibial tuberosity bone block and infrapatellar tendon are reflected proximally, it is necessary to detach the fat pad from the tibia to provide exposure to the whole articular distal end of the femur. If further medial exposure is necessary, the supracondylar synovium can be incised, and then the whole quadriceps mechanism can be reflected proximally and medially. This technique is one way to provide enough exposure if additional medial plating was indicated. However, it may devascularize the distal end of the femur because a large part of the metaphyseal blood flow comes through the reflected tissues. At closure, the tibial tubercle bone block is replaced in its bed and fixed with a 6.5-mm cancellous screw of appropriate length.

Infrapatellar Tenotomy

An alternative method for extensive exposure of the distal femoral articular surface is a Z infrapatellar tenotomy. This technique requires not only repair of the infrapatellar tendon but also protection of the repair with an anterior wire tension band from the patella to the tibial tubercle.

Medial Approach

Occasionally, medial exposure to the distal end of the femur is indicated, primarily for ORIF of type B2 unicondylar medial femoral fractures. However, it is also used in conjunction with lateral exposure when double plating of the distal end of the femur is indicated for severe supracondylar comminution or for bone defects requiring additional medial stabilization and in patients with complex combined supracondylar and intracondylar type C3 distal femoral fractures. The incision is straight medial just anterior to the adductor tubercle and midmedial in the thigh. The deep fascia is incised in the same line as the skin incision. The vastus medialis is reflected anteriorly off the adductor magnus to expose the distal medial shaft of the femur. Care must be taken to identify the superior medial geniculate artery, which must often be ligated. The incision must remain anterior to the proximal insertion of the superficial medial collateral ligament on the adductor

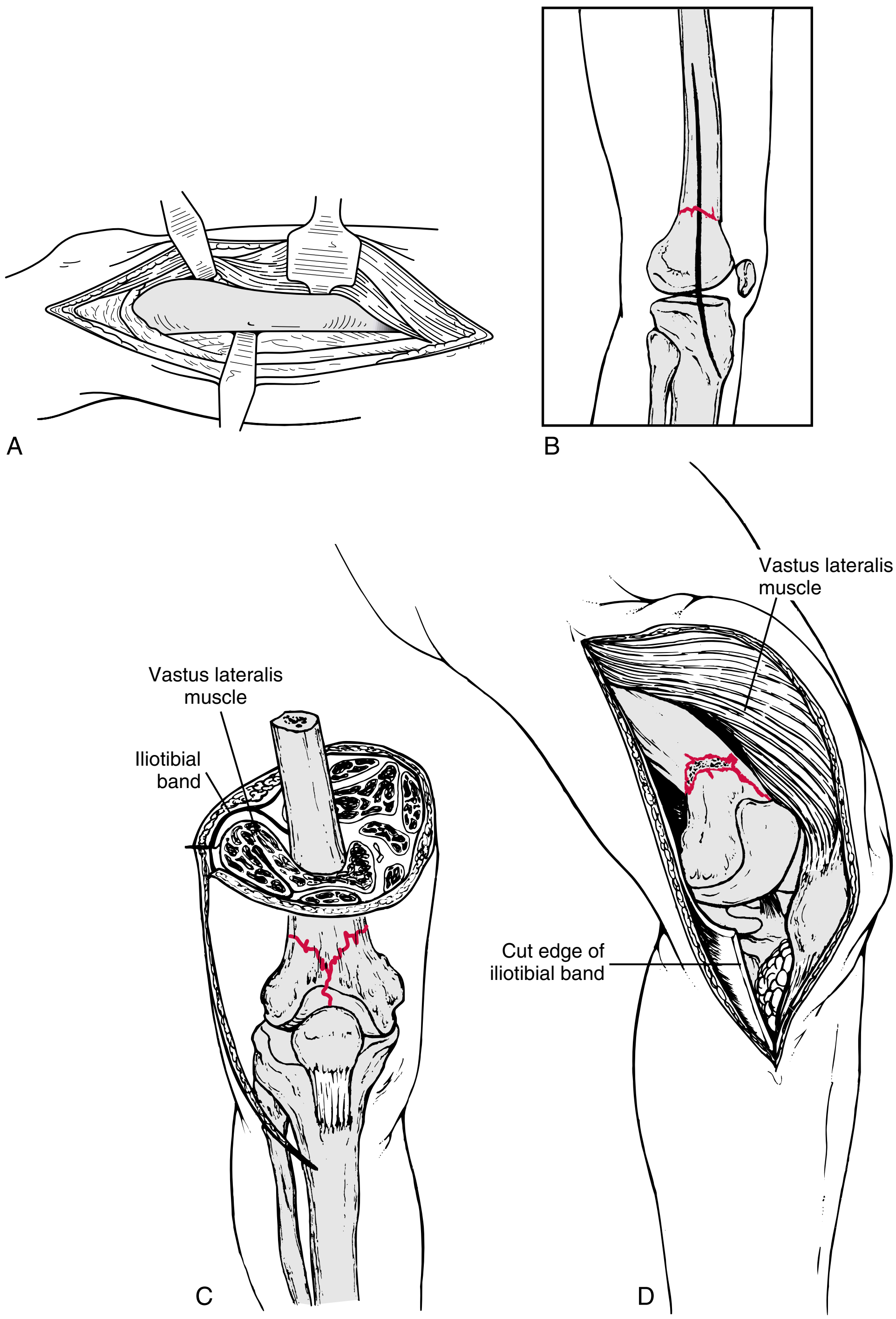

FIGURE 53–10. Conventional lateral approach. *A,* The standard lateral approach to the distal end of the femur with the typical use of a broad retractor. The retractor is placed medially, and muscles are forcefully reflected at the level of the fracture site with soft tissue and periosteal stripping. An additional disturbance of the blood supply to the fracture site is caused by ligation of the perforator vessels. (From Hoppenfeld, S.; deBoer, P.I. Surgical Exposures in Orthopaedics. The Anatomic Approach. Philadelphia, J.B. Lippincott, 1984, pp. 357–387.) *B,* Lateral skin incision. *C,* Demonstration of the lateral incision for femoral exposure posterior to the vastus lateralis and anterior to the intermuscular septum. *D,* Extensive exposure is possible, but care must be taken to not strip the soft tissues unnecessarily.

tubercle. For complete exposure of the medial femoral condyle, the medial patellar retinaculum and capsule are incised, with care taken to avoid damage to the medial meniscus. The major risk with medial exposure is damage to the femoral artery and vein as they pierce the adductor magnus 1 handbreadth above the knee joint and enter the popliteal space.

Of the three extensile exposures available and just described, the most widely used has probably been the tibial tubercle osteotomy. However, a review by Sanders and co-workers[100] recommended an additional medial incision, which is associated with lower morbidity and requires the least additional soft tissue dissection and stripping.

Minimally Invasive Techniques

Treatment of displaced supracondylar femoral fractures by ORIF has traditionally resulted in 70% to 90% good and excellent results.* However, the use of bone grafts is frequently recommended if medial comminution or bone loss is present, particularly in intercondylar type C2 and C3 fractures.[30, 52, 81, 88, 99, 103, 112, 129] Without the use of bone grafts, many series report an increased incidence of delayed union, pseudarthrosis, loss of reduction, and implant failure.[36, 91, 103, 128] The traditional surgical approach for severe intra-articular distal femoral fractures is through a lateral incision with elevation of the vastus lateralis muscle and ligation of the perforating vessels.[86] This approach allows for good visualization and reduction of the shaft fracture (see Fig. 53–10). Reconstruction of complex intra-articular fractures through a lateral exposure, however, may be difficult. Medially placed retractors are often necessary to visualize the articular fragments, and soft tissue is consequently stripped from the metaphyseal bone. As a result, fracture healing may be delayed with increased rates of secondary revision and primary or secondary bone grafting.[36, 81, 99, 101, 103, 128] The following two approaches are suggested as alternatives.

Transarticular Approach and Retrograde Plate Osteosynthesis with a Lateral Parapatellar Arthrotomy (TARPO). Indirect reduction techniques have been developed to avoid the potential complications associated with soft tissue stripping.[74] These techniques have been used successfully in the treatment of proximal and distal femoral fractures and have resulted in improved rates of union in comparison to the "classic" AO technique.[55, 93] With an indirect reduction technique, Ostrum and Geel obtained fracture union in 29 of 30 cases after internal fixation without autogenous bone grafting.[93] Although the authors avoided placing retractors in the medial supracondylar region, the reconstruction required exposure of the anterior and lateral aspect of the distal end of the femur.[93]

Because anatomic articular reconstruction remains a primary goal in these complex fractures and because complete joint visualization is difficult with a lateral approach (particularly one that attempts to avoid soft tissue stripping),[70] the authors developed a new minimally invasive approach.[62, 68, 69] This technique uses a lateral parapatellar arthrotomy for direct reduction of the joint surface and indirect plate fixation to secure the articular block with the femoral shaft (Fig. 53–11). The skin incision is placed above the lateral third of the patella, approximately 15 to 20 cm long. The lateral parapatellar approach extends proximally between the rectus femoris and vastus lateralis muscles along the course of their fibers in the tendinous intersection. Extension underneath the skin is important to get enough retraction of the patella. After retracting the patella medially, excellent access to both femoral condyles is achieved. This exposure facilitates direct anatomic joint reconstruction, even in the posteromedial aspect. After blunt dissection of the iliotibial tract and the muscle fibers with scissors, retrograde insertion of the plate beneath the vastus lateralis muscle is performed.

Approach for Minimally Invasive Percutaneous Plate Osteosynthesis (MIPPO). This approach is designed for only extra-articular or undisplaced fractures because it does not allow adequate joint reduction (Fig. 53–12). The approach was developed for the DCS and later adapted to the less invasive stabilization system for the distal end of the femur (LISS-DF).[65] The DCS was introduced as an alternative to the 95° CBP,[51, 81, 91] with the screw replacing the blade portion of the plate. Although the CBP requires three-plane alignment, the DCS has the advantage of requiring only two-plane alignment. Sagittal-plane alignment with the DCS can be accomplished by rotating the plate-screw construct after insertion.

In the treatment of distal femoral fractures, the DCS is commonly inserted through a standard lateral approach with elevation of the vastus lateralis muscle.[86] The approach provides for wide exposure of the femoral shaft and direct ORIF of the fracture. However, to directly visualize the fracture, the soft tissues are stripped, the perforating arteries are ligated, the nutrient artery may be placed at risk, and local periosteal and medullary perfusion is decreased.[24–26] This soft tissue disruption may lead to a decrease in the rate of union and an increased need for primary and secondary bone grafting in both subtrochanteric and supracondylar femoral fractures.[55, 93]

To limit the amount of soft tissue elevation at the fracture site, indirect reduction techniques have been developed to treat proximal[55] and distal[5, 51, 64, 65, 93] femoral fractures. Each of these techniques limits the approach to a lateral exposure and avoids medial dissection. The reported results of these indirect techniques demonstrate rates of union at least as rapid as those achieved with the "classic" technique, but without the need for a bone graft.[5, 51, 55, 93]

Current indirect reduction techniques limit the amount of medial dissection. Farouk and associates demonstrated that lateral dissection may also decrease the periosteal and medullary circulation by disrupting the femoral perforators and nutrient vessels.[24–26] To preserve the local blood supply, the MIPPO method limits lateral as well as medial dissection.[65]

Approach for Retrograde Nailing. Whereas displaced intra-articular fractures require an arthrotomy for anatomic, open fracture reduction, retrograde nailing of extra-articular fractures can be performed through stab

*See references 14, 30, 33, 52, 81, 91, 94, 99, 103, 109, 110, 112, 119, 121, 123, 129.

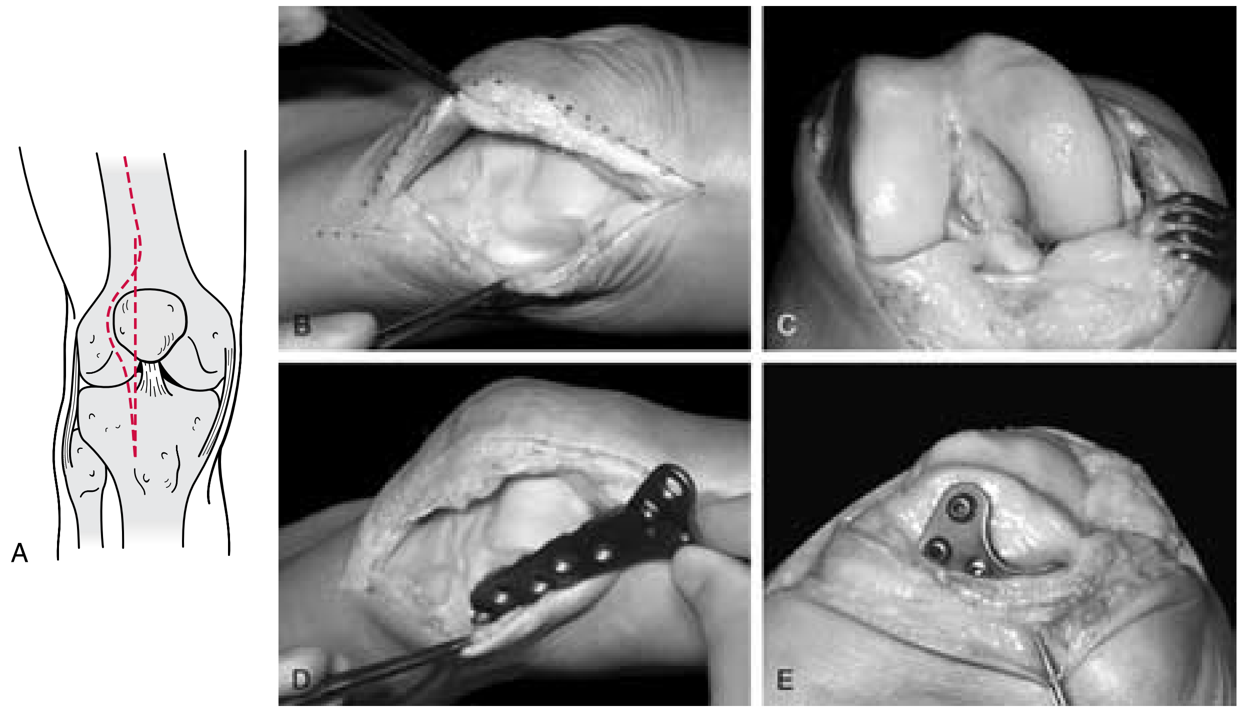

FIGURE 53–11. TARPO: transarticular approach and retrograde plate osteosynthesis with a lateral parapatellar arthrotomy (Krettek et al., 1997) for intra-articular B and C type fractures. *A,* A skin incision is placed above the lateral third of the patella approximately 15 to 20 cm in length. *B,* The lateral parapatellar approach extends proximally beneath the rectus and vastus lateralis muscle along the course of its fibers in the tendinous intersection. *C,* After retracting the patella medially, excellent access to both femoral condyles is achieved. This exposure facilitates direct anatomic joint reconstruction, even in the posteromedial aspects. *D,* After blunt dissection of the iliotibial tract and the muscle with scissors, the plate is inserted retrogradely beneath the vastus lateralis muscle. *E,* After completion of plate fixation.

incisions under image intensifier control. The patient is positioned supine on a radiolucent table to allow fluoroscopy from the hip joints to the knees. The optimal knee position for the approach is approximately 30° to 40° of flexion (Fig. 53–13). Too much knee flexion pulls the patella down and prevents an easy approach. If the position of the knee is too extended, the anterior crest of the proximal end of the tibia limits access to the intercondylar notch. Accurate placement of the skin incision and the starting hole in the bone is verified by visualization on an image intensifier in two planes. The correct entry site is where the anatomic axis of the femoral shaft passes through in extension to the center of the femoral shaft. On the lateral view, this site usually corresponds to a point slightly anterior to the anterior-distal end of Blumensaat's line (Fig. 53–13). On the AP view, the optimal entry site can be determined by projecting the anatomic axis of the femoral shaft through the articular surface.

FRACTURE REDUCTION AND STABILIZATION

Because of the diversity of fracture types encountered in the distal end of the femur, it is necessary to first discuss the basic techniques available for reduction and stabilization and then specific applications for each fracture type.[67]

Conventional Plate Fixation

95° Condylar Blade Plate. For illustrative purposes, the fracture type C1 is selected (T or Y supracondylar fracture with intercondylar extension). The incision is the standard lateral incision as described. The initial step must be anatomic reduction of the condyles, both the distal articular surface and the patellar femoral groove. The reduction is provisionally secured with temporary 2.0-mm K-wire fixation in a lateral-to-medial direction.

The next step is to plan insertion of the 95° condylar blade plate (Fig. 53–14) before placing the intercondylar lag screws. The length of the blade and side plate are determined through preoperative planning, as described previously. The position for insertion of the blade plate is 1.5 to 2 cm from the inferior articular surface and in the middle third of the anterior half of the sagittal diameter of the condyles at their widest point (Fig. 53–15). This position can be determined by palpating the posterior edge of the lateral femoral condyle while visualizing the anterior margin. At its broadest point, the distance is divided in two. The anterior half of this distance is then divided in three; the middle third is the location for insertion of the blade and should be marked with the cautery. This position must be determined exactly because the fixation device is used to realign the condyles and articular surface with the femoral shaft. The blade must be inserted in line with the longest sagittal diameter so that the plate, which is perpendicular, correctly restores the relationship between the condyles and shaft and lies along the shaft, on the lateral view, rather than with its proximal end too far anterior or posterior.

The next step is lag screw fixation of the condyles to each other, usually with 6.5-mm cancellous screws, one

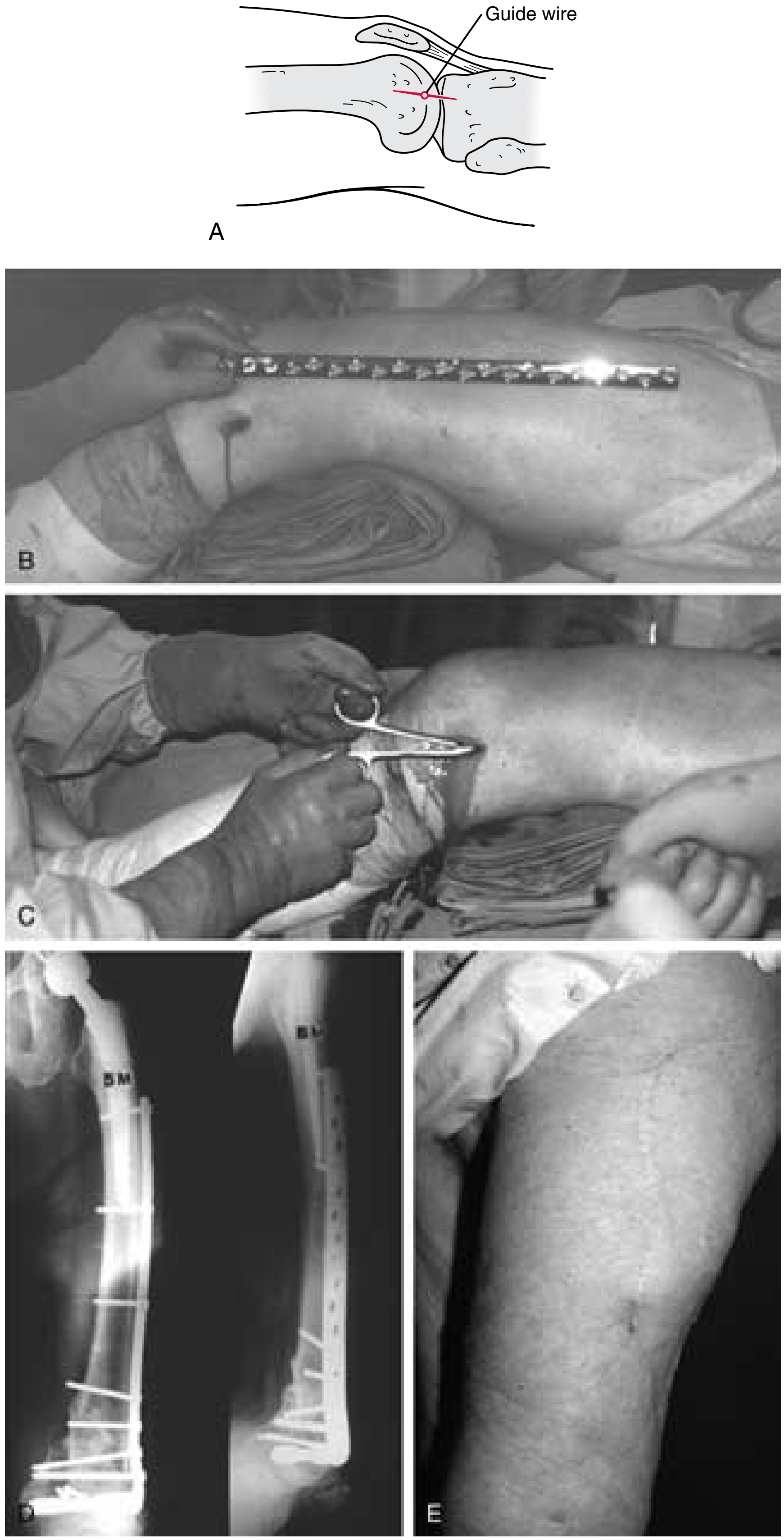

FIGURE 53–12. MIPPO: minimally invasive percutaneous plate osteosynthesis (Krettek et al., 1997) for extra-articular type A fractures. *A,* After adequate placement of the threaded guide wire, a longitudinal 4-cm skin incision centered on the guide pin is made and carried through the iliotibial band. The condylar screw is inserted percutaneously according to the principles of dynamic condylar screw (DCS) application. *B,* The DCS plate length is selected with fluoroscopy. *C,* The iliotibial band is spread for an additional 2 to 3 cm longitudinally to facilitate insertion of the plate. The DCS plate is then inserted through the skin and iliotibial tract incision beneath the lateral vastus muscle. After reinsertion of the guide wire through both the plate and the condylar screw, a T handle (cannulated) is introduced over the guide wire. The T handle is fixed to the condylar screw with a cannulated connecting screw, and the plate is slipped onto the condylar screw by using the modified T handle as a guide. The three or four plate screws are then inserted through a 4-cm percutaneous/transmuscular incision. The screws are placed divergently to increase screw pull-out strength and decrease the length of incision needed for their insertion. *D,* Radiographs 9 months after a supracondylar fracture caused by a fall in an 82-year-old woman with a loosened porous-coated anatomic total-hip endoprosthesis. Insertion of a short plate or a retrograde nail would have created an inherent risk for fatigue fracture between these two implants. Insertion of a long angled blade plate by standard technique would have necessitated a long incision, extended the soft tissue disruption, and increased blood loss. Therefore, MIPPO with a long DCS was chosen. It overlaps the femoral stem, and two screws are inserted in the cement anterior and posterior to the stem. *E,* Soft tissue status 6 weeks after surgery.

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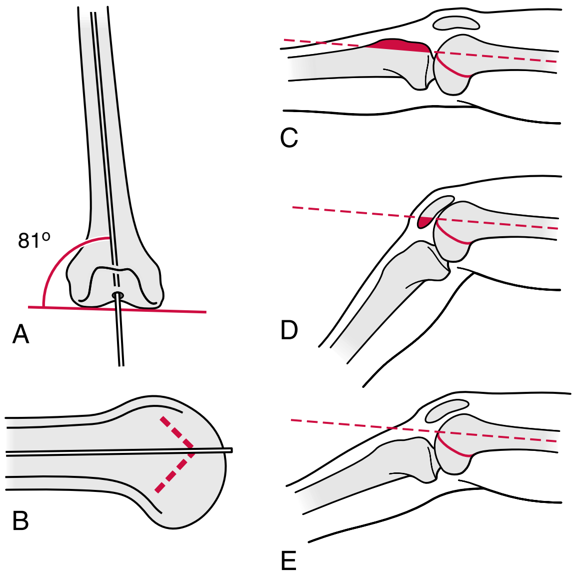

FIGURE 53–13. Positioning and approach for retrograde femoral nailing. *A,* In the anteroposterior view, the entry site is where the femoral anatomic axis crosses the plane of the joint surface. For correct frontal plane alignment, the direction of the nail should duplicate that of the anatomic axis, which intersects the joint plane at a valgus angle of approximately 81°. *B,* On the lateral view, the entry site is just anterior to the distal end of Blumensaat's line. Fluoroscopically, this is usually visible as a line of dense bone, often intersecting an anterior linear density. The apex of this apparent angle points toward the usual entry site. Knee flexion of 30° to 40° is required to gain appropriate access. *C,* The tibia blocks nail insertion if the knee is too extended. *D,* The patella is in the way with too much flexion. *E,* Correct knee flexion of 30° to 40° provides an adequate window for percutaneous nail insertion.

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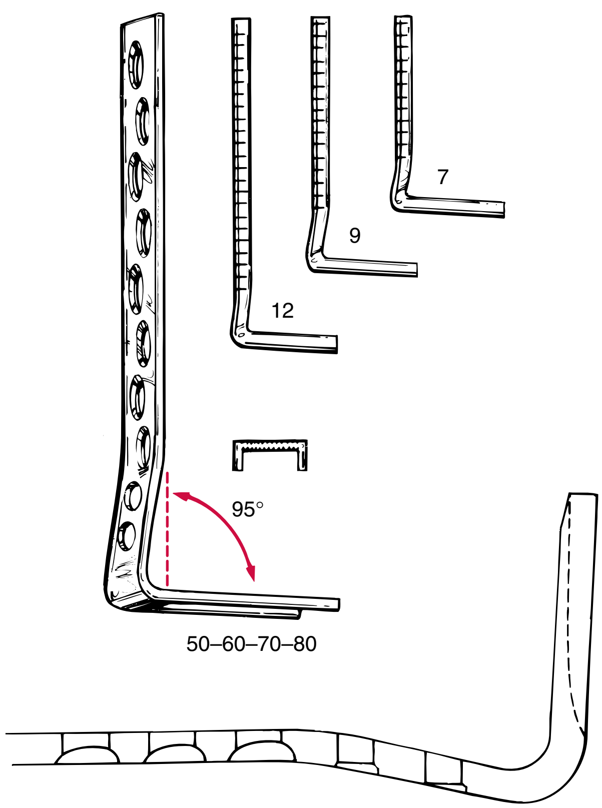

FIGURE 53–14. The 95° condylar buttress plate. Blade lengths range from 50 to 80 mm; plate lengths, from 92 mm (5 holes) to 299 mm (18 holes).

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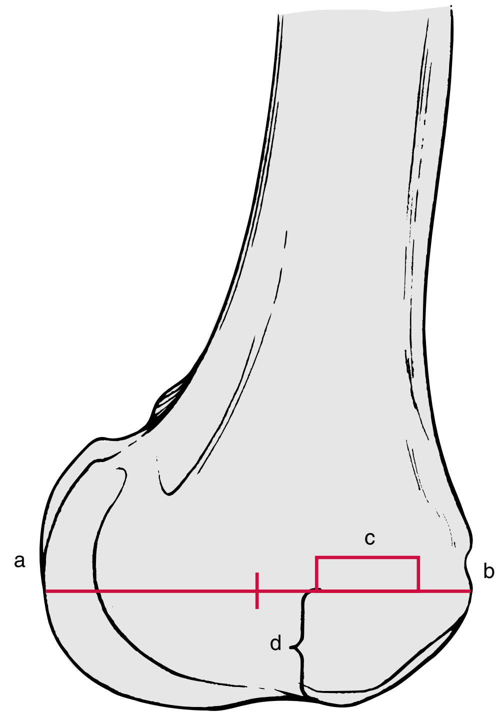

FIGURE 53–15. Position for insertion of the 95° condylar buttress plate in the lateral cortex of the distal end of the femur. *A, B,* Longest sagittal diameter on the lateral femoral condyle. *C,* Middle third of the anterior half. *D,* Distance 1.5 to 2 cm proximal to the articular surface.

placed anteriorly and one posteriorly. Only by first marking the insertion site and path of the seating chisel can these lag screws be placed outside the path of the blade plate. Both 6.5-mm cancellous screws should be inserted slightly proximal to the level of insertion of the blade plate (Fig. 53–16). The anterior screw is inserted in a slightly anterior-to-posterior direction, from lateral to medial, just inferior and lateral to the most anterior aspect of the patellar femoral groove. This anterior 6.5-mm cancellous screw should be inserted without a washer to ensure that it does not interfere with the patellofemoral mechanism. The posterior screw is also inserted slightly proximal to the insertion of the blade and just anterior to the proximal insertion of the lateral collateral ligament. It should be inserted in a slightly posterior-to-anterior direction to avoid penetration of the intracondylar notch and should be inserted with a washer. It is important that both screws act as lag screws (i.e., all their threads must be on the far side of the fracture and neither should penetrate the medial cortex) because long-term pain and disability can result from interference with medial structures during knee movement.

Once the condyles are anatomically reduced and internally fixed, the distal portion of the femur must be properly aligned and attached to the femoral shaft, which is accomplished by inserting the blade plate correctly into the condyles and then using it to reduce and stabilize the fracture. Two temporary K-wires are placed as guides for insertion of the seating chisel of the 95° CBP (see Fig. 53–16). K-wire 1 is inserted across the knee joint parallel to the inferior aspect of the medial and lateral condyles (i.e., the knee joint axis). K-wire 2 is inserted anteriorly across the patellofemoral joint; it slopes in an anterior-to-

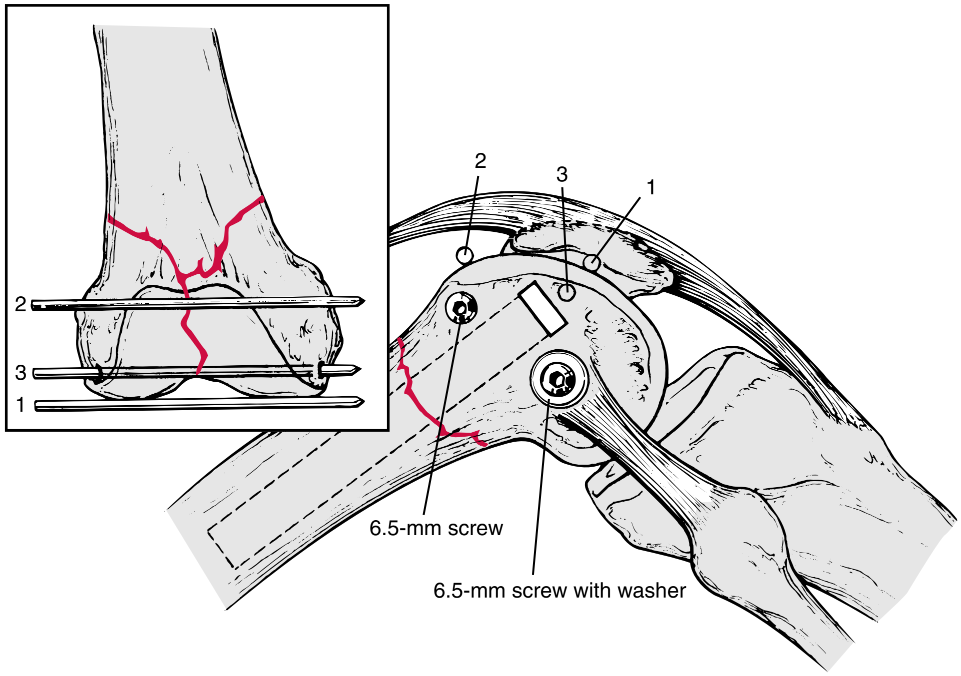

Figure 53–16. Position for insertion of alignment and summation K-wires: K-wire 1, inferiorly along the femoral condyles; K-wire 2, anteriorly along the femoral condyles; and K-wire 3 (summation), parallel to both wires 1 and 2 and inferior to the window for blade plate insertion.

posterior direction and is kept parallel to the condyles in the coronal plane (Fig. 53–17). As originally described, the blade should be inserted parallel to the plane determined by the medial and lateral prominences of the patellofemoral articular surfaces (demonstrated by wire 2). However, such insertion may result in too little purchase in the narrow anterior portion of the distal end of the femur. It is better to consider wire 2 as a boundary limit and insert the summation wire (No. 3), seating chisel, and fixation device blade or screw in a relatively more posterior direction, perpendicular to the cortical surface at the insertion site. The definitive K-wire 3 is inserted approximately 1 cm proximal to the inferior aspect of the knee joint, just inferior to the area marked out on the lateral condyle for insertion of the seating chisel (see Fig. 53–16). K-wire 3, which "summates" the information of wires 1 and 2, represents the definitive guide for insertion of the 95° CBP. It must therefore be parallel to wire 1 in the frontal plane (Fig. 53–16) and to wire 2 in the coronal plane (see Fig. 53–17). If the surgeon is inexperienced with this technique, it is a good idea to fluoroscopically verify that wire 3 is parallel to the knee joint axis in the frontal plane. In fractures without supracondylar comminution, the position of summation wire 3 can also be checked with the condylar guide, which is a mirror image of the condylar plate (Fig. 53–18). Provisional guide wires 1 and 2 are removed before the seating chisel is used. The main principle of 95° distal femoral fracture fixation implants is derived from the fact that on the frontal (AP) projection,

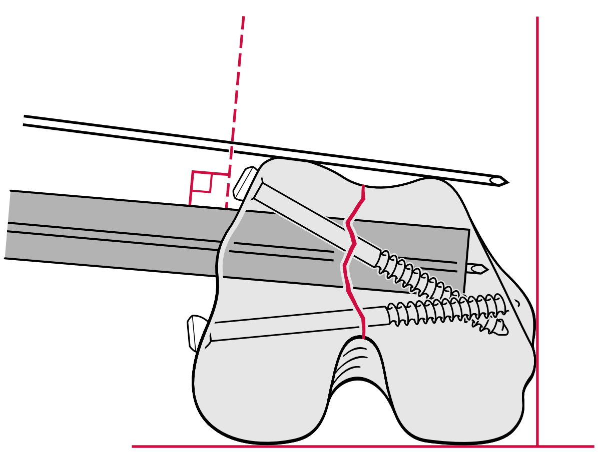

Figure 53–17. A coronal view of the distal end of the femur demonstrates the trapezoidal shape, the angle for the lag screws, and the position for insertion of the chisel.

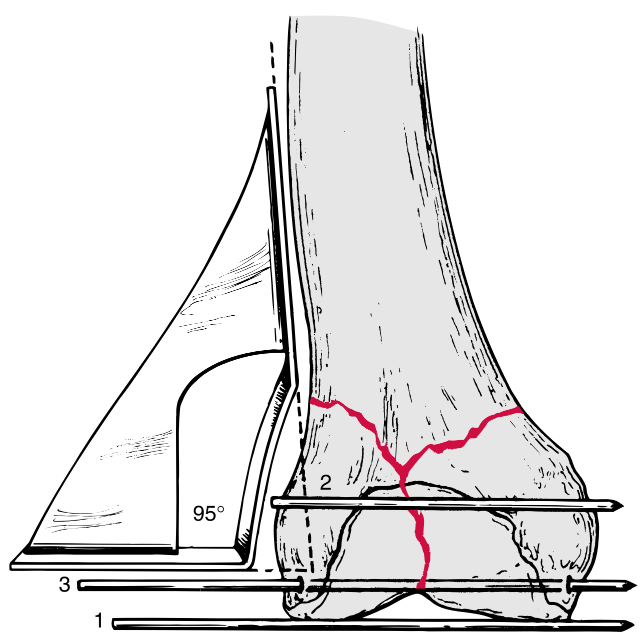

Figure 53–18. Use of the condylar guide for checking the position of summation K-wire 3.

the articular surface lies at an angle of 95° to the lateral femoral shaft. A properly inserted blade, parallel to the articular surface (wire 1), reduces the fracture without varus or valgus malalignment when its plate portion is attached to the femoral shaft. Wire 2 defines the anterior surface of the distal end of the femur, which the blade should diverge from to avoid protrusion through the medial condyle's sloping anterior surface and to ensure adequate distal fixation.

In young patients with dense trabecular cancellous bone, it is necessary to predrill the condylar path tract for the seating chisel. If predrilling is not done, impaction of the seating chisel into the condyles can require tremendous force and, as a result, may disrupt the lag screw fixation of the condyles. Predrilling is easily accomplished with the use of a 4.5-mm drill bit and the appropriate three-hole guide. This guide is applied to the lateral condyle parallel to summation K-wire 3. Three 4.5-mm channels can be drilled out in a lateral-to-medial direction in the previously marked window for insertion of the chisel. If any uncertainty remains, the result can be checked by fluoroscopy. The window in the lateral cortex is then expanded by using the router in the three drill holes. To seat the condylar plate flush with the lateral cortex in young patients, it is helpful to bevel the proximal lip of the lateral window with an osteotome and remove approximately 0.5 cm of bone.

The seating chisel is assembled with the seating chisel guide. The guide allows assessment of rotation (i.e., flexion and extension) in the sagittal plane as the chisel is inserted into the condyles. The seating chisel is then inserted into the condylar fragment while maintaining it parallel to K-wire 3 in both the frontal and coronal planes and ensuring correct rotation in the sagittal plane. The blade must remain parallel to the longest sagittal diameter of the condyles because rotation angulates the fracture on the lateral view. In young patients with good bone, it is helpful to insert the chisel approximately 1 cm at a time and then back it out a few millimeters before continuing. This technique greatly facilitates the ability to subsequently remove the seating chisel after full insertion. Again, if the surgeon is inexperienced with this technique, the use of fluoroscopy provides reassurance of correct position for the seating chisel. The seating chisel is inserted to the predetermined depth. It should be appreciated that the distal part of the femur is a trapezoid, with a 25° angle on the medial side from posterior to anterior (see Fig. 53–17); care must be taken to not penetrate the medial condylar cortex with the seating chisel, which on radiography looks "too short" in relation to the wide posterior cortical shadow. The 95° CBP is then inserted along the prepared tract in the femoral condyles and impacted to lie flush with the lateral cortex.

Before reduction of the fracture, it is necessary to stabilize the fixation of the condylar plate within the condyles by inserting one or two 6.5-mm cancellous lag screws through the distal plate holes into the condylar fragment. These screws not only enhance the rotational stability of the condylar fragment but also prevent lateral excursion of the blade with the application of axial compression. The reconstituted distal portion of the femur, with blade plate securely attached, is then reduced to the femoral shaft and provisionally held there with a Verbrugge clamp around the side plate and shaft. After the comminuted fragments, if any, are reduced, axial compression can be achieved by use of the tension device. (Occasionally, with no bony defect and an anatomic reduction, compression can be accomplished with the use of loaded screws in the dynamic compression plate.) If at all possible, a lag screw should be inserted across the supracondylar fracture through the plate. This screw will greatly enhance the stability of the fixation. If a bone defect or lack of cortical contact is observed after fracture reduction, axial compression cannot be achieved without causing shortening, so the fixation mode must be bridge plating rather than compression plating.

The 95° CBP requires purchase in the distal condyles to be efficacious. Distal fixation is achieved by (1) contact of the broad surface of the blade and (2) addition of distal cancellous lag screws through the plate into the condyles. In very low transcondylar fractures, especially in elderly patients, distal fixation with the CBP will be inadequate, and alternative methods may be indicated. If the lateral condyle or the intercondylar area is markedly comminuted, adequate fixation is achieved with a locking condylar plate or LISS (see later)

Condylar Compression Screw and Side Plate (DCS), Standard Technique. The condylar compression screw system has a design analogous to that of the 95° CBP, but the blade is replaced with a cannulated compression screw (Fig. 53–19). Technically, this device may be easier to use because most surgeons are familiar with cannulated compression screw systems for the fixation of intertrochanteric hip fractures. The condylar compression screw is

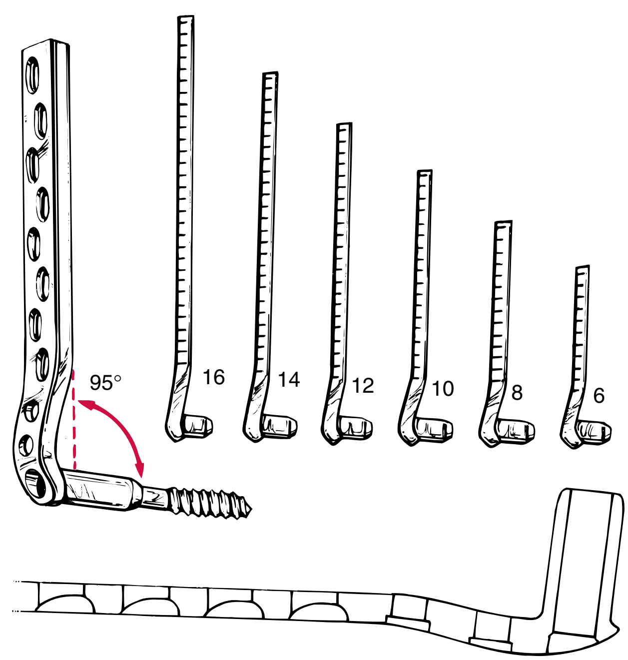

FIGURE 53–19. The condylar compression screw system. The 95° side plate slides over a cannulated lag screw. Lag screw lengths range from 50 to 75 mm; side plates (6 to 16 holes), from 113.5 to 273.5 mm.

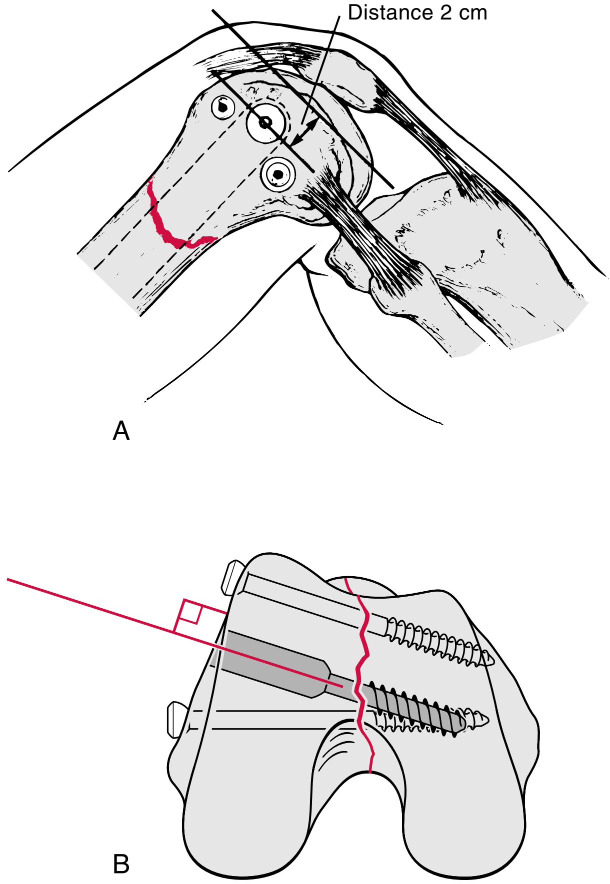

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Figure 53–20. Position for insertion of the condylar compression screw. *A,* Lateral view: junction of the anterior and middle thirds, 2 cm from the articular surface. *B,* Coronal view.

easier to insert into the condyles than the 95° blade plate is for the following reasons:

1. It is a cannulated screw system inserted over a guide wire.
2. By using a power-driven triple reamer, which allows precutting of the path of the condylar screw, the system eliminates the problems encountered in hammering the chisel into the condyles.
3. The system eliminates the necessity to control flexion and extension in the sagittal plane when inserting the condylar screw because it can be corrected by rotation of the screw and side plate.

The operative technique for insertion of the DCS differs from that for the 95° blade plate only in the technique for insertion of the condylar screw. Again, three guide wires are inserted. Wire 1 is inserted parallel to the knee joint axis, and wire 2 is inserted parallel to the anterior patellofemoral articulation. The location on the lateral femoral condyle for insertion of the DCS is slightly more proximal and posterior than that of the 95° blade plate, approximately 2 cm from the inferior articular surface and at the junction of the anterior and middle thirds of the longest sagittal diameter of the lateral femoral condyle (Fig. 53–20). This point is just proximal to the posterior edge of the window for insertion of the 95° blade plate (see Fig. 53–15). The third guide wire becomes the definitive guide for the cannulated screw system. This 230-mm guide wire with a threaded tip is inserted into the premarked area on the lateral cortex parallel to wire 1 and diverging posteriorly from wire 2, as discussed earlier regarding the blade plate (Fig. 53–21). The condylar compression screw angle guide may be helpful in patients without supracondylar comminution. This angle guide is a mirror image of the side plate and is held against the lateral cortex with a T handle. Again, guide wire 3 is the definitive guide for the cannulated condylar screw system and must be inserted parallel to wire 1 and diverge posteriorly from wire 2, perpendicular to the entry site cortex. This process is greatly facilitated, as in hip fracture surgery, by the use of fluoroscopy. The threaded guide wire should be inserted until the tip is felt to just penetrate the medial cortex; fluoroscopy may be deceiving here because the posterior femoral condyles are broader than the anterior ones, especially on the medial side (Fig. 53–22). A reverse-calibrated measuring device is placed over the guide wire to allow direct measurement of length. The triple-cannulated reamer is set for the desired length, which should be 10 mm less than the measurement to prevent penetration of the medial cortex. The channel is power reamed over the guide wire; again, the result can be checked with fluoroscopy. In young patients with firm trabecular cancellous bone, a cannulated tap with a short centering sleeve is used. A cannulated compression screw of the correct length is connected to the T handle and wrench and inserted over the guide wire with the long centering sleeve (Fig. 53–23). It is inserted until the zero mark on the wrench is seen to be flush with the lateral cortex and the handle of the inserter is parallel with the reduced femoral shaft. In elderly patients with osteoporotic bone, the condylar screw can be inserted an extra 5 mm beyond the prereamed channel to obtain better fixation. The appropriate side plate is then slid over the condylar screw and keyed to align with the proximal part of the femur in the sagittal plane. The remainder of the technique is similar to that described for the 95° blade plate.

Condylar Buttress Plate, Standard Technique. The condylar buttress plate was designed to allow multiple lag screw fixation of complex condylar fractures. It consists of a broad compression side plate and a bifurcated, precontoured distal portion to fit the lateral surface of the femoral condyle (Fig. 53–24). The posterior projection is broader and longer than the anterior projection to fit the larger posterior aspect of the femoral condyle, so different plates must be used for the right and the left. It allows insertion of up to six interfragmentary lag screws through the distal portion of the plate for fixation of the condyles. However, this plate is not a fixed-angle device and therefore does not maintain correct axial alignment of the joint axis. It should be used only when the fracture morphology does not allow the use of either the 95° blade plate or the condylar screw. Its primary indications are (1) low transcondylar fractures or comminuted fractures of the lateral or medial condyles in which stable fixation with a fixed-angle device is not possible and (2) coronal or very comminuted articular fractures in which screw fixation of the condyles precludes insertion of a fixed-angle device (Fig. 53–25).

The condylar buttress plate should be part of the armamentarium available for fixation of all distal femoral fractures, even the most simple, in the event that intraoperative complications preclude the use of one of the fixed-angle devices. However, the advent of similar plates with locking screws, to be discussed later, may result in their obsolescence in the near future. It is easy to make errors in alignment and fixation with the condylar buttress plate. The most common mistake is to lag the condyles to the condylar buttress plate in a valgus position. The position should be carefully checked intraoperatively by fluoroscopy with use of the cable technique discussed later (see Fig. 53–32).

Because the condylar buttress plate is not a fixed-angle device, it cannot guarantee axial alignment, especially in the frontal plane. This shortcoming is especially problematic with comminution in the supracondylar region (Fig. 53–26). One of the major long-term deforming forces after fixation of distal femoral fractures is the tendency for the condyles to drift into varus angulation. Such angulation is also a problem with the condylar buttress plate because the individual lag screws are not fixed to the plate and can shift their angulation relative to it (Fig. 53–27). Varus angulation is much more likely to happen in those with supracondylar comminution or bone loss. To avoid the tendency of the fracture to drift into varus in these cases, the use of a medial buttressing plate applied to the medial side of the distal end of the femur, with a bone graft for long-term medial support, has been described.[100] This procedure can readily be accomplished after the lateral fixation through a separate, small medial incision.

Minimally Invasive Plate Osteosynthesis

Positioning of the Patient. Positioning is similar to that for standard procedures; however, a couple of issues must be considered. Patients are placed on a standard radiolucent table with the knee joint line of the injured knee slightly distal to the mechanical hinge of the table. Except for bilateral fractures, the contralateral extremity may be placed on an obstetric leg holder[63, 64] (see Fig. 53–9).

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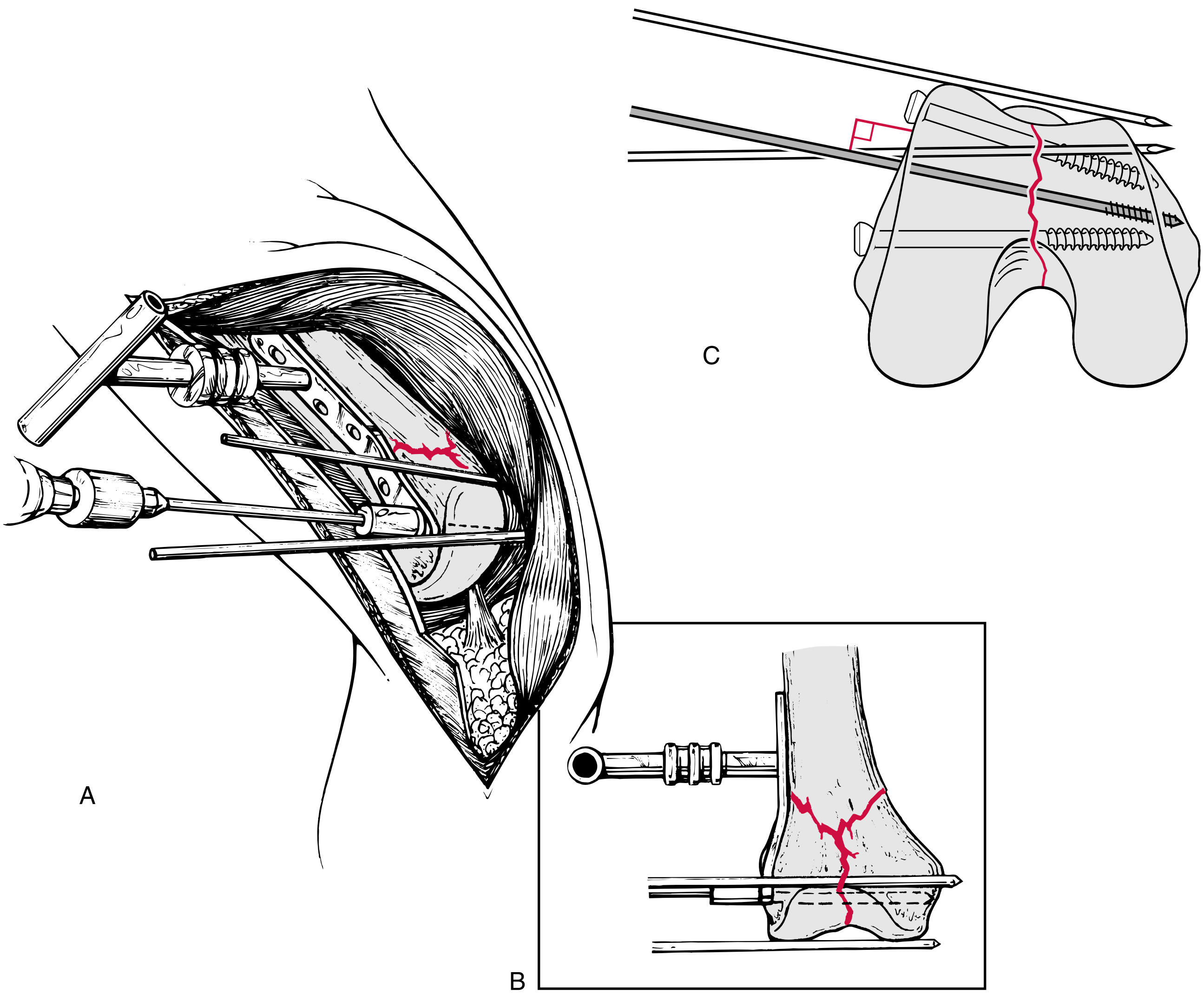

FIGURE 53–21. Technique for insertion of a threaded summation guide wire for placement of a condylar screw. *A*, Position for the condylar compression screw guide. *B*, Anteroposterior view. *C*, Coronal view.

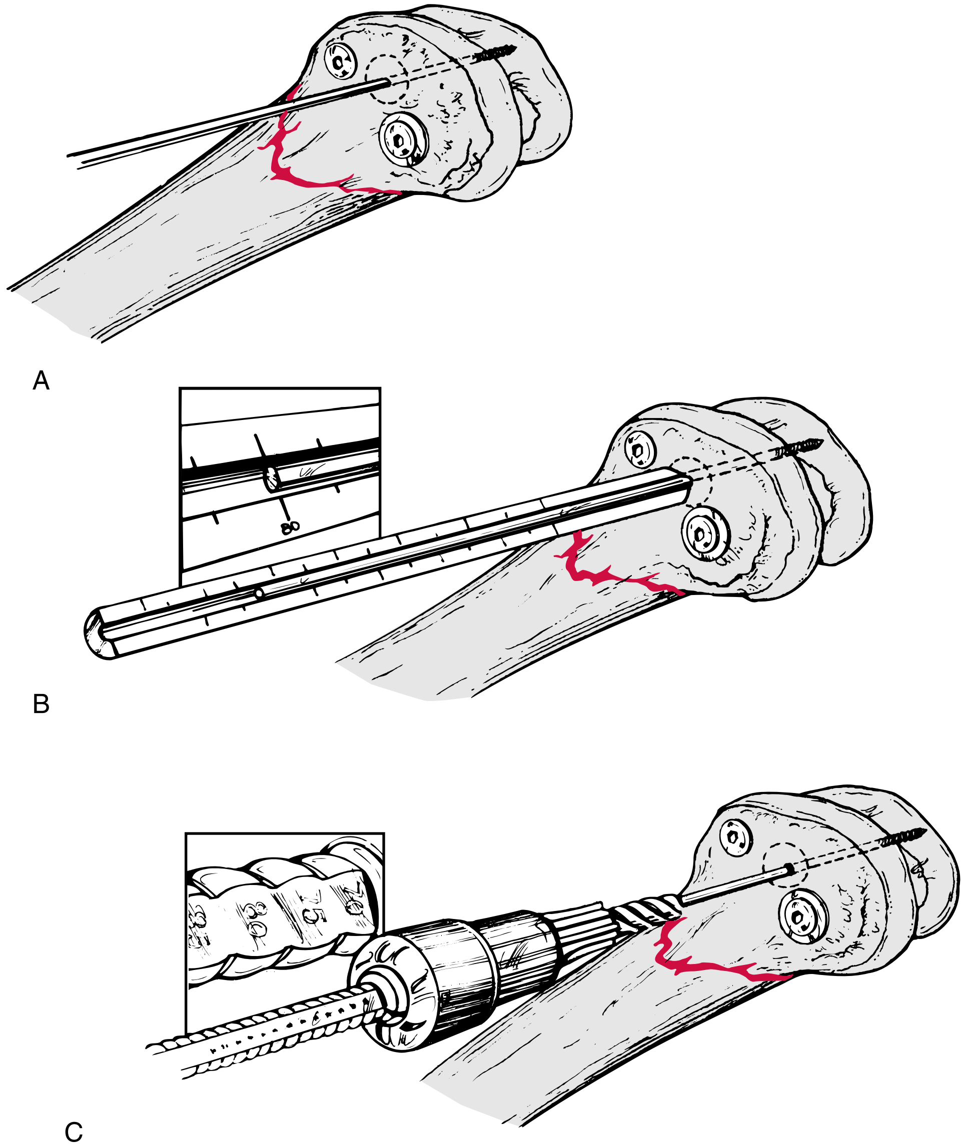

FIGURE 53–22. Technique for measurement of condylar screw length and cannulated reaming. *A,* Final position of the threaded summation guide wire. *B,* Measurement of length. *C,* Use of the triple-cannulated reamer.

Alignment Control. Minimally invasive, indirect fracture fixation techniques have a higher risk of malalignment than open techniques do. We have therefore developed techniques that help control alignment in minimally invasive, indirect fracture fixation techniques[64] (Figs. 53–28 to 53–35).

Before the procedure, the range of rotation of the uninjured hip joint is measured with the hip and knee in flexion or with the hip extended and the knee flexed (Fig. 53–28). The patient's position is checked to verify that the pelvis is not vertically or sagittally rotated. In addition, the shape of the lesser trochanter is stored for later use in the image intensifier with the patella directed anterior or the medial foot edge in a vertical position (Fig. 53–29). During surgery, hints for major rotational malalignment are the so-called cortical step sign and the diameter difference sign (Fig. 53–30). In the case of complex fracture types, the distance between the top of the femoral head and the distal end of the lateral condyle is measured by image intensification and a meter stick (Fig. 53–31). The imaged structures are centered on the screen with the x-ray beam perpendicular to the longitudinal axis. The "cable method" is an easy, flexible, and reproducible technique for analysis of frontal-plane deformity (Fig. 53–32). Several clinical and radiographic techniques are available for assessment of sagittal-plane deformities (Figs. 53–33 to 53–35).

Minimally Invasive Percutaneous Plate Osteosynthesis

In the treatment of proximal and distal femoral fractures, the DCS is commonly inserted through a standard lateral approach with elevation of the vastus lateralis muscle.[86] This approach provides wide exposure of the femoral shaft and facilitates direct ORIF of the fracture. However, to directly visualize the fracture, the soft tissues are stripped, the perforating arteries are ligated, the nutrient artery may be placed at risk, and local periosteal and medullary perfusion are decreased.[24–26] This soft tissue disruption may lead to a decrease in the rate of union and an increased need for primary and secondary bone grafting in both subtrochanteric and supracondylar femoral fractures.[55, 93]

To limit the amount of soft tissue elevation at the fracture site, indirect reduction techniques have been developed to treat proximal[55] and distal[5, 51, 64, 65, 93] femoral fractures. Each of these techniques limits the approach to a lateral exposure and avoids medial dissection. The reported results of these indirect techniques demonstrate rates of union at least as rapid as those with the "classic" technique, but without the need for bone grafting.[5, 51, 55, 93]

Therefore, a method has been developed that limits the amount of both medial and lateral dissection. This technique, MIPPO,[65] was developed for the treatment of extra-articular proximal and distal femoral fractures. It takes advantage of the two-part properties and two-plane alignment requirement of the DCS, which is inserted in percutaneous, submuscular fashion.

Condylar Screw Placement, Surgical Approach, and Plate Fixation. The implant is inserted percutaneously according to the standard principles of DCS application with following modifications (Fig. 53–36). First, a threaded guide wire is placed in the proper frontal and horizontal plane under fluoroscopic guidance. After adequate placement of the threaded guide wire, a longitudinal 4-cm skin incision centered on the guide pin is made and carried through the iliotibial band. With adequate soft tissue protection, the condylar screw hole is drilled and taped and the condylar screw inserted as measured. In supracondylar fractures, the guide wire is temporarily

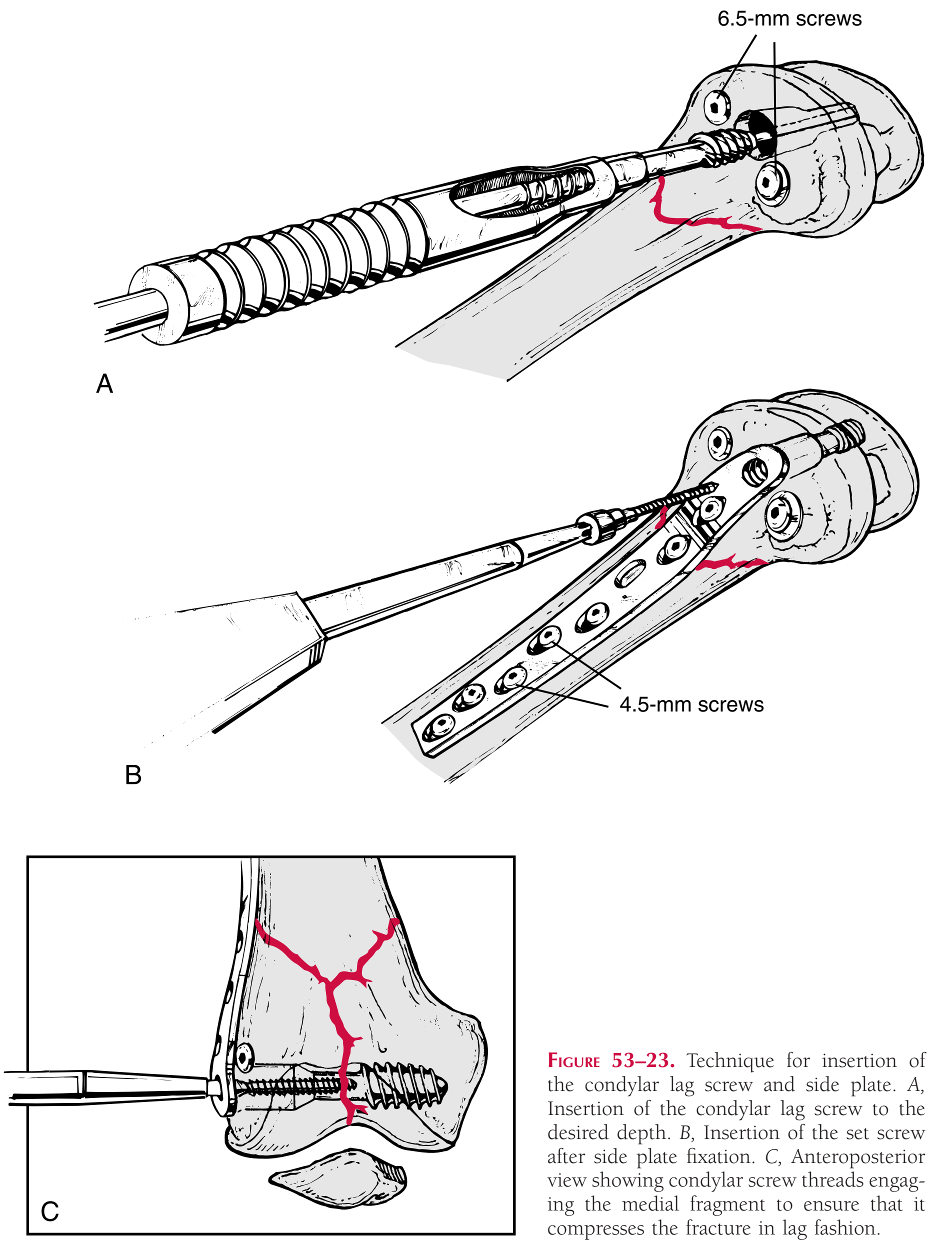

FIGURE 53–23. Technique for insertion of the condylar lag screw and side plate. *A,* Insertion of the condylar lag screw to the desired depth. *B,* Insertion of the set screw after side plate fixation. *C,* Anteroposterior view showing condylar screw threads engaging the medial fragment to ensure that it compresses the fracture in lag fashion.

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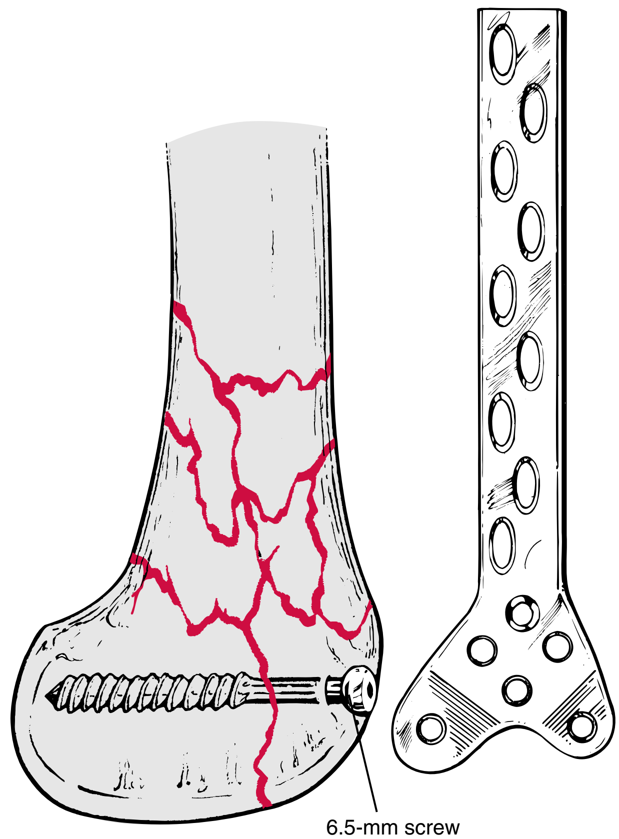

FIGURE 53–24. The condylar buttress plate must often be used when sagittally directed lag screws are required to fix coronal fracture planes.

pushed through the medial condyle, and the iliotibial band is spread for an additional 2 to 3 cm longitudinally to facilitate plate insertion. The DCS plate is inserted through the skin and iliotibial tract incision beneath the lateral vastus muscle. After reinsertion of the guide wire through both the plate and the condylar screw, a modified cannulated T handle (Stratec Waldenburg, Switzerland) is introduced over the guide wire. The T handle is fixed to the condylar screw with the cannulated long coupling screw, and the plate is slipped onto the condylar screw by using the modified T handle as a guide.

The condylar screw and its attached proximal or distal joint fragment are fixed to the shaft fragment indirectly and nonanatomically. The position of the plate can still be adjusted in the sagittal plane with the T handle mounted to the joint fragment to allow corrections in the sagittal plane. Once adequate alignment is achieved, a small custom-made transmuscular clamp can be used for temporary fixation. Limb axes, length, and rotation are then confirmed with the previously described clinical and image intensification techniques.[62, 63, 66, 68] The three or four plate screws are then inserted through a 4-cm percutaneous/transmuscular incision. The screws are placed divergently to increase screw pull-out strength and decrease the length of the incision needed for their insertion (see Fig. 53–12). The distractor is not routinely used, nor is bone graft or bone cement. Suction drains are not generally used.

Transarticular Approach and Retrograde Plate Osteosynthesis

Because anatomic articular reconstruction remains a primary goal in these complex fractures and complete joint visualization is difficult with a lateral approach (particularly with one that attempts to avoid soft tissue stripping), a new minimally invasive approach, TARPO, has recently been developed.[62, 68, 69] This technique uses a lateral parapatellar arthrotomy for direct reduction of the joint surface and an indirect plate fixation technique to secure the articular block to the femoral shaft.

The joint is approached through a lateral parapatellar

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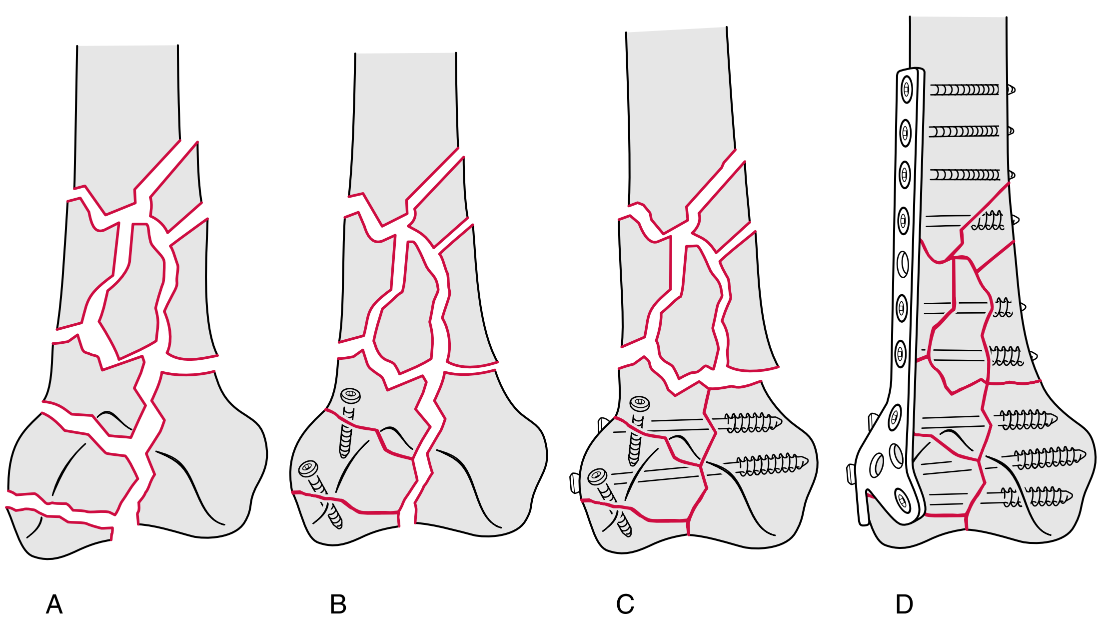

FIGURE 53–25. Stepwise reconstruction of 33C3 distal femoral fractures with the condylar buttress plate (Krettek and Tscherne, 1996). *A,* Fracture pattern 33C3. *B,* Reconstruction of the medial and lateral condyle (3.5-mm small-fragment screws). *C,* Fixation of both condyles (6.5-mm cancellous screws). *D,* Reduction of the reconstructed joint block with the femoral shaft and fixation with a condylar buttress plate.

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FIGURE 53–26. Closed supracondylar comminuted C2 fracture of the distal end of the right femur in a 23-year-old man. Anteroposterior (AP) *(A)* and lateral *(B)* radiographs. *C,* Intraoperative clinical picture showing the intracondylar fracture. *D,* The intracondylar fracture is reduced with a clamp and stabilized with two 6.5-mm cancellous screws. *E,* Restoration of the condyles to the shaft with a 95° condylar blade device and reduction of the fracture with bone clamps (no anteromedial supracondylar soft tissue stripping). *F,* AP radiograph after axial compression of the indirectly reduced supracondylar comminuted fractures with the eccentric compression device.

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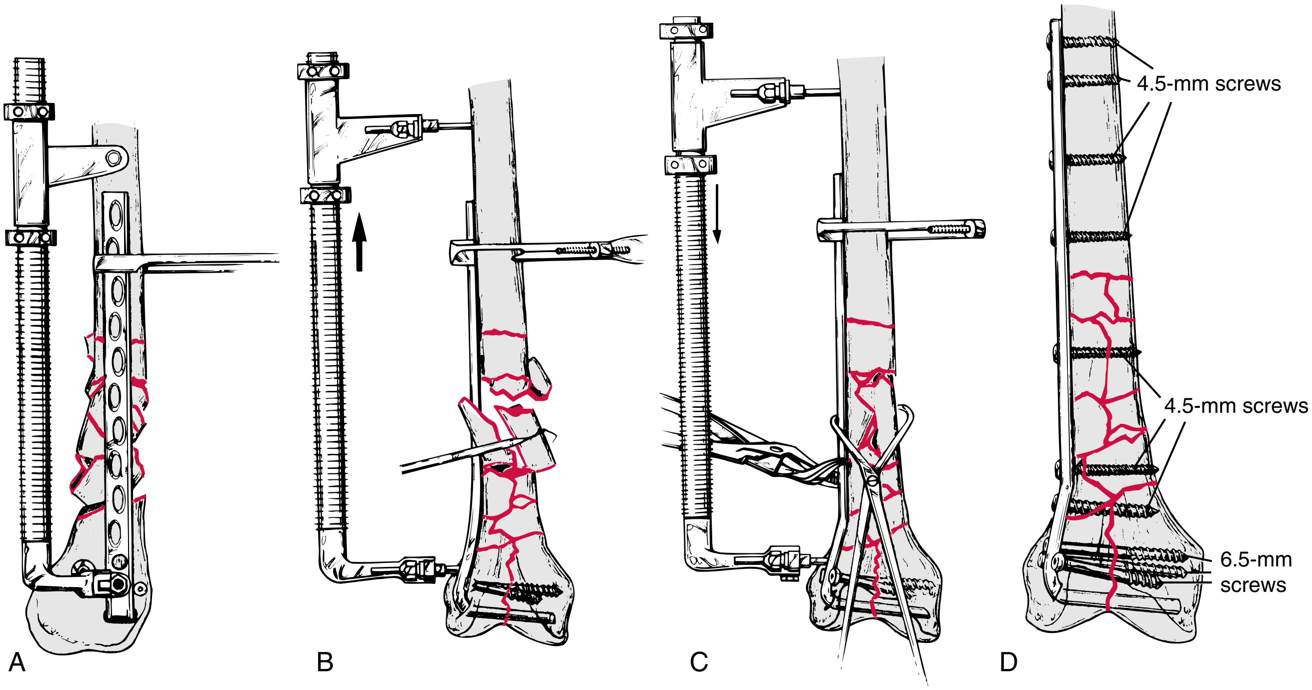

FIGURE 53–27. Technique for use of the femoral distractor for indirect fracture reduction after plate fixation distally. *A,* Insertion of Schanz screws proximally and distally (the latter through the plate). *B,* Distraction applied for fracture reduction. The fracture fragments are teased into place with a dental pick while avoiding unnecessary soft tissue stripping. *C,* Compression with the femoral distractor to provide axial loading when the fracture has sufficient bony support with the use of bone reduction clamps as indicated. *D,* Final construct after indirect fracture reduction, screw stabilization of the plate proximally, and judicious lag screw fixation of the fracture as indicated.

arthrotomy approximately 15 to 20 cm long (see Fig. 53–11). A proximal deep incision is developed between the rectus and the vastus lateralis muscles along the course of the muscle fibers. The incision is carried distally to the tibial tuberosity. The patella is retracted medially to provide extensive exposure to both femoral condyles. Direct anatomic joint reconstruction is performed with K-wires, screws, and reabsorbable pins.

Fixation of the Joint to the Proximal Shaft. Fixation of the reconstructed condylar block to the proximal shaft fragment is performed indirectly and nonanatomically.

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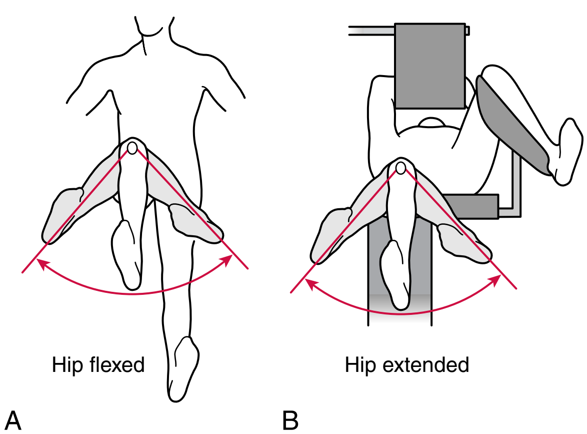

FIGURE 53–28. Clinical techniques for analysis of femoral rotation (Krettek et al., 1997). *A,* Drawing shows a patient with the hip and the knee flexed. Range of rotation is assessed before draping on the unaffected side, to be duplicated by fixation of the fractured femur. *B,* This can also be done with the hip extended and the table bent to allow knee flexion.

Either a dynamic compression plate (DCS), a condylar buttress plate, or an LISS-DF is placed beneath the vastus lateralis muscle in a distal-to-proximal direction. If a condylar buttress plate is used, the plate is fixed first to the condylar block to optimize plate position and fixation. The plate is fixed percutaneously and transmuscularly with an oscillating drill and self-tapping screws. Temporary plate fixation for stabilization during alignment control is achieved with the help of a specially designed MIPPO clamp (see Fig. 53–8). Three or four diverging plate screws, often sufficient for proximal plate fixation, are placed through a 3-cm incision. Limb length, rotation, and axes are determined with clinical and fluoroscopic techniques.[62, 66, 68] The distractor is not used routinely, nor is bone grafting or cementing performed routinely. Suction drains are used when necessary.

Less Invasive Stabilization System

Apart from biologic problems in distal femoral fractures, mechanical problems at the bone–implant interface related to mechanical instability (loss of frontal-plane alignment and movement of screws in this plane similar to that of windshield wiper blades) have been well described[19, 47, 59, 60] (Fig. 53–37). Studies have shown that the fixed-angle mechanical advantage of angular stability between the plate and screws increases stability.[23, 43, 59] The two key concepts of the LISS are (1) an anatomically precontoured condylar "buttress" plate to which the screws interlock and (2) the use of self-drilling, self-tapping monocortical screws (Fig. 53–38). The LISS combines some properties of a condylar buttress plate with the fixed-angle concept of a DCS. For insertion, the plate is attached to an insertion guide, which allows positioning of the plate and provides holes for the drill sleeves. The LISS acts mechanically as an internal fixator. Monocortical self-drilling screws are locked in the anatomically pre-shaped plate to provide angular stability and fix the bone fragments after indirect reduction has been performed. Furthermore, an aiming guide allows insertion of the plate and subsequent percutaneous placement of screws in the femoral shaft. The stability of the bone–implant construct is based on the angular stability of the plate–screw interface and not on friction between the plate and bone resulting from tightly applied screws.

Implant Concept. Fixed-angle devices have been tested mechanically and clinically and compared with implants without a fixed angle.[58, 61, 80, 105] A mechanical evaluation of the LISS in a paired human cadaver model used randomly selected femurs instrumented with a five-hole LISS in the distal end.[23] In the first series of paired femurs, the LISS was compared with a six-hole DCS, and in the second series it was compared with a seven-hole 95° CBP. A 1-cm gap was cut to mimic a group A3 fracture. The load was applied proximally through the "head of the femur" and distally through the lateral condyle. The applied cyclical load was increased in four stages (F_{min} = 100 N; F_{max} = 1000 N, 1400 N, 1800 N, 2200 N) for 10 cycles each.

Three different systems fixed on paired cadaver human femurs, LISS versus CBP and LISS versus DCS, were compared with respect to their potential to withstand applied load. During the loading cycles, the construct underwent reversible as well as permanent deformation. The total irreversible deformation for LISS was 51% lower than DCS and 62% lower than the CBP system. Ten of 12 paired tests showed more subsidence in the conventional bicortical fixation technique.

Bicortical fixation seems unnecessary with these plates because the plate itself mimics the second cortex. Without any need to penetrate the far cortex, self-drilling screws are possible[118] and facilitate percutaneous fixation. Drilling, length measurement, tapping, and screw insertion are all combined into a single screw insertion procedure. A correct insertion angle of the screw into the plate is necessary to allow interlocking of the screw to the plate, which can be ascertained with the LISS aiming guide. Distal fixation is designed to respect the anatomy of the distal end of the femur. The angles between the screws and the LISS are chosen to prevent screw penetration into the intercondylar notch or the knee. The LISS allows placement of seven long screws into the condyles.

The surgical technique differs from that for conventional open reduction.[120] The approach closely matched the technique used for plate placement as described for intra-articular[64] and extra-articular fractures.[65]

Preoperative Planning. A preoperative radiograph of the whole femur with good exposure of the knee joint, preferably including the hip joint, is necessary. Radio-

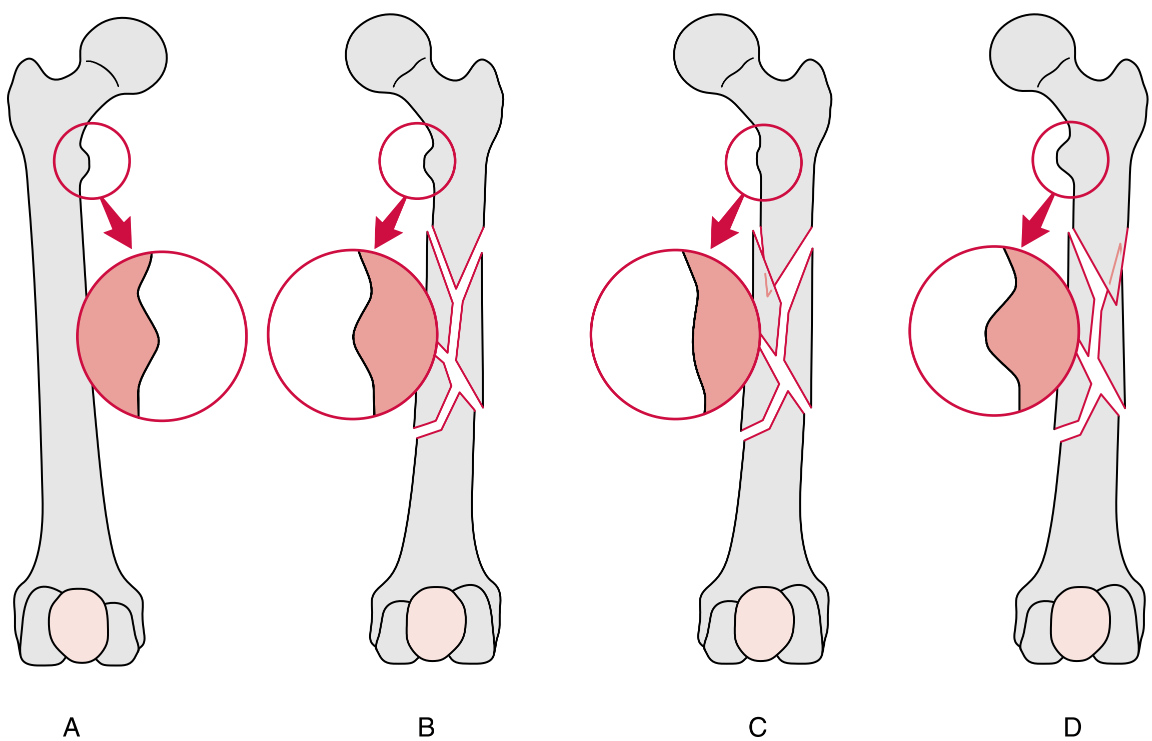

FIGURE 53–29. Lesser trochanter shape sign (Krettek et al., 1997). Radiologic determination of rotation intraoperatively by comparison of the shape of the lesser trochanter on the ipsilateral and contralateral sides. *A,* Preoperatively, before positioning the patient, the shape of the lesser trochanter on the contralateral side is stored in the image intensifier's memory, whereas the position of the patella is controlled and oriented strictly in an anterior direction. *B,* Before locking the second main fragment, the patella is oriented in a strictly anterior direction, whereas the proximal fragment is rotated until the shape of the lesser trochanter on the ipsilateral side matches the contralateral shape. *C,* In the event of an external rotation deformity, the shape of the lesser trochanter is diminished. With the patella pointing in a strictly anterior direction, the lesser trochanter is partially hidden by the proximal femoral shaft. *D,* In the case of an internal rotation deformity, the shape of the lesser trochanter is enlarged. With the patella pointing in a strictly anterior direction, the lesser trochanter is less hidden by the proximal femoral shaft.

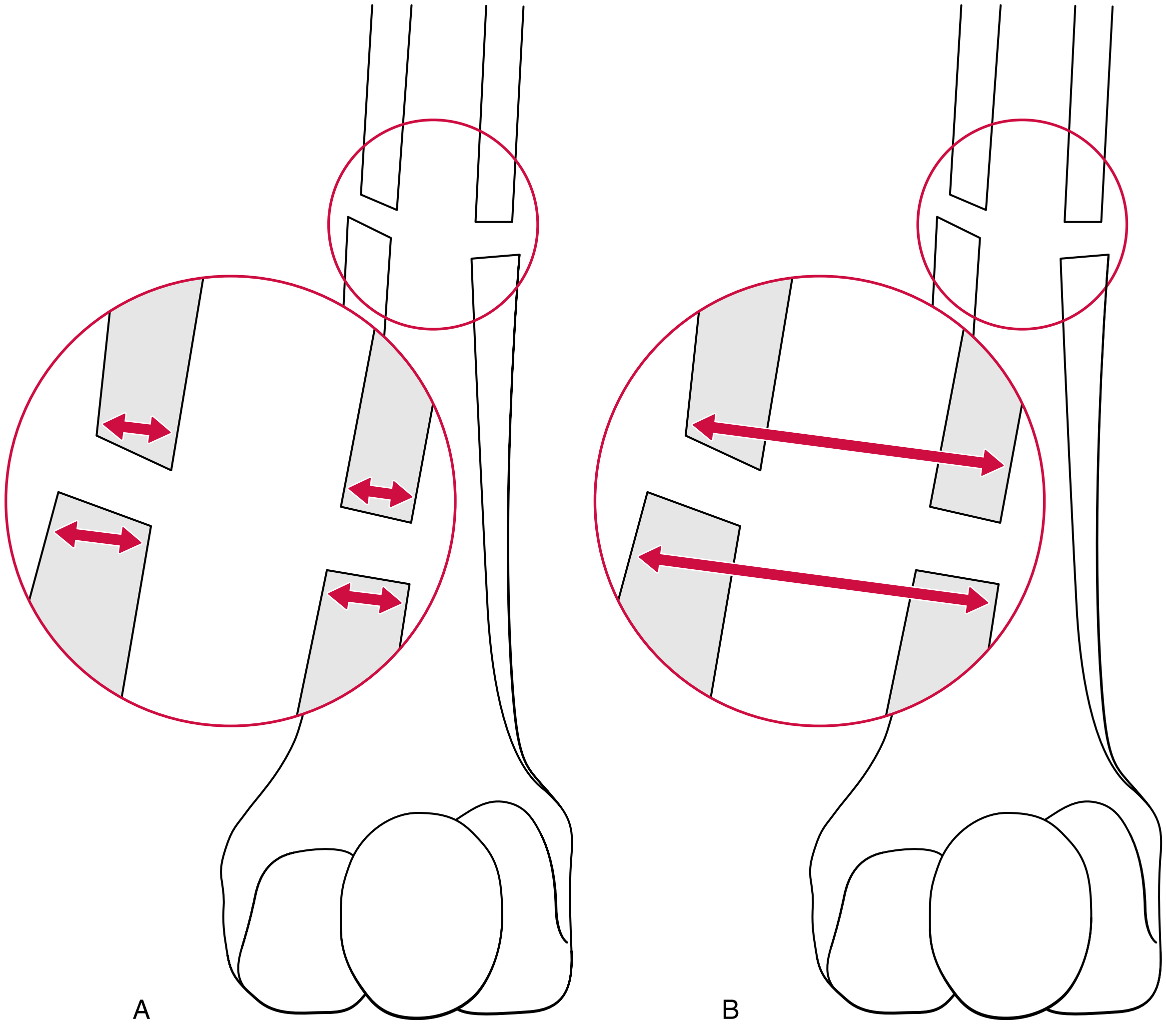

FIGURE 53–30. Radiologic determination of rotation intraoperatively by the cortical step sign and the diameter difference sign (Krettek et al., 1997). *A,* Cortical step sign. In the presence of rotational deformity, the cortical structures of the proximal and distal main fragments can be projected in different thicknesses. *B,* Diameter difference sign. This sign is positive at levels at which the diameter is oval rather than round. In these cases, the transverse diameters of the proximal and distal main fragments can be projected as different diameters.

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graphic preoperative selection of screw length is possible with an AP radiograph of the knee and the LISS radiographic calibrator placed medial or lateral at the height of the femoral condyles. The length of the calibrator on the film is measured, as well as the width of the femoral condyles. By tracing both measurements on the screw length table, one of four groups of screw lengths is chosen. The length of the plate should be long enough to ensure possible placement of at least four screws in the proximal fragment. To choose the correct approach, the fracture is classified according to the AO classification.[88] Group A fractures are best fixed from a short lateral approach. Group B and C fractures with intra-articular displacement are fixed through an anterior transarticular approach with a lateral parapatellar arthrotomy.

Approach. Type A distal femoral fractures and group C2 fractures without intra-articular displacement are stabilized with the previously described percutaneous approach (MIPPO)[64] (Fig. 53–39). The skin incision is guided by an orthograde femoral condyle projection (medial and lateral condyle shadows superimposed) in an

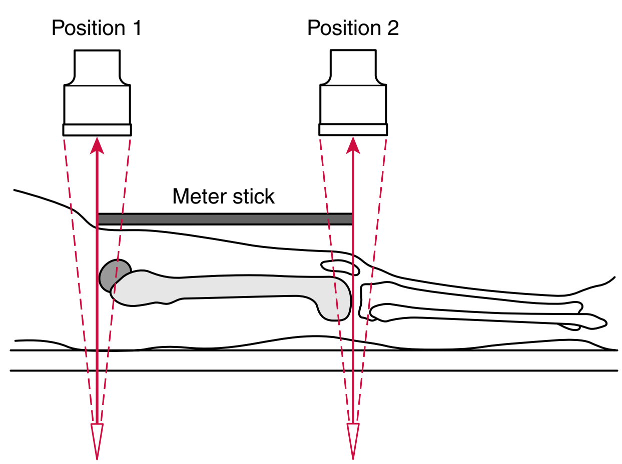

FIGURE 53–31. Technique for analysis of femoral length in a drawing depicting the arrangement of the patient, image intensifier, and meter stick for analysis of femoral length discrepancies (Krettek et al., 1997). Correct measurement requires orthograde projection of both the meter stick and bone. The point of measurement must be in the center of the image display, with the central ray perpendicular to the long axes of both the femur and meter stick.

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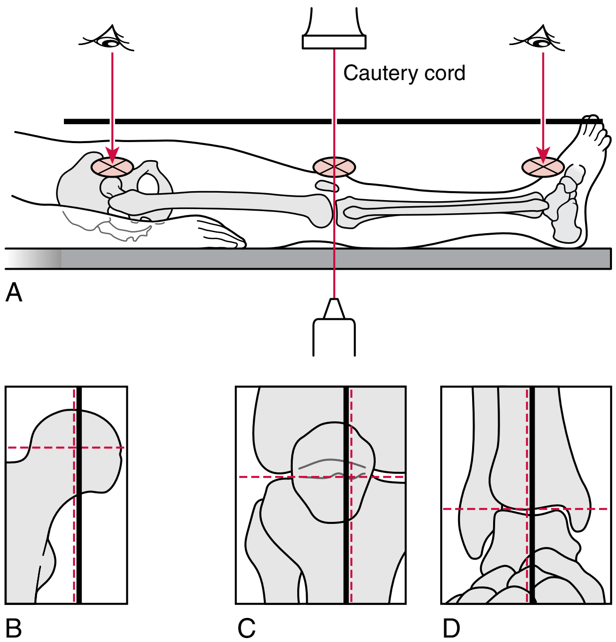

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FIGURE 53–32. Cable method for analysis of frontal-plane deformity. To assess frontal-plane alignment, the electrocautery cable is stretched from a position over the center of the femoral head to the center of the tibiotalar joint to radiographically display the mechanical axis of the lower extremity. With the knee in extension and rotated so that the patella is in the midline, the image over the knee joint demonstrates where this axis crosses the knee joint. This view permits quantitative assessment of alignment and comparison with the opposite leg. Normally, the mechanical axis is 10 ± 7 mm medial to the midline of the knee (see Chapter 62).

intensified view of the lateral image. The incision is made in line with the axis of the femoral shaft starting at the joint line and going proximally. This approach is not adequate for C3 fractures and type B fractures or for group C2 fractures with intra-articular displacement. For such injuries, we use TARPO[65] (Fig. 53–40). The incision for TARPO is enlarged proximally along the interval between the rectus and vastus lateralis muscles and splits the fibers of the quadriceps tendon. It is carried distally to the tibial tubercle. With displacement of the patella medially, the femoral condyles are fully exposed without disrupting the soft tissues from the bone. Direct anatomic joint reconstruction can be performed with K-wires, screws, and resorbable pins. Placement of lag screws between the femoral condyles must be planned to avoid the LISS and its screws.

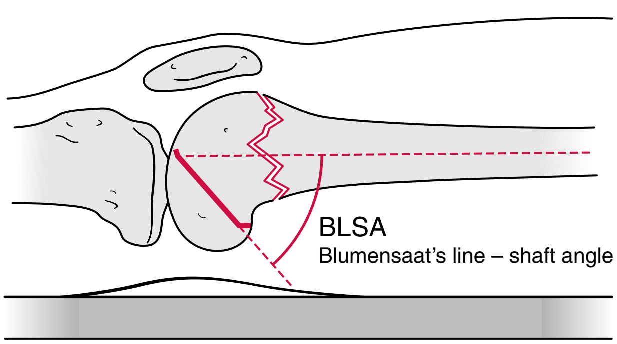

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FIGURE 53–33. Blumensaat's line-shaft angle (BLSA) as an intraoperative guideline for correct alignment in the sagittal plane (Krettek et al., 1997). With the knee flexed 30°, this line is reported to intersect the lower pole of the patella. However, during reconstruction, we recommend that BLSA be adjusted so that it is equal to that of the opposite femur.

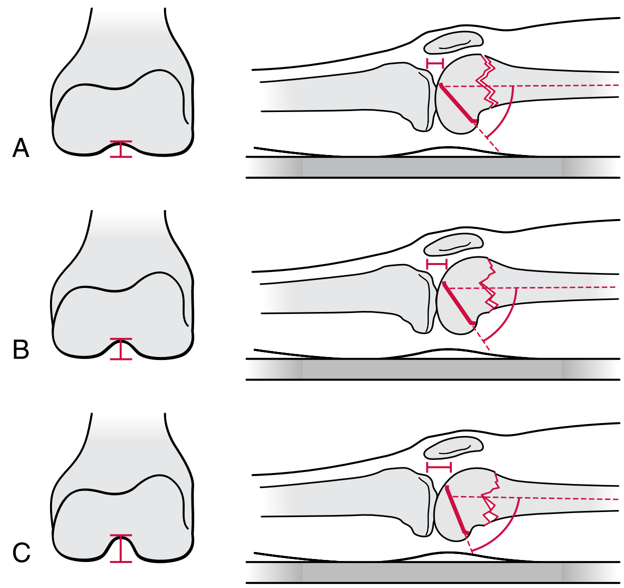

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FIGURE 53–34. Recurvatum deformity in the distal end of the femur (Krettek et al., 1997). *A,* Normal appearance of the intercondylar notch with the knee centered in the x-ray beam. *B, C,* The increasing recurvatum deformity is difficult to detect if only the shape of the condyles is analyzed. However, the increased height of the intercondylar notch on the anteroposterior view and the increased Blumensaat line-shaft angle in the lateral view help detect and quantify the recurvatum deformity

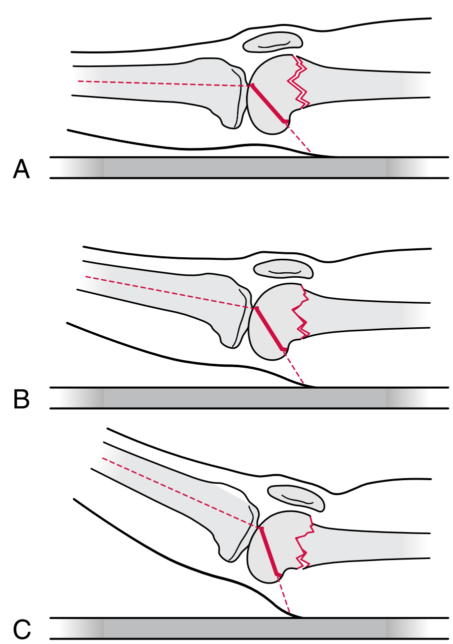

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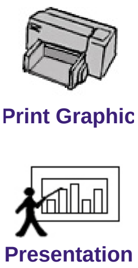
FIGURE 53–35. Hyperextension test for recurvatum (Krettek et al., 1997): schematic representation of the effects of recurvatum deformity. *A,* Extension within normal limits (slight overextension between 5° and 10°). *B* and *C,* Recurvatum deformity results in pathologic overextension, depending on the amount of recurvatum deformity.



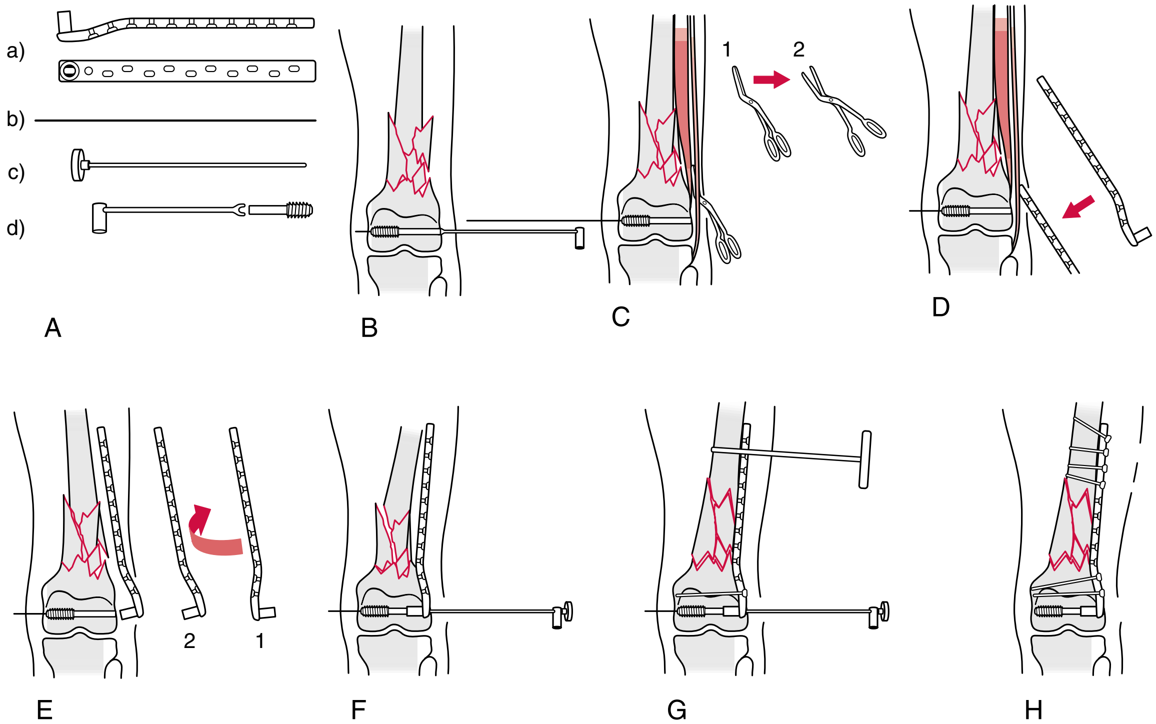
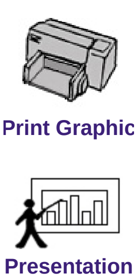


Figure 53–36. Instruments and step-by-step procedure for minimally invasive percutaneous plate osteosynthesis (MIPPO). *A,* Modified dynamic condylar screw (DCS) instruments. *B,* Screw insertion. *C,* Splitting of the iliotibial tract. *D,* Insertion of the DCS side plate. *E,* Side plate rotation and preparation for assembly. *F,* Side plate sliding on the DCS screw. *G,* Fixation of the plate to the shaft. *H,* Completion of MIPPO.



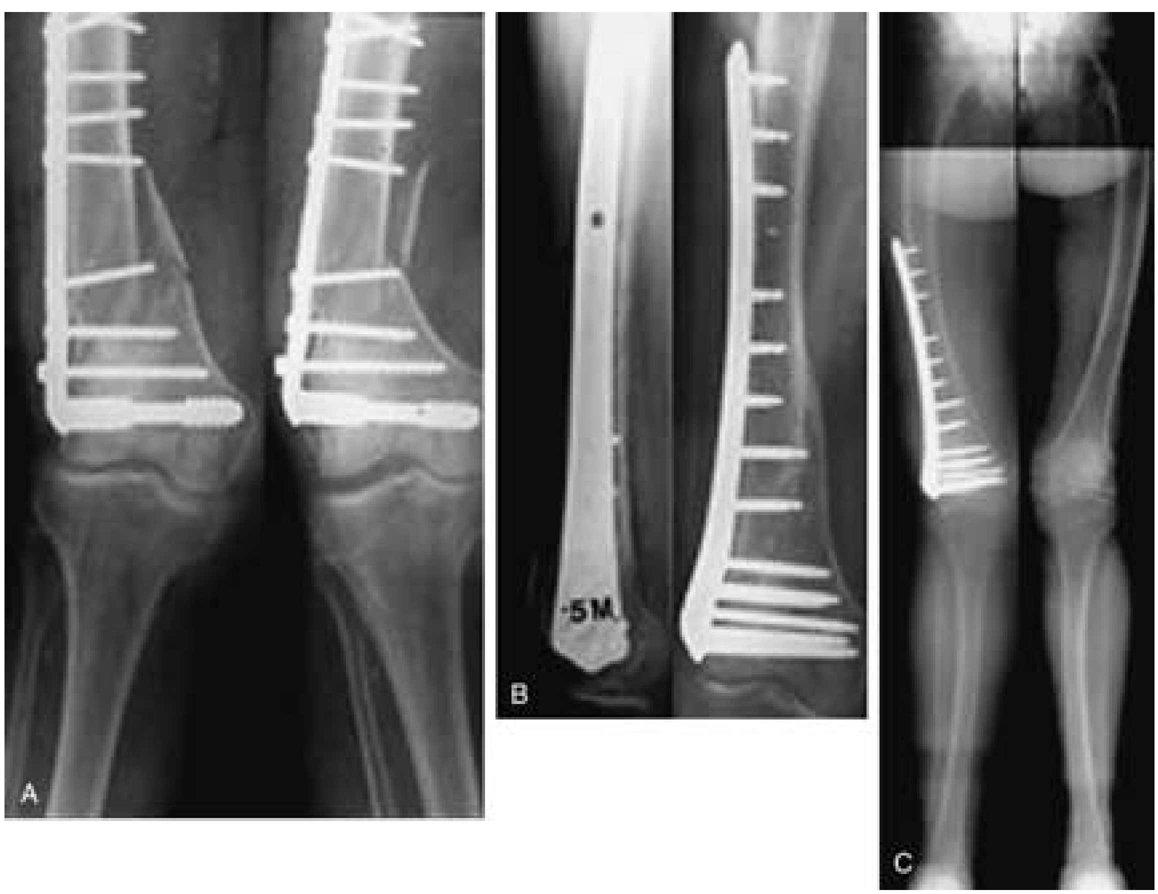


Figure 53–37. Treatment of instability 1 week after dynamic condylar screw (DCS) fixation in an 86-year-old woman. *A,* Radiographs showing the degree of instability with a “windshield wiper effect.” *B,* Healed fracture after 5 months. *C,* Long leg standing views.

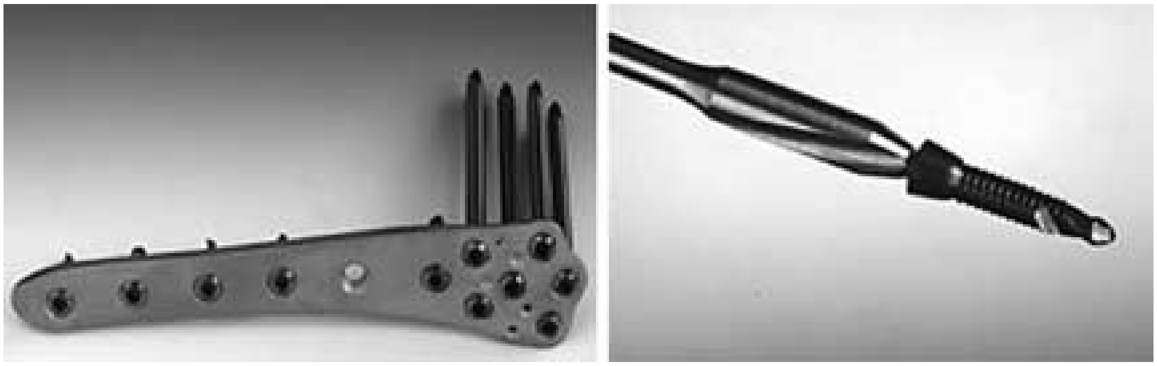


FIGURE 53–38. Less invasive stabilization system (LISS) with monocortical, self-drilling, and self-tapping screws and screwdriver.

Reduction Aids. After reconstruction of the condylar block, reduction of the block to the proximal fragment is performed with indirect reduction techniques. It is important to realize that this reduction needs to be accomplished before the LISS is definitively fixed to the femur. If manual traction is insufficient, a distractor or a temporary external fixator is useful. In extra-articular fractures, Schanz screws are inserted into either the distal and proximal main fragment or the proximal end of the tibia or medial condyle.

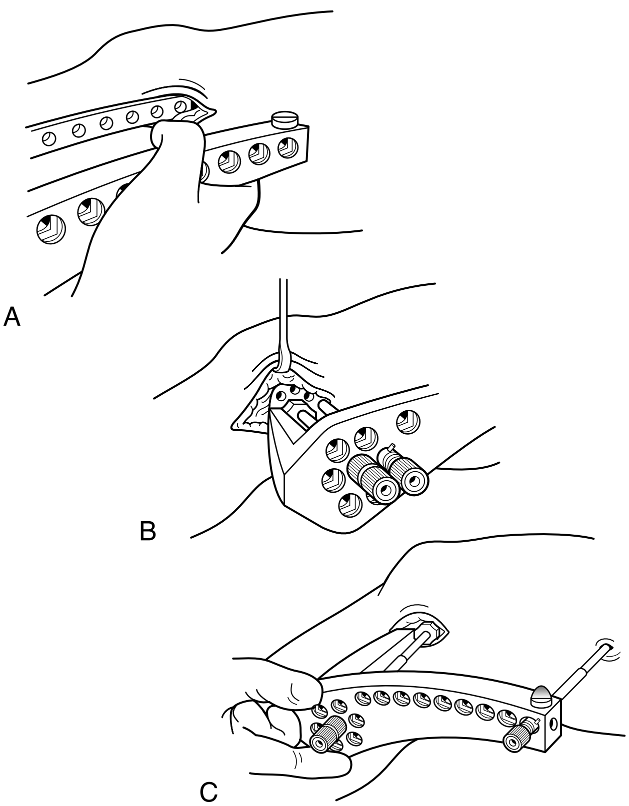


FIGURE 53–39. Insertion of the less invasive stabilization system (LISS) through the minimally invasive percutaneous plate osteosynthesis (MIPPO) approach. *A,* Sliding the LISS along the lateral cortex. *B,* Positioning of the end of the LISS on the lateral condyle. *C,* The stabilization bolt is inserted into the most proximal hole.

Instruments. The LISS set consists of different insertion guides for the left and right sides, a torque-limited (4.0 Nm) screwdriver, stabilization and fixation bolts for the aiming arm, an aiming device for K-wires, and a tensioning device. The LISS is connected to the insertion guide with a fixation bolt, which has to be inserted into the central distal hole (hole A). The fixation bolt is fixed into the LISS and tightened. For better stabilization during insertion, a stabilization bolt is inserted into hole B, the next proximal hole to hole A. After insertion of the LISS underneath the vastus lateralis muscle, the second stabilization bolt is changed from hole B to the most proximal hole to enhance the stability of the LISS–insertion guide construct (see Fig. 53–39).

Implant Insertion. The LISS with its insertion guide is introduced between the iliotibial tract and the periosteum under the vastus lateralis muscle while feeling the tip of the LISS slide along the bone. The LISS is moved proximally and then back distally toward the knee until it has good contact with the lateral femoral condyle. Care is taken to keep the insertion guide at angle of approximately 15° to the sagittal plane to fit to the condyles. Were it orientated strictly in the sagittal plane, a gap between the anterior distal part of the LISS and the lateral femoral condyles would result. This gap might restrict knee motion because of anterior hardware prominence and could direct the distal femoral screws too anteriorly.

Fixation of the LISS. In any intracondylar fracture, the condyles are fixed first through an anterior transarticular approach with a lateral parapatellar arthrotomy and carefully placed lag screws, K-wires, or both, followed by determination of the correct position of the femoral condyles. The distal end of the LISS is positioned approximately 1 to 1.5 cm proximal to the joint line. Because of the weight of the insertion guide, the LISS has a tendency to move toward external rotation and create a gap between the condyles and the LISS. Careful biplanar fluoroscopy is recommended to ensure the right position of the LISS at the condyles to avoid a position that is too far anterior. The condylar block usually has a tendency to rotate into a recurvatum position because of pull of the gastrocnemius muscle. This complication can be prevented by putting a pillow under the distal end of the femur and flexing the knee.

When correct alignment has been achieved, the LISS is preliminarily fixed to the condylar block with K-wires in

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Figure 53–40. Transarticular approach and retrograde plate osteosynthesis (TARPO) for an intra-articular fracture stabilized with a less invasive stabilization system (LISS). *A,* LISS plate with distal locked screws and insertion guide with distal and proximal stabilizing bolts in place. *B,* Insertion of the LISS through the TARPO approach after reconstruction of the comminuted articular portion of a C3 fracture. *C,* Lateral preoperative radiograph. *D,* Anteroposterior (AP) preoperative radiograph. *E,* Appearance of the leg immediately after wound closure. *F,* AP radiograph 2 months after fixation. *G,* Lateral and AP radiographs of the healed fracture 7 months after injury.

hole A and additional K-wire holes. The direction of the K-wires is checked with the image intensifier to verify that they are running parallel to the distal edge of the femoral condyles. If not done preoperatively, the screws for distal fixation are chosen by a single direct fluoroscopic measurement of condylar width with a ruler.

The position of the LISS on the femoral shaft must also be verified because of the tendency for the proximal end of the LISS to be placed too far anterior on the femoral shaft. Such placement can cause the screw to be inserted at a tangent and result in insufficient holding strength (Fig. 53–41). Good purchase of monocortical screws requires a true lateral position of the LISS on the femoral shaft.

Preliminary fixation to the femoral shaft is done with a K-wire through the proximal fixation bolt, and the tension device is inserted into the second hole to further ensure fixation and contact between the LISS and bone (Figs. 53–42 and 53–43) so that alignment can be checked. Additional screws are then seated in the proximal and distal fragments. An irrigated drilling guide is used to reduce the heat generated by insertion of the self-drilling screws.

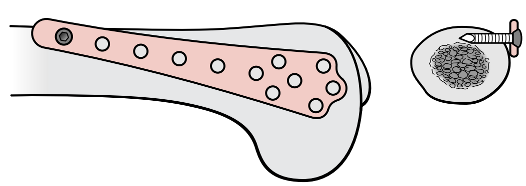

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Figure 53–41. Placement of the proximal end of the less invasive stabilization system (LISS) too far anterior causes tangential placement of screws and dangerously reduces holding strength.

FIGURE 53–42. *A,* Tensioning instrument. *B,* Reduction with the tensioning instrument to push the less invasive stabilization system (LISS) onto the femur.

Insertion of the first screw can displace the femoral shaft away from the LISS and cause loss of reduction. Because the screws are locked into the LISS regardless of whether they have any grip in the bone, care is needed to ensure adequate resistance during the drilling phase.

At least four screws should be used in the proximal as well as the distal main fragment. A "stopper" for insertion guide holes can be used to mark screws as they are inserted.

Tips and Tricks for Reduction. The first screw in each main fragment determines length and rotation. Because the screw head is threaded and locks into the plate, it is impossible to pull the plate and bone together as it is with traditional unthreaded screw heads. Thus, the LISS instruments include a plate-seating device ("tensioning instrument") consisting of a monocortical self-drilling 4.0-mm screw with a long-threaded shaft. A nut on this shaft is turned to pull the femoral shaft and LISS together (see Fig. 53–42).

When the LISS is used, preliminary reduction must be accomplished first. The stability of the osteosynthesis is not dependent on contact and friction between the plate and the bone. The LISS acts like an internal fixator. Some space between LISS and bone can be tolerated, and to improve alignment, it is sometimes necessary to vary the distance from the bone to the LISS. The plate-seating device can be used to push the plate onto the bone. The 4.0-mm screw gets good purchase in the lateral femoral cortex, and the plate and bone can be approximated. In the metaphyseal area, this plate-seating device usually pulls out of the thin cortex, so additional help is needed. In this region, a large gap between the LISS and the femur disturbs knee motion. To avoid impairment of knee motion, a pointed forceps or a pointed hook retractor can be used to hold the LISS in place until it is securely fixed.

Small frontal-plane deformities can be compensated by loosening the distal screw with a few turns. After reduction under fluoroscopic control (cable technique), the screw can be retightened and the position fixed. With a slight deviation in angle between the LISS and screw, angled interlocking is possible, although major angular changes (>5°) require complete screw removal. Reduction is performed while the LISS is fixed to the bone with K-wires. A change in length and rotation cannot be done without taking all the screws out either proximally or distally.

Postoperative Treatment. Postoperative care is the same for conventional and minimally invasive approaches. Patients are initially exercised on continuous passive-motion machines. They are allowed partial weight bearing (15 to 20 kg) and are advanced to full weight bearing when their postoperative radiographs demonstrate callus. In multiply injured patients, the postoperative treatment is adapted to treat the other associated injuries. Casts and splints are not used. Implant removal is facilitated by the use of a specifically designed MIPPO plate remover.

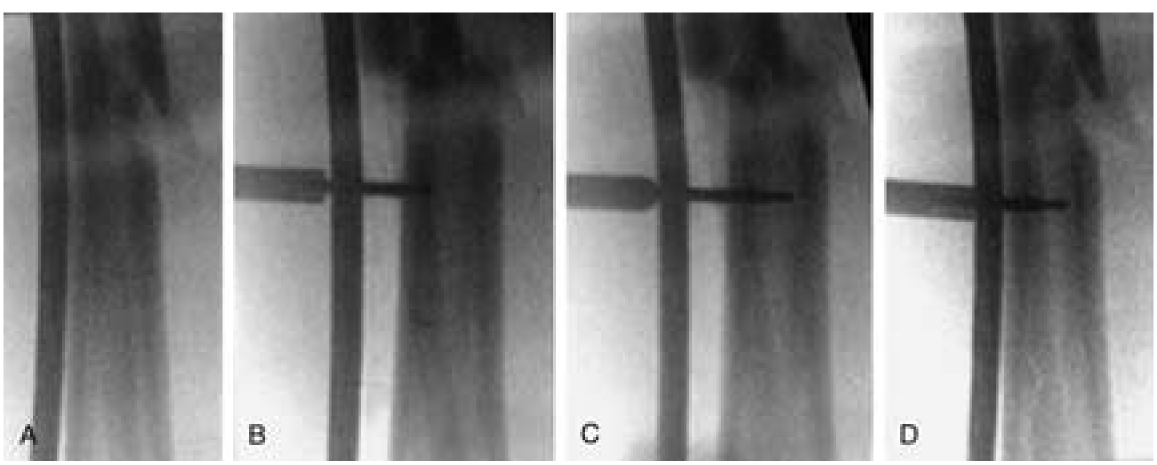

FIGURE 53–43. *A,* Reduction before insertion of the tensioning instrument. *B,* Loss of reduction. *C,* Tensioning instrument driven into place. *D,* Use of the tensioning instrument.

Intramedullary Nail Fixation

Antegrade Interlocking Intramedullary Reamed Nail. It is possible to stabilize supracondylar femoral fractures with an antegrade reamed IM locked nail. Previously, most authors recommended that the fracture be at least 10 cm from the joint line; however, Leung and co-workers[71] in 1991 treated all ASIF type A, type C1, and type C2 fractures within 9 cm of the knee joint. Butler and associates,[10] also in 1991, treated similar patterns of supracondylar-intercondylar femoral fractures associated with ipsilateral femoral shaft fractures with an antegrade interlocked IM rod. The criterion for the distal fracture was that it be within 5 cm of the epiphyseal scar. In both series, intra-articular fracture components were anatomically aligned and preliminarily stabilized before insertion of the locked nail. Dominguez and colleagues have also confirmed satisfactory use of antegrade nailing for distal femoral fractures.[21]

If the intercondylar component was displaced, Butler and associates advocated supine nailing on a radiolucent operating room table, without traction, to allow visualization of the articular cartilage through a parapatellar arthrotomy. Two lag screws were routinely used for fixation of the intracondylar fracture to ensure screw placement in the anterior and posterior portions of the femoral condyles and thereby prevent the screws from impeding subsequent passage of the nail. The arthrotomy was then closed, the patient reprepared, and closed antegrade IM rodding performed. This procedure is much more technically demanding than standard femoral shaft IM nailing and requires a great deal of experience with IM nailing of femoral fractures. Intraoperatively, attention must be directed to maintaining axial alignment, length, and rotation, especially when the procedure is done on a fracture table with the patient in the lateral decubitus position, because the tendency is to then fix the distal fragment in an externally rotated and valgus position. If at all possible, the supine position with use of a distal femoral traction pin is preferable for distal femoral fractures, and specific attention must be paid to maintaining alignment during nail insertion.

Because correct placement of the locking screws necessitates very distal nail insertion, the choice of nail length is extremely important. Leung and co-workers[71] cut the distal 15 mm from the rod to shorten it to just below the distal screw hole. The tip of the nail was then driven as close to subchondral bone as possible. Bucholz and colleagues[9] reported on nail breakage in distal femoral fractures, especially through the distal interlocking screw holes. Most occurred within 5 cm of the fracture after IM nailing with distal interlocking, and these authors cautioned about its use for fractures with significant comminution or for very low fractures. Given these concerns, Butler and associates[10] recommended restricted weight bearing and had no implant failures in their series.

Retrograde Intramedullary Nailing for Distal Femoral Fractures. Retrograde IM nailing from an intra-articular, intercondylar approach was introduced during the late 1980s and continues to increase in popularity for more proximal femoral fractures, as well as the distal ones for which such nails were first introduced.[37, 38] Like antegrade IM nailing, this technique offers indirect reduction with less soft tissue exposure and theoretically less interference with fracture healing than occurs with plate fixation through the conventional lateral approach. Proximal and distal locking screws help maintain reduction. However, direct exposure and adequate reduction with supplementary internal fixation are still required for intra-articular fractures, nail insertion does not restore alignment of metaphyseal fractures as it does in the diaphysis, and theoretical concerns about knee joint damage have not been answered with long-term follow-up studies, although problems have not been obvious. Furthermore, initial clinical series have shown some problems with delayed union. However, as experience increases, it appears that for properly selected type A and C fractures and with carefully planned, well-executed procedures, retrograde IM nailing offers a valuable addition to our armamentarium, particularly for floating knees,[31, 92] significant soft tissue injuries, and obese patients and after suitable knee replacement arthroplasties. Retrograde nailing is an advantageous and attractive option for patients with ipsilateral hip fractures. Although extensive intercondylar comminution involving the nail entry site makes retrograde nailing challenging and may contraindicate it, many C1 and some carefully chosen C3 fractures can be treated with retrograde IM nails after adequate articular segment reduction and fixation.

The GSH nail, a short retrograde nail with multiple locking screws and a small sagittal-plane bend several centimeters above its distal end, was the first extensively used retrograde IM nail. It is cannulated for insertion over a guide wire and has an insertion guide for placement of proximal and distal locking screws. Like other short IM nails, it has had some problems with fractures adjacent to its tip, often related to difficulty inserting diaphyseal locking screws. Such problems can be avoided with longer nails that extend to the lesser trochanter. Shorter nails can be valuable when an intramedullary implant such as a hip prosthesis is already present, although subsequent fracture between the two IM devices remains a hazard. Several manufacturers have now developed locking IM nails for retrograde use in the femur, and efforts to improve their design and instrumentation continue. Several issues are common to all of them.

Retrograde IM nailing for distal femoral fractures has certain challenges: (1) the surgeon must reduce the fracture because the nail does not do it automatically. (2) A correct entry site is essential. For an intra-articular fracture (type C1, C2, or C3), the intra-articular components must be reduced anatomically and fixed securely, usually with independent lag screws, in a way that will not interfere with insertion of the nail and that is stable enough so that insertion does not disrupt or destabilize the reduction. (3) The nail must not protrude into the joint. (4) Intraoperative confirmation of alignment (frontal, sagittal), rotation, and length is necessary. (5) Proximal locking is required.

These challenges can be met by careful preoperative planning and meticulous technique.

Planning. Preoperatively, with an AP radiograph of the intact knee positioned so that the patella is in the midline, the anatomic axis of the femoral diaphysis is drawn. This line is extended across the knee joint to show the location of the proper nail entry site on an AP radiograph. The joint line is drawn, and the angle laterally between it and the mechanical axis is measured. This anatomic lateral distal femoral angle is normally 81° ± 2°, and duplication of the angle by fracture reduction during nail insertion and distal locking will provide symmetric varus/valgus alignment. Attention must be paid to femoral rotation and to sagittal-plane angulation at the fracture site because they can affect this measurement. Preoperative assessment of the intact lateral radiograph of the distal end of the femur, with the anatomic axis of the femoral shaft drawn in, permits confirmation of the entry site on the lateral view, where it is also the intersection of the mechanical axis and the knee joint surface. Sagittal-plane alignment of the distal femoral fracture may be difficult to determine by inspection of the cortical surfaces, but it can be quantitated well by using the angle made by Blumensaat's line and the anatomic axis (see Fig. 53–33). Similarly, the alignment assessment tools presented earlier (see Figs. 53–28 to 53–35) should be used to ensure that adequate alignment is achieved during retrograde IM nailing. Thus, preoperatively it is important to assess the length of the intact side (see Fig. 53–31), particularly if fracture comminution makes it hard to determine and if there are rotational clues such as the radiographic appearance of the trochanteric region with the knee axis horizontal (see Fig. 53–29) and the arcs of internal and external rotation of the hip (see Fig. 53–28). The internal diameter of the femoral shaft is measured on AP and lateral views to estimate the probable diameter of the nail after reaming has been carried out, usually to a size 1 to 2 mm greater than the diameter of the nail.

Technique. The patient is positioned supine on a radiolucent table. The fluoroscope can be on either side of the table but must permit unobstructed view of both entire femurs in the AP, lateral, and oblique planes. The entire involved limb is prepared from the lower part of the abdomen and iliac crest to well below the knee and sterilely draped to permit free manipulation. A percutaneous "stab" incision as described earlier can be used if the fracture does not involve the articular surface. If it does, exposure must be adequate to reduce and fix the condyles and assess the entry site during insertion of the nail. Either a medial or a lateral parapatellar incision, similar to the TARPO approach, will serve. The entry site and direction of its proximal prolongation must be fluoroscopically confirmed on AP and lateral views, which can be done by inserting a guide wire and, once it is properly positioned, passing a cannulated drill over this wire. Correct knee flexion, over a bump of variable size, is essential (see Fig. 53–13).

Once a proper entry site is prepared, a reaming guide wire is inserted across the fracture and proximally into the intertrochanteric region. Reduction can be aided with a Schanz screw in the proximal segment (Fig. 53–44), perhaps one placed for initial temporary external fixation. Femoral alignment during reaming and nailing can be aided by the use of a properly positioned and adjusted external fixator or femoral distractor. Nail length is chosen to allow proximal locking in the metaphyseal bone with its thinner cortex, unless proximal femoral hardware must be accommodated. Reaming through the isthmus and sufficiently proximally to accommodate the diameter of the nail is carried out incrementally with cannulated reamers over the guide wire, and debris is carefully removed from the knee. Enough reaming to permit easy nail insertion is essential because too tight a fit might require excessive force and threaten reduction or associated injuries. Nail insertion must be done precisely, with maintenance of alignment of the nail in the distal segment, which is difficult when the medullary diameter at the fracture site is typically several times larger than the diameter of the nail. Precise insertion is aided by leg positioning and the use of external fixation or manipulating pins or clamps on the distal segment. The nail must be inserted to a proper depth, 1 mm or more below the articular cartilage.[85] Once there, the position of the nail in the distal end of the femur can be stabilized by insertion of its locking screws, aided if required by "Poller" (positioning) screws (Fig. 53–45).

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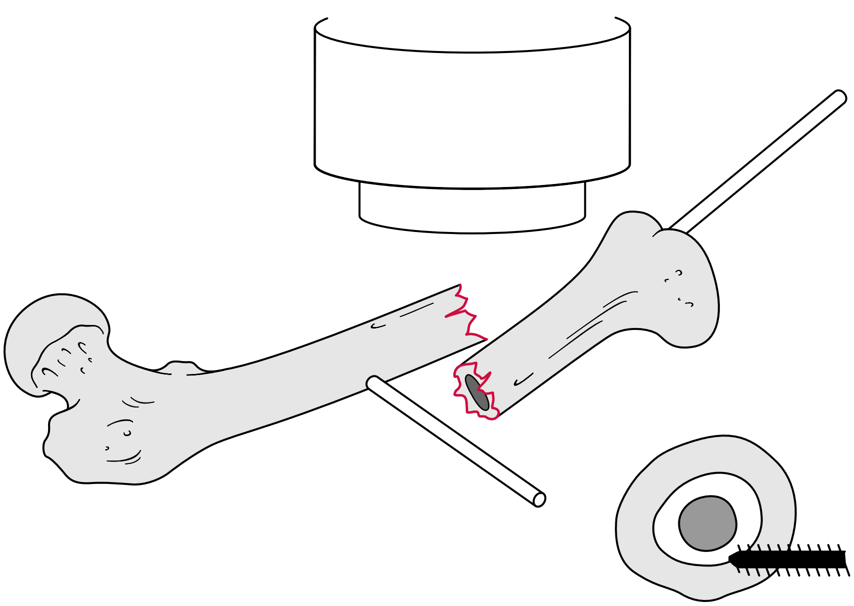

FIGURE 53–44. Reduction technique in retrograde nailing. Reduction is facilitated by the use of Schanz screws in the proximal main fragment.

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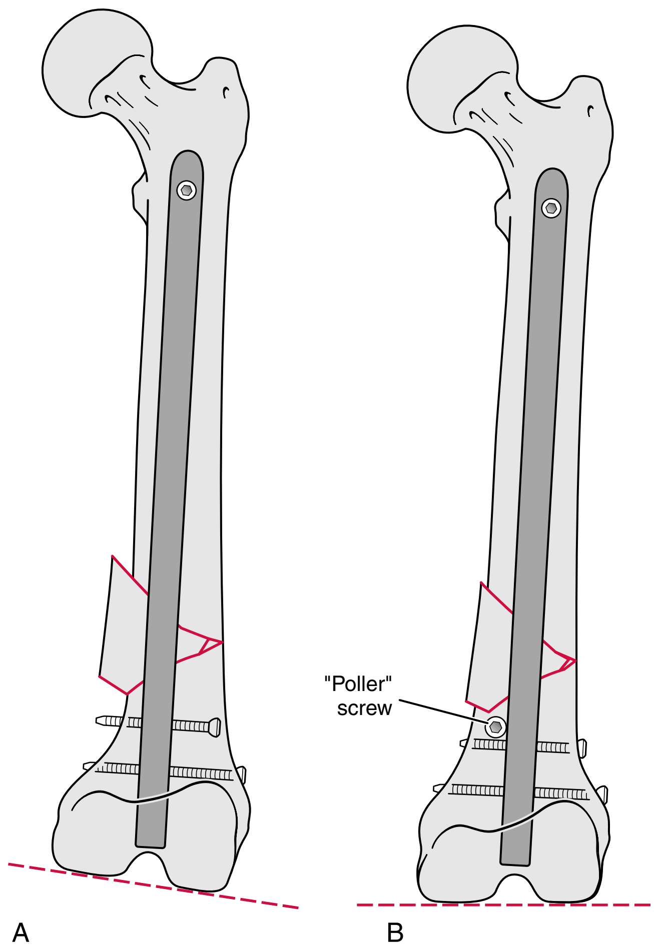

FIGURE 53–45. Poller screw principle in retrograde nailing. Poller screws help prevent malalignment and increase the stability of the bone-implant complex.

After insertion of the nail to an appropriate depth and during distal locking of the nail, it is essential to confirm satisfactory alignment with the techniques described earlier (see Figs. 53–28 to 53–35). Definitive AP alignment is done with the mechanical axis–"cable" technique. Sagittal-plane alignment is quickly checked with the hyperextension test (see Fig. 53–35) and more precisely with Blumensaat's line-shaft angle (see Fig. 51–33). Once the angulation is correct, length and rotation are adjusted as needed, and proximal locking is carried out, typically "freehand" in the AP or lateral directions under fluoroscopic guidance, in accordance with the design of the chosen nail. Depending on contact stability of the fracture fragments, either "static" (round hole) or the easier "dynamic" (oval hole) locking may be selected. Locking through the ample soft tissues of the proximal part of the thigh requires care to avoid neurovascular structures, which are theoretically outside the screw tract, and also attention to maintain control of the screw (a suture around it facilitates retrieval if necessary).[96] After locking, alignment should be reconfirmed. If still satisfactory, the knee is thoroughly irrigated to remove any reaming debris, the subchondral position of the nail, including any "end-cap," is confirmed, and the wound is closed in layers, with a drain used only if bleeding is significant. Although range of motion can and should begin as soon as possible, weight bearing should be protected until fracture healing is sufficient at both the articular and more proximal sites.

Several series have reported on the use of supracondylar IM nails as an alternative to standard AO internal fixation methods in the treatment of some supracondylar-intercondylar distal femoral fractures.[18, 39, 45, 72, 131] Clinical results now appear to be fairly similar. It is important to remember that retrograde IM nails do not provide as much stability as fixed-angle 95° implants,[60, 78] which may compromise the care of some injuries, but the optimal fixation stiffness for distal femoral fractures remains unknown.

SPECIFIC CONSIDERATIONS AND RECOMMENDATIONS

Because of the tremendous diversity of fractures encountered in the distal end of the femur, specific techniques are required for their stabilization. Fracture types are discussed according to the Müller classification. The fixations described are those recommended and used by us.

Type A Fractures

Extra-articular distal femoral fractures are subdivided into type A1 (noncomminuted), type A2 (metaphyseal wedge), and type A3 (comminuted) fractures. They are best stabilized with a fixed-angle device, either the 95° CBP or the DCS. In type A1 fractures, temporary reduction of the supracondylar component can be obtained with the use of crossed K-wires. In type A2 and A3 fractures, it is important to preserve the vascularity of all fracture fragments. To accomplish supracondylar reduction and fixation without unnecessary devascularization, the indirect techniques proposed by Mast and co-workers should be used.[74] The condylar fragment is stabilized, and the 95° blade plate or condylar screw is inserted as previously described. Additional lag screws are required in the distal plate holes to stabilize the implant to the condylar fragment. With only a small malreduction or limited comminution in the supracondylar region, distraction for fracture reduction can be achieved by using the AO/ASIF articulated tension device in the reversed mode. The tension device is fixed to the femoral shaft with a 4.5-mm cortical screw, just proximal to the proximal tip of the side plate. The hook on the tension device is reversed and inserted under the proximal end of the side plate in a notch designed for this purpose. Spreading the tension device distracts the fracture by pushing the fixed-angle plate with the attached condyles distally. Distraction and reduction can be checked by fluoroscopy. If necessary, individual large fragments can be teased into reduction on the medial side with the use of a dental pick or small instrument. Again, care must be taken to avoid unnecessary soft tissue stripping. Once reduction has been accomplished, lag screw fixation of these fragments can be achieved through the plate. The tension device is then reversed, the hook is placed in the proximal hole of the side plate, and axial compression is applied across the fracture before insertion of the proximal plate screws (see Fig. 53–26).

With more significant comminution, as in a severe type A3 supracondylar fracture, the reversed tension device may not provide enough distraction to allow atraumatic reduction of the fragments. The AO femoral distractor is an excellent device for this purpose and should be used because of the tremendous mechanical advantage that it allows, not only for distraction but also for maintenance of axial alignment and rotational control of the distal fragment; moreover, use of the AO distractor precludes the necessity of exposing the multiple supracondylar fragments to achieve reduction (see Fig. 53–27). First, the blade plate or condylar compression screw is inserted into the distal end of the femur as described previously. Precise orientation of the blade or screw, as preoperatively planned from a radiograph of the normal side, is essential. One of the distractor bolts or a 5-mm Schanz screw is then inserted into one of the distal two holes of the plate. A second bolt or Schanz screw is inserted into the femur well proximal to the plate. Before insertion of these two bolts, the surgeon should correct rotational alignment. The bolts or Schanz screws for the distractor must be inserted parallel to each other in the frontal plane to maintain axial alignment. By turning the adjusting nut on the femoral distractor, the supracondylar fracture can be distracted to restore axial length and alignment. Fracture reduction is facilitated by overdistraction and by visualizing the fracture on the fluoroscope. Commonly, the fracture fragments are reduced according to the principle of "ligamentotaxis" through the application of tension on the soft tissue attachments. As with the reversed tension device, a dental pick can be used to gently tease in major fragments on the medial side and avoid unnecessary soft tissue stripping. Atraumatic bone clamps are applied if necessary, followed by lag screw fixation of the larger comminuted fragments to each other or to the plate.

If cortical contact has occurred, the distraction can be released, axial compression can be applied proximally with the tension device, and the proximal plate can be fixed to the shaft with 4.5-mm cortical screws. However, if comminution is severe or a bone defect is noted in the supracondylar region, after distraction of the fracture and restoration of axial alignment, rotation, and length, the proximal plate should be held to the femoral shaft with a Verbrugge clamp and fixed with 4.5-mm cortical screws without addressing the comminuted supracondylar area. The surgeon then must assess medial stability. Lack of medial cortical contact as a result of severe comminution or a bone defect may cause the fixed-angle device to fail through cyclical loading. If medial cortical contact is not present or delayed healing is likely, additional medial support with a T plate through a limited medial exposure is indicated. (Adjunctive medial bone grafting is also indicated; see later discussion.) IM nailing, either antegrade or retrograde, is another option for type A distal femoral fractures. Restoration and maintenance of normal alignment are essential.

Type B (Unicondylar) Fractures

Type B1 and B2 Fractures. A type B1 or B2 distal femoral fracture is a unicondylar fracture of either the lateral or medial condyle. The fracture is exposed through a small medial or lateral incision. The condyle must be anatomically reduced and held temporarily with K-wires. In young patients with firm cancellous bone, stable fixation can be achieved with the use of 6.5-mm cancellous screws (32-mm threads) and washers. However, in elderly patients with osteoporotic bone, additional fixation is required. The use of a buttress plate that allows cancellous screw fixation through the distal holes is preferred. Similarly, to counteract the potential for sheer and proximal fracture migration, an antiglide or buttress plate is indicated if the condylar fracture line extends into the proximal metadiaphyseal area. A well-contoured T buttress plate with 6.5-mm cancellous lag screws distally, 4.5-mm cortical screws proximally, and lag screws across the fracture line is recommended.

Type B3 Fractures. A type B3 unicondylar distal femoral fracture is a coronal fracture through the femoral condyle (Hoffa fracture). The possibility of both condyles being involved should be remembered. Preoperative CT scanning may be very helpful. As with B1 and B2 injuries, a medial or lateral incision is necessary to expose the articular condyle. Anatomic reduction of the articular surface is mandatory; the reduction is temporarily stabilized with K-wires. Permanent stable fixation is accomplished with lag screws inserted in the AP direction at a right angle to the plane of the fracture. The screws should be inserted as far laterally or medially as possible to avoid the articular cartilage. The size of the fragments determines the size of the screw. For larger fragments, 6.5-mm cancellous screws with 16-mm threads should be used, whereas 4-mm cancellous screws are used for smaller fragments. If it is necessary to insert the screws through articular cartilage because of the particular fracture morphology, the screw heads should be countersunk. Occasionally, screws are best inserted posteriorly, directly across the condylar fracture.

Osteochondral Fractures. Osteochondral fractures of the femoral condyles are not uncommon. Sometimes it is difficult to differentiate fractures caused by osteochondritis dissecans from those caused by an acute traumatic episode. If the fracture occurs in the patellofemoral articulation or in the weight-bearing region of the femoral condyles or if it is large enough, it should be anatomically reduced and stabilized with small screws, countersunk as required, or absorbable pins.

Type C Fractures

Type C fractures are bicondylar supracondylar femoral fractures that separate both condyles from each other and from the femoral shaft.

Type C1 and C2 Fractures. Type C1 and C2 fractures are bicondylar supracondylar fractures without intercondylar comminution. Type C2 is complicated by additional supracondylar comminution. The implant of choice is a fixed-angle device, either the 95° blade plate or the condylar compression screw. Of prime importance is anatomic reconstruction of the vertical component of the intercondylar fracture and thus reconstruction of the articular surface, which is accomplished temporarily with provisional K-wire fixation and then definitively with the use of 6.5-mm lag screws, as described in the section on use of the 95° blade plate (see Fig. 53–26). Once the condyles are reconstituted to one fragment, the fracture pattern is converted to type A2 or A3, depending on the presence of supracondylar comminution. The technique for stabilization of the condyles to the shaft is then identical to that previously described for type A2 or A3 supracondylar fractures. If intramedullary fixation is chosen, it is essential that the articular condyles first be reduced anatomically and securely fixed with lag screws. Great care should then be taken to maintain this reduction and ensure anatomically normal alignment during insertion and locking of the nail.

Type C3 Fractures. The most complex and difficult of all the distal femoral fractures is a type C3 fracture, which has both supracondylar and intercondylar comminution. This lesion often necessitates a more extensile approach involving bilateral approaches or an osteotomy of the tibial tubercle to ensure an adequate view of the femoral condyles from below. The first step is anatomic reconstruction of the articular surface, which is not always possible because of articular damage, impaction, or severe comminution. However, if possible, it should be accomplished provisionally with the use of K-wires. Definitive fixation of the articular fragments is then accomplished with lag screws. Optimally, they should be inserted through the nonarticular portions of the joint. If not possible, every attempt should be made to avoid inserting the screws through the weight-bearing area of the joint surface, and the screw heads should be countersunk below the level of the articular cartilage. Special types of screws such as Herbert and Acutrak screws should be considered, as should absorbable fixation pins.

If significant comminution is present between the condyles, it is important to not narrow the intercondylar distance and hence the femoral articulation with either the tibia or the patella. In this situation, intercondylar screws across the area of the comminution should be inserted as position screws and not as lag screws. A corticocancellous iliac crest bone graft can also be fashioned to fill the defect and allow increased stability and possibly lag screw fixation across the condyles. The use of a 95° blade plate or a condylar compression screw is optimal. If correctly inserted, they not only restore axial alignment but also, by virtue of the fixed angle, provide better long-term stability. However, in low supracondylar fractures and those with significant intercondylar comminution or condylar bone loss, it may not be possible to obtain stability of the blade or the condylar screw. Additionally, in fractures with significant comminution, especially in the coronal plane, condylar lag screw fixation may preclude the ability to insert a fixed-angle device. In these instances, the implant of choice has been the condylar buttress plate, which allows multiple lag screw fixation in the condyles (see Fig. 53–24). Although the condylar buttress plate is an excellent salvage device for more complicated fractures, it poses significant inherent problems, as discussed earlier. Axial alignment is more difficult to obtain, and fixation failure may occur with repeated cyclical loading. Intraoperative fluoroscopy or radiography is necessary to confirm the alignment; often, additional medial support to prevent long-term varus malalignment is indicated. Plates with locking screws (LISS, locking condylar plate) may therefore be better choices for these complex distal femoral fractures. Once the articular portion of the distal end of the femur is reconstructed, the condylar block is reattached to the shaft as previously described for type A3 comminuted supracondylar fractures.

Frontal-Plane Fractures

Fracture lines in the frontal (coronal) plane are found in type B3 and C3 distal femoral fractures (Fig. 53–46*A*). They produce fragments that are largely, if not totally, articular without extra-articular sites for screw fixation. Frontal-plane fracture fragments are often quite thin. Finding a place to put screws that provide good fixation but do not encroach on the joint is often quite challenging. Helpful techniques for dealing with these injuries—cortical bone "washers" and threaded screw washers—are illustrated in Figure 53–49*B* to *D*. K-wires and absorbable pins offer supplementary assistance.

Temporary Shortening–Secondary Lengthening

In the presence of soft tissue and bone defects, temporary shortening plus secondary lengthening is a good option in situations without sufficient soft tissue coverage in the original length. Later, the soft tissue can be covered in either a single step with a flap in combination with bone reconstruction or continuously.

Definitive Shortening

Definitive shortening is a simple and safe option in patients with bilateral metaphyseal comminution or contralateral amputation.

Periprosthetic Fractures above Total Knee Arthroplasty

Supracondylar femoral fractures after total knee replacement are complex injuries that present numerous potential complications. They can significantly alter the integrity of the total knee implant. This increasingly prevalent injury is common enough to be encountered by many surgeons. However, it is still sufficiently rare that few have significant experience with this injury. DiGioia and Rubash[20] defined fractures after total knee arthroplasty as being in the supracondylar region if they were within 15 cm of the knee joint. In addition, fractures occurring within 5 cm of the most proximal extent of the IM stem of a knee prosthesis should be included in this definition. Predisposing factors for fracture after total knee arthroplasty include notching of the anterior femoral cortex, preexisting neurologic disorders, osteopenia, conditions that induce osteopenia (e.g., rheumatoid arthritis, steroid use), and revision arthroplasty with distal femoral bone loss.[17, 20] A wide variety of treatment options have been used in treating distal femoral fractures after total knee arthroplasty, including skeletal traction, brace immobilization and casting, rigid plate-and-screw fixation, IM rodding, and full revision arthroplasty with an IM stem to fix the fracture. The most appropriate management of these injuries has not been clearly defined.

The first reports of periprosthetic distal femoral fractures appeared in the literature in the early 1980s. Hirsch and colleagues,[41] Merkel and Johnson,[77] and Figgie and associates[27] concluded that initial treatment of supracondylar femoral fractures after total knee arthroplasty

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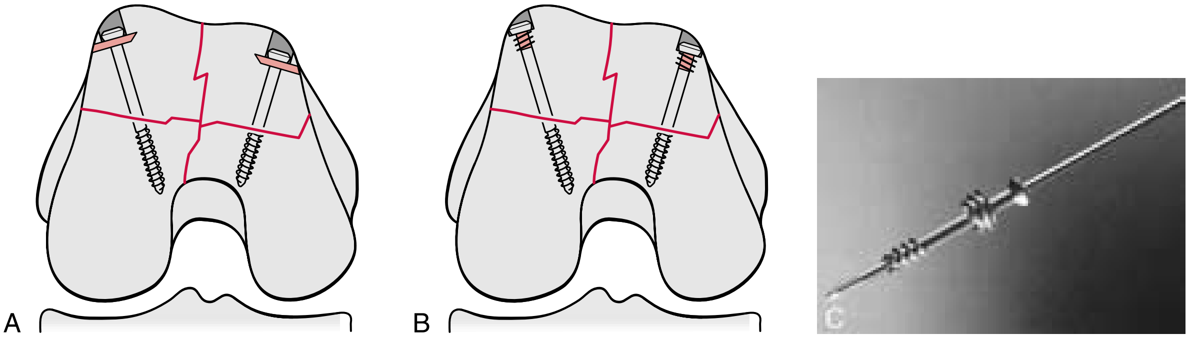

FIGURE 53–46. Problems and solutions for frontal-plane fractures. Fixation of a frontal-plane fracture components with 4.0-mm screws. The subchondral bone is usually mechanically strong. However, insertion and countersinking of the screw results in an articular cartilage defect. Placing the screw obliquely, from outside the articular cartilage, results in weak screw fixation. *A,* Schematic drawing of a solution involving a "biologic washer" made out of a piece of cortical bone from the supracondylar zone. It is inserted from the lateral direction, outside the cartilage, to reinforce the screw head's anchorage. The bony washer increases the contact surface and holding power of the screw. An additional screw should be placed more proximally in the articular fragment to stabilize its fixation. *B,* Schematic drawing of a similar fracture repaired with small screw-threaded washers to augment screw fixation. *C,* Photograph of a threaded washer, which is screwed into the bone to lie flush with its surface (Synthes).

should be nonoperative, with closed reduction, traction, and cast bracing. When satisfactory alignment cannot be maintained with such conservative treatment, open reduction with rigid internal fixation is indicated, provided that the bone stock is adequate.[27, 77]

In contrast, Culp and co-workers[17] found that the best treatment of all fractures was early open reduction followed by early motion. Bogoch and associates[4] supported early treatment with ORIF after having significant difficulty maintaining fracture reduction by closed means. Garnavos and colleagues[29] treated seven patients with displaced fractures above a knee prosthesis by traction. Four of these patients later required a surgical procedure to treat malunion or nonunion. However, five of six patients with similar injuries treated operatively returned to their prefracture activities. Garnavos and colleagues concluded that displaced fractures above a knee prosthesis should be treated by immediate stable internal fixation and early mobilization and that nonoperative treatment was satisfactory only for undisplaced fractures. Figgie and associates[27] suggested that in the event of implant loosening at the time of fracture, a Neer grade III fracture, or a grade I or II fracture without adequate bone stock, immediate revision arthroplasty with a custom prosthesis and distal femoral allograft is indicated to minimize prolonged immobilization.

Chen and colleagues,[12] in a multicenter review in 1994, incorporated the experience of many investigators to examine the success of operative and nonoperative procedures. They found an 83% rate of satisfactory results in Neer grade I fractures treated conservatively. In contrast, only a 64% rate of satisfactory results was achieved in displaced fractures, and no statistical difference was found between the operative and nonoperative groups. Based on an operative complication rate of 7.4% for deep infection, a 1.2% perioperative death rate, a nonunion rate of 7.4%, and a malunion rate of 3%, they suggest that conservative treatment is a better initial option, especially in elderly patients with underlying osteoporosis and medical problems. If nonoperative treatment fails to achieve a satisfactory outcome, secondary surgical intervention is advocated. The authors found that the results of a salvage operation are not compromised by the initial trial of nonoperative treatment. In fact, revision arthroplasty was found to have a success rate of 91%, and they concluded that in the treatment of Neer grade II periprosthetic fractures, revision arthroplasty is superior to ORIF.[12] Based on these findings, we recommend the following treatment algorithm for supracondylar femoral fractures after total-knee replacement:

Type I (Nondisplaced Fractures). Use nonoperative methods first; if the fracture becomes displaced, go to type II treatment.

Type II (Displaced/Comminuted Fractures). If the prosthesis is loose, revise.

Choose ORIF if

1. The patient is unable to tolerate prolonged bedrest.
2. Bone is of sufficient quality to hold screws.
3. The patient has multiple or bilateral fractures.

Choose traction if

1. The patient can tolerate bedrest.
2. Acceptable alignment is achieved.
3. Bone is of poor stock, thus precluding ORIF.
4. The patient has a high risk of infection.

A very similar treatment protocol has been proposed by Digioa and Rubash.[20]

The advent of the GSH and other supracondylar femoral nails provided another option for the treatment of supracondylar femoral fractures above a total knee prosthesis. Rolston and co-workers[98] reported results equal to those achieved with revision arthroplasty. Functional outcome also seemed better in patients managed with the GSH nail versus ORIF with a plate-and-screw implant. Jabczenski and Crawford,[48] in a preliminary small study of retrograde nailing for the treatment of four supracondylar femoral fractures above total knee implants, reported that all fractures had healed and were fully weight bearing at 4 months. However, McLaren and associates[76] warned that the GSH nail is not indicated in any fracture in which the femoral component is loose.

Because of their good fixation even in osteoporotic bone, the LISS and locking condylar plate are excellent options for suitable periprosthetic fractures in which the prosthesis is secure and the fracture configuration permits satisfactory application of these devices (Fig. 53–47).

Supracondylar femoral fractures above a total knee implant are difficult fractures to treat optimally.[111] A wide variety of treatment options are available to the orthopaedic surgeon, including brace immobilization, skeletal traction, open reduction with plate-and-screw fixation, retrograde IM rodding, and revision arthroplasty with a long-stem prosthesis. Although many authors recommend conservative treatment for this injury, the trend is toward operative stabilization to ensure anatomic realignment and early mobilization of the knee joint.[20]

When confronted with a supracondylar fracture above a total knee arthroplasty, the surgeon's first obligation is to assess the integrity of the bone–prosthesis interface. Accurate evaluation is often impossible until the prosthesis is seen in place during surgery. Therefore, the surgeon should be prepared for both femoral and tibial revision with a more constrained prosthetic design. Revision arthroplasty with intramedullary stabilization is indicated for patients whose knee arthroplasties have failed because of instability, stiffness, loosening, or component failure and for patients who have extremely distal or comminuted fractures complicated by femoral metaphyseal osteoporosis.[40]

Technically, when performing revision procedures, femoral bone stock should be preserved and every attempt made to maintain intercondylar continuity. Reconstruction is easier if the two condyles are maintained as one unit. If comminution is present along with loss of ligamentous stability, a more constrained prosthesis with an IM stem is indicated. Often, even with tight-fitting stems, it is difficult to maintain femoral length because of comminution and osteopenia of supracondylar bone stock. Bone allograft consisting of a femoral head or the entire distal end of the femur may be needed.[29] The tendency toward proximal migration of the joint line should be avoided because it retards flexion and transmits increased stress to the femoral components. The patellofemoral articulation can serve as a guide to joint placement.[40]

Internal fixation is recommended for fractures in which the prosthesis has a stable interface with the condyles, provided that adequate bone stock is available distally to permit fixation. Modern plating techniques, though very successful in younger patients with supracondylar distal femoral fractures, have met with limited success in the treatment of fractures above an implant because of the paucity of distal bone stock and the poor quality of bone available for fixation. The GSH supracondylar femoral nail has the advantage of allowing internal fixation without opening the fracture site, thus facilitating early rehabilitation. When applied to periprosthetic fractures above total knee arthroplasties, the nail is placed through the intercondylar notch of the femoral component. The nail is available in 12- and 13-mm diameters and fits through many standard implants. However, a preoperative sunrise radiograph should be obtained to measure intercondylar distance before surgery. The GSH nail can be used only when the prosthesis is one that provides access to the femoral medullary canal through the intercondylar entry site.[48] Although preliminary results are encouraging,[48, 98] this device is in investigational stages and requires further study. As mentioned earlier, distal femoral fixation plates with fixed-angle locking screws are another alternative to consider.

Bone Grafting

All patients undergoing ORIF of distal femoral fractures should have the ipsilateral iliac crest prepared sterilely in case adjunctive bone grafting is necessary. For comminuted supracondylar fractures (either in elderly patients or in younger patients after high-energy trauma) and for fractures in which adequate medial stability cannot be achieved at the time of fracture reduction and stabilization, primary medial autogenous cancellous bone grafting is indicated. For fractures with significant bone devascularization, such as high-energy or open fractures, bone grafting is also indicated. However, the timing of grafting depends on the condition and control of the soft tissues. If at all in doubt, bone grafting should be delayed after severe soft tissue injuries. In fractures necessitating additional medial plating (i.e., when significant instability or a bone defect is present), bone grafting is also indicated. The liberal use of autogenous cancellous bone graft in supracondylar femoral fractures with bone loss, severe comminution, or bony devascularization helps preserve the integrity of the implant until bone healing can occur.

The intercondylar portion of the distal end of the femur is well vascularized, and nonunion is very rare. The only indication for intercondylar bone grafting is for significant comminution or bone defects, especially between the condyles. By fashioning a well-contoured corticocancellous graft, the defect can be spanned to permit compression fixation between the condyles and increase the stability of the construct.

Most investigators recommend the use of autologous bone graft when medial comminution or bone loss is present.[30, 81, 99, 103] Recently, however, Ostrum and Geel[93] prospectively investigated the use of indirect reduction techniques, as described by Mast and co-workers,[74] without supplementary bone graft for the treatment of

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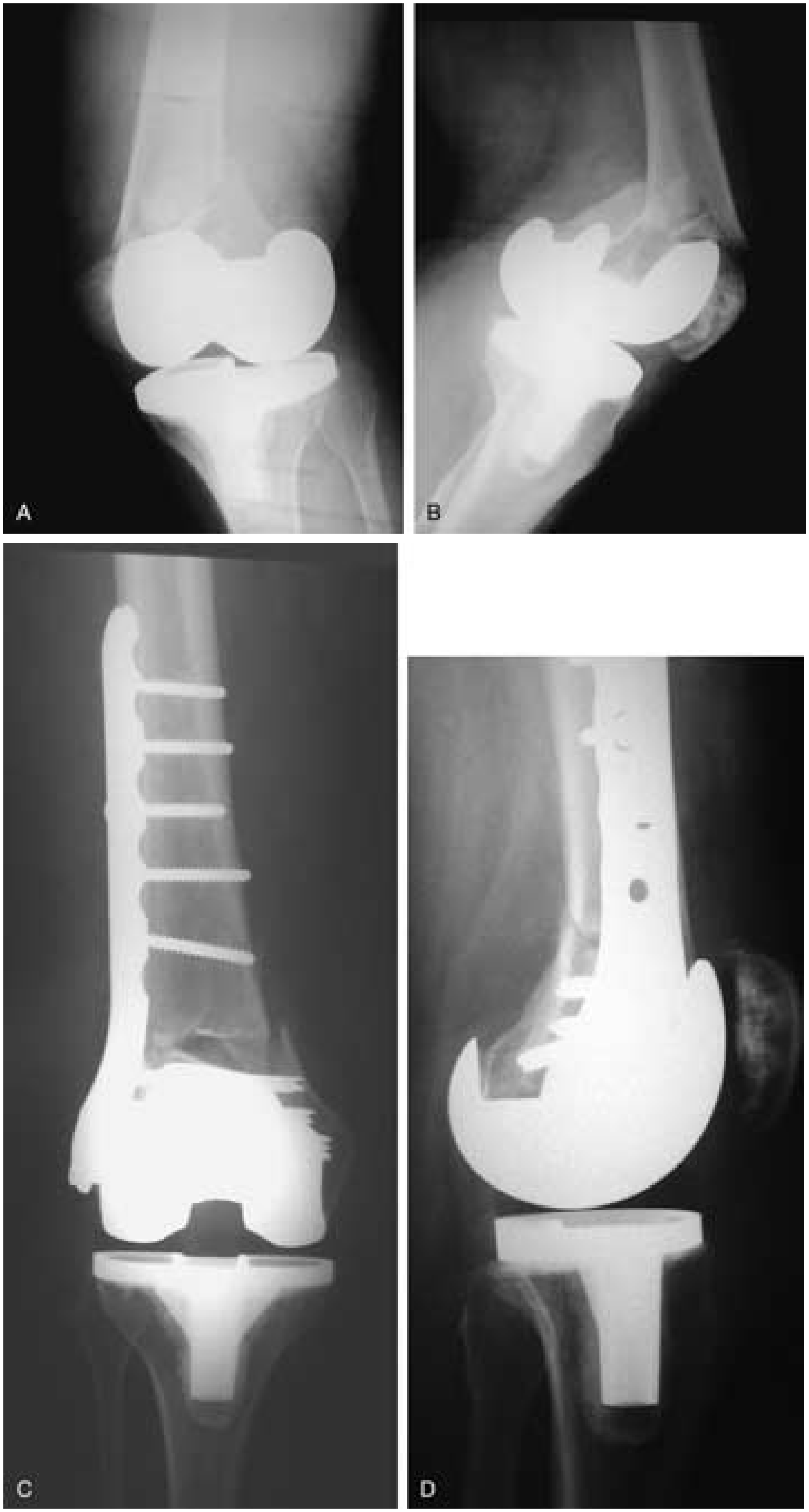

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FIGURE 53–47. Fixation of a periprosthetic supracondylar fracture with a locking plate. *A, B,* Preoperative anteroposterior and lateral radiographs. *C, D,* Healing fracture with anatomic alignment 10 weeks after repair. (Case of John Froehlich, M.D., Brown University, Providence, RI.)

supracondylar-intercondylar fractures of the femur. The obvious advantages include not only avoidance of the need for additional bone graft surgery but also preservation of medial bony and soft tissue vascularity. These authors reported excellent to satisfactory results in 86.6% of patients treated with this technique. Most of the failures, they believed, resulted not from the indirect reduction techniques but rather from the extent of the bony injuries. They suggested that this technique may not be suitable for severe open fractures or when marked osteoporosis is present; for such cases, they recommended standard bone graft techniques. Similar good results were reported by Bolhofner and associates.[5] Bone loss, wide displacement, or injury-related soft tissue stripping may require a medial bone graft. Rather than going around the fixed fracture and causing additional devascularization, the graft can be inserted through the fracture site before it is fixed or, alternatively, through a small medial incision. Also through a medial incision, formation of an adequate bony medial buttress can be encouraged by fixation of a corticocancellous graft, as illustrated in Figure 53–48.

Adjunctive Fixation Techniques

Bone Cement (Liquid Injection). In elderly patients with severe osteoporosis, the holding power of screws is often inadequate to provide stable fixation. Screw fixation can be greatly enhanced with the use of methyl methacrylate. It is advisable to keep both the methyl methacrylate powder and the liquid methyl methacrylate refrigerated before use to slow the polymerization process down. Questionable screws are removed, and the precooled methyl methacrylate is mixed and (while liquid) poured into a 30-mm plastic syringe. It is then injected into the screw holes under pressure. (To facilitate this process, it is useful to widen the tip of the syringe with a 3.5-mm drill bit.) The screws are then inserted into their respective holes but are not fully tightened. Once the cement hardens, the screws are tightened the final few turns. This technique greatly enhances the stability of the screw–bone interface and provides more stable fixation. Care must be taken to avoid extravasation of the methyl methacrylate into the fracture site because in this location it may interfere with fracture healing. In addition, if the distal cortex of a screw hole is intra-articular, the insertion of methyl methacrylate under pressure is contraindicated to avoid extravasation of cement into the joint.

Bone Cement (Dough Insertion Technique). Struhl and colleagues[117] described a different technique for methyl methacrylate enhancement of screw fixation in osteoporotic patients with supracondylar-intercondylar femoral fractures. The proximal end of the distal fragment is cleaned of all cancellous bone by curette and saved as bone graft. A dynamic compression screw is then placed in the distal fragment. Methyl methacrylate in its doughy state is finger-packed to fill the distal fragment and surround the screws. Care is taken to exclude cement from the fracture site. The proximal fracture fragment is then approached by removal of cancellous bone from the medullary canal. A cement restrictor is placed in the proximal femoral canal above the proposed level of the plate. The canal is then filled with relatively liquid cement. Again, cement is kept from the fracture site. The cement is allowed to harden, and reduction is accomplished. The dynamic compression screw–side plate construct is rotated into place along the proximal shaft, and the AO tensioning device is used to give maximal compression. The proximal screw holes are then filled after drilling and tapping through the hardened intramedullary cement. Bone graft is packed around the fracture site. The authors stated that this technique provides sufficient fixation in osteoporotic patients to allow early motion and partial weight bearing.

Cerclage Wires. The use of adjunctive cerclage wire fixation may be indicated in elderly patients with osteoporotic bone. To avoid devascularization of the fracture, its use should not be indiscriminate, but one or two cerclage wires in the supracondylar area may occasionally help restore reasonable fragment alignment and thereby provide greater stability.

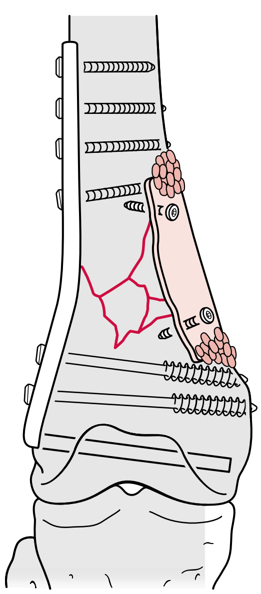

Figure 53–48. Bone grafting technique in the presence of large medial defects (Krettek and Tscherne, 1994). To avoid additional soft tissue disruption, the corticocancellous graft is inserted through a separate medial approach and fixed with small-fragment screws.

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FOLLOW-UP CARE AND REHABILITATION

Postoperatively, the area from the groin to the toes is covered by a soft, bulky dressing. Müller and colleagues[86] recommended immobilization of the knee at 90° of flexion on a Böhler-Braun frame for 3 to 4 days. Following the work by Driscoll and co-workers,[22] it became apparent that immediate continuous passive motion not only enhances cartilage healing but also helps prevent quadriceps contractures, decreases swelling, and enhances early knee motion. Use of the continuous passive-motion machine immediately after surgery is tolerated better by the patient if the joint is injected before wound closure with 20 mL of 0.5% bupivacaine with epinephrine (1:200,000). Continuous passive motion is maintained full-time until ambulation is commenced on the third to fourth postoperative day and thereafter used only intermittently while the patient is in bed. In conjunction with this treatment, the patient initiates active exercises of the quadriceps and hamstring musculature on postoperative day 2. Gait training on days 3 to 5 progresses from use of the parallel bars to a walker or crutches, with weight bearing as determined by intraoperative stability of the fixation. If stable fixation has been achieved, the patient can begin immediate minimal weight bearing (20- to 30-lb loading). Active physical therapy and limited weight bearing with crutches or a walker are continued until clinical and radiographic evidence of fracture healing. At this point (usually 2 to 3 months after surgery), the patient progressively increases weight bearing and resistance exercises until solid union is achieved at about 4 to 6 months.

The necessity for additional support is determined by the presence of additional or associated injuries, the type of reduction, and the stability of fixation obtained at the time of surgery. In patients who have associated ligamentous disruptions of the knee, functional bracing or cast bracing is indicated to control motion in the allowable range and yet allow early active mobilization of the knee. However, the primary indication for additional external support is tenuous internal fixation. Only the surgeon, at the end of the procedure, can determine the efficacy of the fixation. If any suspicion remains regarding the adequacy of fixation, the holding power of the bone, or the stability of the construct, external protection must be used to avoid loss of fixation, malunion, or nonunion before bone healing. However, as with all periarticular fractures, early active motion must be encouraged to promote restoration of joint motion and function. The judicious use of functional or cast braces lends external support while still allowing active rehabilitation. In patients with markedly unstable fixation, postoperative skeletal traction provides the best control and stability for fracture healing. The patient should be encouraged, even in traction, to start early and active (though limited) functional rehabilitation of the knee. Intermittent, brief removal of traction for active-assisted range-of-motion exercises can often be done until sufficient fracture healing allows discontinuation of skeletal traction.

COMPLICATIONS

Infection

The major complication of operative intervention in the management of distal femoral fractures is infection. In the older literature, especially that of the 1960s, the postoperative infection rate was approximately 20%.[89, 116] In more recent literature, the infection rate from operative stabilization of these demanding fractures has ranged from zero to approximately 7%.[13, 30, 36, 53, 81, 99, 103] Factors that predispose to infection include (1) high-energy injuries, especially when extensive bony devascularization has occurred; (2) open fractures; (3) extensive surgical dissection that further compromises bony vascularity; (4) an inexperienced operating team with prolonged open wound time; and (5) inadequate fixation. Acceptable rates of postoperative infection can be obtained with meticulous surgical technique, gentle handling and preservation of soft tissues, the use of prophylactic antibiotics, and adequate, rigid bony stabilization with external or internal fixation. Optimal timing of surgery is essential, especially with open wounds or major soft tissue injuries. Additionally, open wounds should not be primarily closed but should be treated by serial débridement in the operating room until delayed primary closure or additional soft tissue procedures can be safely performed. By strict adherence to these principles, the benefits of stable internal fixation and early mobilization will produce better functional results and outweigh the risks of infection (a 1% to 2% incidence is acceptable).

The presence of a postoperative infection mandates aggressive management. The patient must be immediately returned to the operating room for irrigation and débridement. As long as the internal fixation is sound and adequate, it should not be removed. If a large soft tissue defect is present, antibiotic-impregnated cement beads serve not only to leach antibiotic locally into the hematoma but also as a soft tissue spacer. Repeated irrigation plus débridement is performed until bone cultures indicate that the infection is controlled. Antibiotic coverage is recommended for 6 weeks or longer if a deep wound infection involves the knee or fracture site.

Nonunion

Nonunion of fractures of the distal third of the femur have been reported to occur regardless of the treatment modality used. The incidence varies greatly in the literature, but some of the early larger series reported a rate of nonunion after ORIF of more than 10%.[89] More recent series indicate a nonunion rate of zero to 4% with ORIF.* The nonunion invariably occurs in the supracondylar rather than the intercondylar region. Factors predisposing to nonunion include (1) bone loss or defect; (2) high-energy injuries, especially fractures that are open or comminuted with extensive soft tissue stripping and loss of bony vascularity; (3) inability of the surgical team to obtain adequate bony fixation; (4) failure to augment healing in comminuted fractures with autogenous bone graft; and (5) the presence of a wound infection.

Nonunion of the distal end of the femur is an extremely difficult management problem, and the best treatment is prophylaxis. In long-standing nonunion, the knee joint becomes stiff, and most of the motion that is present occurs through pseudarthrosis. Successful management requires that both stable fixation of the nonunion and restoration of knee movement be regained in one stage. Early postoperative mobilization increases the vascularity to the area and decreases the lever arm on the fixation of the nonunion. Nonunion fixation in the supracondylar region, if the fractures are high supracondylar ones, can be

*See references 13, 30, 36, 53, 81, 95, 99, 103, 122, 130.

accomplished with a locked IM nail. However, most cases of supracondylar nonunion are not amenable to this form of treatment and require internal fixation with a fixed-angle device and side plate. The addition of lag screws significantly increases the stability across the nonunion site. If the nonunion is hypertrophic, stable fixation with subsequent restoration of mechanical stability is all that is required. If the nonunion is atrophic, in addition to mechanical stability, the biologic potential of the bone to heal must be restored by decortication and bone grafting in all such injuries (Fig. 53–49). If a bone defect is present or the distal fragment is small and osteopenic, adequate fixation with a fixed-angle device may not be possible. In that case, both medial and lateral buttress plating may be indicated. If distal femoral fixation cannot be achieved, Beall and colleagues[2] recommended the use of an IM rod driven across the knee joint as a salvage procedure (Fig. 53–50).

Malunion or Malalignment

Malunion after treatment of distal femoral fractures is more common with conservative than with operative treatment. The major problems are malrotation, shortening, and axial malalignment. If conservative treatment with traction or bracing cannot maintain length, rotation, or axial alignment, ORIF should be considered.

Even if anatomic reduction is obtained by ORIF, the distal femoral fixation has a tendency to fail and produce a varus malunion if significant supracondylar comminution is present.[100] To avoid this complication, supplementary medial bone grafting or plating is indicated. An additional problem with ORIF is fixation of the distal fragment in either too much extension or too much flexion. This mistake can occur when the distal fragment is small and it is difficult to determine the correct flexion or extension alignment at the time of surgical reconstruction. Varus or valgus deformities can result from the use of fixed-angle devices from the lateral side of the distal end of the femur, unless these devices are absolutely parallel to the knee joint AP axis. To avoid these potential malalignment problems with internal fixation, adequate preoperative planning is essential. Determining normal anatomy from the opposite, uninvolved side, choosing the exact location for the fixation device, and obtaining adequate intraoperative radiographs to ensure that the preoperative plan is followed all help avoid the problem of malalignment. (See also Alignment Control, p. 1983.)

When IM nails are used for distal femoral and

Figure 53–49. Atrophic nonunion of a supracondylar femoral fracture. Successful treatment with a blade plate after initial retrograde intramedullary (IM) nailing. *A, B,* Preoperative radiographs of a type 3A open femoral fracture after a 10-m fall. *C, D,* Anteroposterior (AP) and lateral radiographs after débridement and open reduction plus internal fixation with intercondylar lag screws and a retrograde IM nail.
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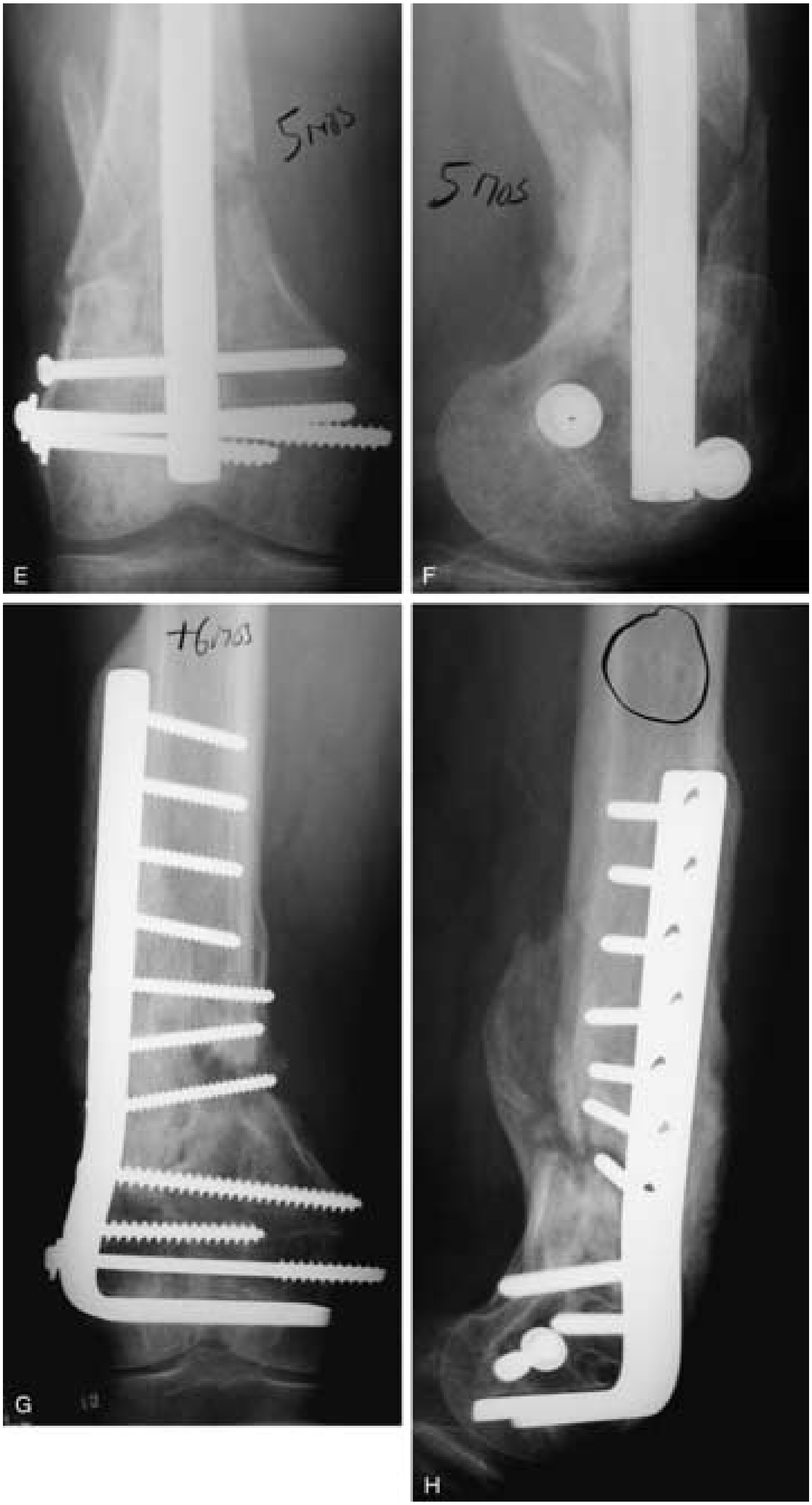

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FIGURE 53–49 *Continued. E, F,* AP and lateral radiographs 5 months later. The patient had persistent pain, hardware loosening, and no callus bridging the metadiaphyseal nonunion, although the articular fracture is healed. Tissue taken for culture at exploration proved negative. *G, H,* AP and lateral radiographs 6 months after repair. A 95° blade plate was applied with an external tension device (*circled* screw hole on the lateral view), and an iliac crest bone graft was used to stimulate healing in atrophic nonunion.

FIGURE 53–50. Atrophic aseptic nonunion 20 years after radiation therapy for soft tissue sarcoma. After failure of fixation with a 95° blade plate, an antegrade intramedullary nail across the knee joint permitted pain-free ambulation for 6 years until the nail broke at the nonunion. Its replacement with a larger closed-section nail was again successful.

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supracondylar fractures, especially with the patient on a fracture table in the lateral decubitus position, there is a tendency to nail the distal fragment in valgus angulation with excessive malrotation. Appreciation and avoidance of this potential problem are essential at the time of nailing.

Once distal femoral malunion is established, the degree and planes of deformity must be exactly determined, which requires adequate AP and lateral radiographs of the involved and the contralateral side and appreciation of both displacement and angulation in all planes. Shortening must also be ascertained, and scanograms may thus be indicated. Rotational malalignment is best determined clinically or, if necessary, with CT scanning. Correction of malunion is accomplished with a supracondylar osteotomy. The type of osteotomy is determined by the deformity present (Fig. 53–51).

Rarely, an intercondylar malunion is associated with deformity of the articular surface. Tomograms or a CT scan may be required to establish the exact degree of the deformity. This problem significantly complicates treatment because an intra-articular osteotomy is required to correct the additional deformity.

Loss of Fixation

One of the major complications after ORIF of the distal end of the femur is loss of bony fixation. Factors predisposing to loss of fixation include (1) increased comminution, (2) increased age and osteopenia, (3) low transcondylar and comminuted intercondylar fractures in which distal fixation is hard to achieve, (4) poor patient compliance with loading and weight bearing before healing, and (5) infection. Optimally, early mobilization is preferred after ORIF, initially with continuous passive motion and subsequently with active and active-assisted physical therapy. However, the surgeon must determine at the time of surgery the degree of bony fixation achieved. If the quality of the bone or the fracture type prevents stable or adequate fixation, mobilization should be delayed, and supplementary procedures such as bone grafting or double plating are required. Once evidence of progressive loss of fixation is noted, the surgeon must decide whether union can still be achieved, by decreasing mobilization or weight bearing, without loss of function. If not, repeat open reduction and stabilization are indicated. The addition of a biologic stimulator such as a bone graft is also useful in this scenario to speed union before fixation is lost.

Whenever loss of fixation occurs, infection must be definitely excluded as a cause. Careful clinical evaluation, a leukocyte count with differential, a sedimentation rate, and aspiration under fluoroscopy are all probably indicated. In addition, a nutritional consultation may be advisable. In a nutritionally depleted patient, some form of hyperalimentation should be considered before further reconstructive procedures are undertaken[49] (see Fig. 53–49).

Contractures and Decreased Knee Motion

After treatment of distal femoral fractures, it is common to have some loss of motion. However, it is important to obtain functional range of motion (i.e., full extension and at least 110° of flexion). Moore and co-workers[84a] found that patients with decreased range of motion were usually young patients who had sustained high-energy trauma. The extent of their soft tissue injuries often necessitated immobilization of the knee joint. To prevent this complication, we advocate early motion of the knee joint, particularly in patients with an intra-articular fracture component.

If range of motion is limited, the cause must be determined. Possibilities include (1) malreduction of the articular surface, either patellofemoral or tibiofemoral; (2) intra-articular hardware; (3) intra-articular joint adhesions; (4) ligamentous or capsular contractures; (5) quadriceps or hamstring scarring; and (6) post-traumatic arthritis.

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FIGURE 53–51. Malunion after a technically unsatisfactory fixation repaired with a focal dome osteotomy and fixator-assisted antegrade intramedullary (IM) nailing. The patient was hemiplegic on the opposite side because of a previous head injury. IM nailing was chosen to facilitate mobility with earlier weight bearing. *A,* Anteroposterior (AP) radiograph of unconventional fixation with a dynamic compression plate attached to a malpositioned dynamic condylar lag screw distally. *B,* Standing AP radiograph showing a varus deformity. The mechanical axis of the left lower extremity is 6.5 cm medial to the position of that on the right. *C,* Proposed focal dome osteotomy with two possible locations drawn (see Chapter 62). *D,* Intraoperative AP radiograph after osteotomy and insertion of the nail with the temporary external fixator still in place. *E,* Lateral intraoperative radiograph. *F,* Four-month postoperative AP radiograph showing healing in correct alignment, the pain relieved, and the patient fully weight bearing for 2 months.

After the cause is determined, a decision can be made regarding whether an option for improvement exists. If malreduction of the articular surface or intra-articular hardware is present, the only chance of restoring function is repeat surgery to correct the deformity or remove the hardware. Intra-articular adhesions and periarticular and muscular contractures should be initially treated with aggressive physical therapy. If this measure fails, manipulation under anesthesia, arthrotomy and lysis of adhesions, and progressive capsular, ligamentous, and muscular release may be indicated. Severe quadriceps contractures are particularly vexing problems to treat, especially if the muscle is scarred to the supracondylar region of the distal part of the femur. If the limitation in motion is significant, quadriceps release from the underlying bone may be indicated. In patients with intramuscular quadriceps contracture and scarring, some form of quadriceps release or lengthening may be indicated. For rehabilitation after any of these procedures, we recommend immediate postoperative continuous passive motion, followed by an aggressive range-of-motion and strengthening program.

If significant post-traumatic arthrosis or arthritis develops in the joint with pain and limitation of motion, it should be treated initially with anti-inflammatory agents and physical therapy procedures to decrease the inflammation and increase motion. If these measures prove unsuccessful, arthroscopic evaluation of the articular surface may be indicated. If significant long-term pain, decreased function, and disability ensue, salvage procedures such as arthrodesis or arthroplasty may be indicated.[46]

REFERENCES

1. Arneson, T.J.; Melton, L.J., III; Lewallen, D.G.; O'Fallon, W.M. Epidemiology of diaphyseal and distal femoral fractures in Rochester, Minnesota, 1965–1984. Clin Orthop 234:188–194, 1988.
2. Beall, M.S.; Nebel, E.; Bailey, R. Transarticular fixation in the treatment of nonunion of supracondylar fractures of the femur: A salvage procedure. Am J Bone Joint Surg 61:1018–1023, 1979.
3. Benum, P. The use of bone cement as an adjunct to internal fixation of supracondylar fractures of osteoporotic femurs. Acta Orthop Scand 48:52–56, 1977.
4. Bogoch, E.; Hastings, D.; Gross, A.; Gschwend, N. Supracondylar fractures of the femur adjacent to resurfacing and MacIntosh arthroplasties of the knee in patients with rheumatoid arthritis. Clin Orthop 229:213–220, 1988.
5. Bolhofner, B.R.; Carmen, B.; Clifford, P. The results of open reduction and internal fixation of distal femur fractures using a biologic (indirect) reduction technique. J Orthop Trauma 10:372–377, 1996.
6. Bone, L.T. The management of fractures in the patient with multiple trauma. J Bone Joint Surg Am 68:945–949, 1986.
7. Brown, A.; D'Arcy, J.C. Internal fixation for supracondylar fractures of the femur in the elderly patient. J Bone Joint Surg Br 53:420–424, 1971.
8. Browner, B.D.; Burgess, A.R.; Robertson, R.J.; et al. Immediate closed antegrade Ender nailing of femoral fractures in polytrauma patients. J Trauma 24:921–927, 1984.
9. Bucholz, R.W.; Ross, S.E.; Lawrence, K.L. Fatigue fracture of the interlocking nail in the treatment of fractures of the distal part of the femoral shaft. J Bone Joint Surg Am 69:1391–1399, 1987.
10. Butler, M.S.; Brumback, R.J.; Ellison, T.S.; et al. Interlocking intramedullary nailing for ipsilateral fractures of the femoral shaft and distal part of the femur. J Bone Joint Surg Am 73:1492–1502, 1991.
11. Butt, M.S.; Krikler, S.R.; Ali, M.S. Displaced fractures of the distal femur in elderly patients. J Bone Joint Surg Br 77:110–114, 1995.
12. Chen, F.; Mont, M.A.; Bachner, B.S. Management of ipsilateral supracondylar femur fractures following total knee arthroplasty. J Arthroplasty 9:521–526, 1994.
13. Chiron, H.S.; Casey, P. Fractures of the distal third of the femur treated by internal fixation. Clin Orthop 100:160–170, 1974.
14. Chiron, H.S.; Tremoulet, J.; Casey, P.; Muller, M. Fractures of the distal third of the femur treated by internal fixation. Clin Orthop 100:160–170, 1974.
15. Connolly, J.F. Closed management of distal femoral fractures. Instr Course Lect 36:428–437, 1987.
16. Connolly, J.F.; Dehne, E. Closed reduction and early cast-brace ambulation in the treatment of femoral fractures. J Bone Joint Surg Am 55:1581–1599, 1973.
17. Culp, R.W.; Schmidt, R.D.; Hands, G.; et al. Supracondylar fracture of the femur following prosthetic knee arthroplasty. Clin Orthop 222:212–222, 1987.
18. Danziger, M.; Caucci, D.; Zechner, B.; et al. Treatment of intercondylar and supracondylar distal femur fractures using the GSH supracondylar nail. Am J Orthop 8:684–690, 1995.
19. David, S.M.; Harrow, M.E.; Peindl, R.D.; et al. Comparative biomechanical analysis of supracondylar femur fracture fixation: Locked intramedullary nail versus 95-degree angled plate. J Orthop Trauma 11:344–350, 1997.
20. DiGioia, A.M., III; Rubash, H.E. Periprosthetic fractures of the femur after total knee arthroplasty: A literature review and treatment algorithm. Clin Orthop 271:135–142, 1991.
21. Dominguez, I.; Moro Rodriguez, E.; De Pedro Moro, J.A.; et al. Antegrade nailing for fractures of the distal femur. Clin Orthop 350:74–79, 1998.
22. Driscoll, S.W.; Keeley, F.W.; Salter, R.B. The chondrogenic potential of free autogenous periosteal grafts for biological resurfacing of major full-thickness defects in joint surfaces under the influence of continuous passive motion. J Bone Joint Surg Am 68:1017–1034, 1986.
23. Fankhauser, C.; Frenk, A.; Marti, A. A comparative biomechanical evaluation of three systems for the internal fixation of distal fractures of the femur. Abstract CD. Paper presented at the 24th Annual Meeting of the Orthopaedic Research Society, Anaheim, California, 1999, p. 498.
24. Farouk, O.; Krettek, C.; Miclau, T.; et al. Effects of percutaneous and conventional plating techniques on the blood supply to the femur. Arch Orthop Trauma Surg 117:438–441, 1998.
25. Farouk, O.; Krettek, C.; Miclau, T.; et al. Minimally invasive plate osteosynthesis and vascularity: Preliminary results of a cadaver injection study. Injury 28(Suppl 1):7–12, 1997.
26. Farouk, O.; Krettek, C.; Miclau, T.; et al. The minimal invasive plate osteosynthesis: Is percutaneous plating biologically superior to the traditional technique? J Orthop Trauma 13:401–406, 1999.
27. Figgie, M.P.; Goldberg, V.M.; Figgie, H.E., III; Sobel, M. The results of treatment of supracondylar fracture above total knee arthroplasty. J Arthroplasty 5:267–276, 1990.
28. Firoozbakhsh, K.; Behzadi, K.; Decoster, T.A.; et al. Mechanics of retrograde nail versus plate fixation for supracondylar femur fractures. J Orthop Trauma 9:152–157, 1995.
29. Garnavos, C.; Rafiq, M.; Henry, A.P. Treatment of femoral fracture above a knee prosthesis: 18 cases followed 0.514 years. Acta Orthop Scand 65:610–614, 1994.
30. Giles, J.B.; DeLee, J.C.; Heckman, J.D.; Keever, J.E. Supracondylar-intercondylar fractures of the femur treated with a supracondylar plate and lag screw. J Bone Joint Surg Am 64:864–870, 1982.
31. Gregory, P.; DiCicco, J.; Karpik, K.; et al. Ipsilateral fractures of the femur and tibia: Treatment with retrograde femoral nailing and unreamed tibial nailing. J Orthop Trauma 10:309–316, 1996.
32. Green, N.E.; Allen, B.L. Vascular injuries associated with dislocation of the knee. J Bone and Joint Surg Am 59:236–239, 1977.
33. Hall, M.F. Two-plane fixation of acute supracondylar and intracondylar fractures of the femur. South Med J 71:1474–1479, 1978.
34. Hampton, O.P. Wounds of the Extremities in Military Surgery. St. Louis, C.V. Mosby, 1951.
35. Healy, J.H.; Lane, J.M. Treatment of pathologic fractures of the distal femur with the Zickel supracondylar nail. Clin Orthop 250:216–220, 1990.
36. Healy, W.L.; Brooker, A.F. Distal femoral fractures. Comparison of open and closed methods of treatment. Clin Orthop 166–171, 1983.

37. Helfet, D.L.; Lorich, D.G. Retrograde intramedullary nailing of supracondylar femoral fractures. Clin Orthop 350:80–84, 1998.
38. Henry, S.L. Supracondylar femur fractures treated percutaneously. Clin Orthop 375:51–59, 2000.
39. Henry, S.; Trager, S.; Green, S.; Seligson, D. Management of supracondylar fractures of the femur with the GSH supracondylar nail. Contemp Orthop 22:631–640, 1991.
40. Henry, S.L.; Booth, R.E. Management of supracondylar fractures above total knee prosthesis. Tech Orthop 9:243–252, 1994.
41. Hirsch, D.M.; Bhalla, S.; Roffman, M. Supracondylar fracture of the femur following total knee replacement. J Bone Joint Surg Am 63:162–163, 1981.
42. No reference cited.
43. Hopf, T.; Osthege, S.(1987) Die interfragmentaere Kompression des ZESPOL-Osteosynthese-Systems. Experimentelle biomechanische Untersuchung. [Interfragmental compression of the Zespol osteosynthesis system. Experimental biomechanical studies.] Z Orthop Ihre Grenzgeb 125:546–552, 1987.
44. Hoppenfeld, S.; deBoer, P. The femur. In: Surgical Exposures in Orthopaedics. The Anatomic Approach. Philadelphia, J.B. Lippincott, 1984, pp. 357–387.
45. Iannacone, W.M.; Bennett, F.S.; DeLong, W.G., Jr.; et al. Initial experience with the treatment of supracondylar femoral fractures using the supracondylar intramedullary nail: A preliminary report. J Orthop Trauma 8:322–327, 1994.
46. Insall, J.N. Surgery of the Knee. New York, Churchill Livingstone, 1984.
47. Ito, K.; Grass, R.; Zwipp, H. Internal fixation of supracondylar femoral fractures: Comparative biomechanical performance of the 95-degree blade plate and two retrograde nails. J Orthop Trauma 12:259–266, 1998.
48. Jabczenski, F.F.; Crawford, M. Retrograde intramedullary nailing of supracondylar femur fractures above total knee arthroplasty. J Arthroplasty 10:95–101, 1995.
49. Jenson, J.E.; Jenson, T.G.; Smith, T.K. Nutrition in orthopaedic surgery. J Bone Joint Surg Am 64:1263–1271, 1982.
50. Johansen, K.; Bandyk, D.; Thiele, B.; Hansen, S.T. Temporary intraluminal shunts: Resolution of a management dilemma in complex vascular injuries. J Trauma 22:395–402, 1982.
51. Johnson, E.E. Combined direct and indirect reduction of comminuted four-part intraarticular T-type fractures of the distal femur. Clin Orthop 231:154–162, 1988.
52. Johnson, K.D. Internal fixation of distal femoral fractures. Instr Course Lect 36:437–448, 1987.
53. Johnson, K.D.; Hicken, G. Distal femoral fractures. Orthop Clin North Am 18:115–131, 1987.
54. Kennedy, J.C. Complete dislocation of the knee joint. J Bone Joint Surg Am 45:889–904, 1963.
55. Kinast, C.; Bolhofner, B.R.; Mast, J.W.; Ganz, R. Subtrochanteric fractures of the femur. Clin Orthop 238:122–130, 1989.
56. Kirschner, M. Ueber Nagelextension. Beitr Klin Chir 64:266–279, 1909.
57. Kolmert, L.; Wulff, K. Epidemiology and treatment of distal femoral fractures in adults. Acta Orthop Scand 53:957–962, 1982.
58. Kolodziej, P.; Lee, F.S.; Patel, A.; et al. Biomechanical evaluation of the Schuhli nut. Clin Orthop 347:79–85, 1998.
59. Koval, K.J.; Hoehl, J.J.; Kummer, F.J.; Simon, J.A. Distal femoral fixation: A biomechanical comparison of the standard condylar buttress plate, a locked buttress plate, and the 95-degree blade plate. J Orthop Trauma 11:521–524, 1991.
60. Koval, K.J.; Kummer, F.J.; Bharam, S.; et al. Distal femoral fixation: A laboratory comparison of the 95 degrees plate, antegrade and retrograde inserted reamed intramedullary nails. J Orthop Trauma 10:378–382, 1996.
61. Kowalski, M.J.; Schemitsch, E.H.; Harrington, R.M.; et al. A comparative biomechanical evaluation of a noncontacting plate and currently used devices for tibial fixation. J Trauma 40:5–9, 1996.
62. Krettek, C. Komplextrauma des Kniegelenkes—Diagnostik, Management und Therapieprinzipien. Handout D3. Zentraleuropäischer Unfallkongress Budapest 4.-7.5., Tscherne, H., Hrsg. Budapest, 1994, pp. 1–5.
63. Krettek, C.; Miclau, T.; Grün, O.; et al. Techniques for assessing limb alignment during closed reduction and internal fixation of lower extremity fractures. Tech Orthop 14:247–256, 1999.
64. Krettek, C.; Schandelmaier, P.; Miclau, T.; et al. Transarticular joint reconstruction and indirect plate osteosynthesis for complex distal supracondylar femoral fractures. Injury 28(Suppl 1):A31–A41, 1997.
65. Krettek, C.; Schandelmaier, P.; Miclau, T.; Tscherne, S. Minimally invasive percutaneous plate osteosynthesis (MIPPO) using the DCS in proximal and distal femoral fractures. Injury 28(Suppl 1): A31–A41.
66. Krettek, C.; Schandelmaier, P.; Miclau, T.; et al. Intraoperative control of axes, rotation and length in femoral and tibial fractures—technical note. Injury 29(Suppl 3):C29–C39, 1998.
67. Krettek, C.; Schandelmaier, P.; Stephan, C.; Tscherne, H. Kondylenplatten- und Kondylenschraubenosteosynthese (DCS)—Indikation, technische Hinweise und Ergebnisse. OP J 13:294–304, 1997.
68. Krettek, C.; Schandelmaier, P.; Tscherne, H. Distale Femurfrakturen: Transartikuläre Rekonstruktion, perkutane Plattenosteosynthese und retrograde Nagelung. Unfallchirurg 99:2–10, 1996.
69. Krettek, C.; Tscherne, H. Distal femoral fractures. In: Fu, F.H.; Harner, C.D.; Vince, K.G., eds. Knee Surgery. Baltimore, Williams & Wilkins, 1994, pp. 1027–1035.
70. Lee, T.T.; Gravel, C.J.; Chapman, M.W. (1994) Operative management of the supracondylar fracture of the femur: Comparison of the anterolateral approach to other surgical approaches. Poster. Presented at the annual meeting of the Orthopaedic Trauma Association, 1994, p. 166.
71. Leung, K.S.; Shen, W.Y.; So, W.S.; et al. Interlocking intramedullary nailing for supracondylar and intercondylar fractures for the distal part of the femur. J Bone Joint Surg Am 73:332–340, 1991.
72. Lucas, S.E.; Seligson, D.; Henry, S.L. Intramedullary supracondylar nailing of femoral fractures: A preliminary report of the GSH supracondylar nail. Clin Orthop 296:200–206, 1993.
73. Mahorner, H.R.; Bradburn, M. (1933) Fractures of the femur. Report of 308 cases. Surg Gynecol Obstet 56:1066–1979, 1933.
74. Mast, J.; Jakob, R.; Ganz, R. Planning and Reduction Technique in Fracture Surgery. New York, Springer-Verlag, 1989.
75. Matter, P.; Rittman, W. The Open Fracture. Huber, Bern, Switzerland, 1978.
76. McLaren, A.C.; Dupont, J.A.; Chroeber, D.C. Open reduction internal fixation of supracondylar femur fractures above total knee arthroplasties using the intramedullary supracondylar rod. Clin Orthop 302:194–198, 1992.
77. Merkel, K.D.; Johnson, E.W. Supracondylar fracture of the femur after total knee arthroplasty. J Bone Joint Surg Am 68:29–43, 1986.
78. Meyer, R.W.; Plaxton, N.A.; Postak, P.D.; et al. Mechanical comparison of a distal femoral side plate and a retrograde intramedullary nail. J Orthop Trauma 14:398–404, 2000.
79. Meyers, M.H.; Moore, T.M.; Harvey, J.P. Traumatic dislocation of the knee joint. J Bone Joint Surg Am 57:430–433, 1975.
80. Miclau, T.; Remiger, A.; Tepic, S.; et al. A mechanical comparison of the dynamic compression plate, limited contact–dynamic compression plate, and point contact fixator. J Orthop Trauma 9:17–22, 1995.
81. Mize, R.D.; Bucholz, R.W.; Grogan, D.P. Surgical treatment of displaced, comminuted fractures of the distal end of the femur. J Bone Joint Surg Am 64:871–878, 1982.
82. Modlin, J. Double skeletal traction in battle fractures of the lower femur. Band 4:19–129, 1945.
83. Moll, J. The cast brace walking treatment of open and closed femur fractures. South Med J 66:345–352, 1973.
84. Mooney, V. Fractures of the distal femur. Instr Course Lect 36:427, 1987.
84a. Moore, T.J.; Watson, T.; Green, S.A.; et al. Complications of surgically treated supracondylar fractures of the femur. J Trauma 27:402–406, 1987.
85. Morgan, E.; Ostrum, R.F.; DiCicco, J.; et al. Effects of retrograde femoral intramedullary nailing on the patellofemoral articulation. J Orthop Trauma 13:13–16, 1999.
86. Müller, M.E.; Allgöwer, M.; Schneider, R.; Willenegger, H. Manual of Internal Fixation, 3rd ed. New York, Springer-Verlag, 1991.
87. Müller, M.E.; Nazarian, S.; Koch, P. 1987. Classification AO des Fractures. Springer-Verlag New York,
88. Müller, M.E.; Nazarian, S.; Koch, P.; Schatzker, J. The Comprehensive Classification of Fractures of Long Bones. New York, Springer-Verlag, 1990.

89. Neer, C.S.; Grantham, S.A.; Shelton, M.L. Supracondylar fracture of the adult femur. A study of one hundred and ten cases. J Bone Joint Surg Am 49:591–613, 1967.
90. Nielsen, B.F.; Petersen, V.S.; Varmarken, J.E. Fracture of the femur after knee arthroplasty. Acta Orthop Scand 59:155–157, 1988.
91. Olerud, S. Operative treatment of supracondylar-condylar fractures of the femur: Technique and results in fifteen cases. J Bone and Joint Surg Am 54:1015–1032, 1972.
92. Ostrum, R.F. Treatment of floating knee injuries through a single percutaneous approach. Clin Orthop 375:43–50, 2000.
93. Ostrum, R.; Geel, C. Indirect reduction and internal fixation of supracondylar femur fractures without bone graft. J Orthop Trauma 9:278–284, 1995.
94. Pritchett, J.W. Supracondylar fractures of the femur. Clin Orthop 184:173–177, 1984.
95. Regazzoni, P.; Leutenegger, A.; Ruedi, T.; Staehelin, F. Erste Erfahrungen mit der dynamischen Kondylenschraube (dcs) bei distalen Femurfrakturen. Helv Chir Acta 53:61–64, 1986.
96. Riina, J.; Tornetta, P.; Ritter, C.; et al. Neurologic and vascular structures at risk during anterior-posterior locking of retrograde femoral nails. J Orthop Trauma 12:379–381, 1998.
97. Rockwood, C.A., Jr.; Ryan, V.L.; Richards, J.A. Experience with quadrilateral cast brace. Abstract. J Bone Joint Surg Am 55:421, 1973.
98. Rolston, L.R.; Christ, D.J.; Halpern, A.; et al. Treatment of supracondylar fractures of the femur proximal to a total knee arthroplasty. J Bone Joint Surg Am 77:924–931, 1995.
99. Sanders, R.; Regazzoni, P.; Ruedi, T. Treatment of supracondylar-intraarticular fractures of the femur using the dynamic condylar screw. J Orthop Trauma 3:214–222, 1989.
100. Sanders, R.W.; Swiontkowski, M.; Rosen, H.; Helfet, D. Complex fractures and malunions of the distal femur: Results of treatment with double plates. J Bone Joint Surg Am 73:341–346, 1991.
101. Sanders, R.; Swiontkowski, M.F.; Rosen, H.; Helfet, D. Double plating of comminuted, unstable fractures of the distal part of the femur. J Bone Joint Surg Am 73:341–346, 1991.
102. Schatzker, J.; Horne, G.; Waddell, J. The Toronto experience with the supracondylar fracture of the femur, 1966–72. Injury 6:113–128, 1974.
103. Schatzker, J.; Lambert, D.C. Supracondylar fractures of the femur. Clin Orthop 138:77–83, 1979.
104. Schatzker, J.; Tile, M. The Rationale of Operative Fracture Care. New York, Springer-Verlag, 1987.
105. Seide, K.; Zierold, W.; Wolter, D.; et al. The effect of an angle-stable plate-screw connection and various screw diameters on the stability of plate osteosynthesis. An FE model study. Unfallchirurg 93:552–558, 1990.
106. Seinsheimer, F. Fractures of the distal femur. Clin Orthop 153:169–179, 1980.
107. Shahcheraghi, G.H.; Doroodchi, H.R. Supracondylar fracture of the femur: Closed or open reduction? J Trauma 34:499–502, 1993.
108. Shelbourne, K.D.; Brueckmann, F.R. Rush pin fixation of supracondylar and intercondylar fractures of the femur. J Bone Joint Surg Am 64:161–169, 1982.
109. Shelton, M.L.; Grantham, S.A.; Neer, C.S.; Singh, M. A new fixation device for supracondylar and low femoral shaft fractures. J Trauma 14:821–835, 1974.
110. Shewring, D.J.; Meggitt, B.F. Fractures of the distal femur treated with the AO dynamic condylar screw. J Bone Joint Surg Br 74:122–125, 1992.
111. Short, W.H.; Hootnick, D.R.; Murry, D.G. Ipsilateral supracondylar femur fractures following total knee arthroplasty. Clin Orthop 158:111–116, 1981.
112. Siliski, J.M.; Mahring, M.; Hofer, H.P. Supracondylar-intercondylar fractures of the femur. Treatment by internal fixation. J Bone Joint Surg Am 71:95–104, 1989.
113. Sisto, D.J.; Warren, R.F. Complete knee dislocation. A follow-up study of operative treatment. Clin Orthop 198:94–101, 1985.
114. Slatis, P.; Ryoppy, S.; Huttinen, V. AO osteosynthesis of fractures of the distal third of the femur. Acta Orthop Scand 42:162–172, 1971.
115. Steinman, F.R. Eine neue Extensionsmethode in der Frakturenbehandlung. Zentralbl Chir 34:398–442, 1907.
116. Stewart, M.J.; Sisk, T.D.; Walace, S.L. Fractures of distal third of the femur. J Bone Joint Surg Am 48:784–807, 1966.
117. Struhl, S.; Szporn, M.N.; Cobelli, N.J.; Sadler, A.H. Cemented internal fixation for supracondylar femur fractures in osteoporotic patients. J Orthop Trauma 4:151–157, 1990.
118. Tepic, S.; Remiger, A.R.; Morikawa, K.; et al. Strength recovery in fractured sheep tibia treated with a plate or an internal fixator: An experimental study with a two-year follow-up. J Orthop Trauma 11:14–23, 1997.
119. Trentz, O.; Tscherne, H.; Oestern, H.J. Operationstechnik und Ergebnisse bei distalen Femurfrakturen. Unfallheilkde 80:441–448, 1977.
120. Tscherne H. Femoral shaft and distal femur. In: Müller, M.E.; Allgöwer, M.; Schneider, R.; Willenegger, H., eds. Manual of Internal Fixation. Berlin, Springer-Verlag, 1991, pp. 535–552.
121. Tscherne, H.; Oestern, H.J.; Trentz, O. Spätergebnisse der distalen Femurfraktur und ihre besonderen Probleme. Zentrabl Chir 102:897–904, 1977.
122. Tscherne, H.; Trentz, O. [Recent injuries of the femoral condyles.] Langenbecks Arch Chir 345:396–401, 1977.
123. van der Werken, C.; Marti, R.K.; Raaymakers, E.L. Distal femoral fractures, results of operative treatment. Neth J Surg 33:230–236, 1981.
124. No reference cited.
125. Walling, A.K.; Seradge, H.; Spiegel, P.G. Injuries to the knee ligaments with fractures of the femur. J Bone Joint Surg Am 64:1324–1327, 1982.
126. Wenzel, H.; Casey, P.A.; Herbert, P.; Belin, J. Die operative Behandlung der distalen Femurfraktur. AO Bull 1970.
127. Wiggins, H.E. Vertical traction in open fractures of the femur. US Armed Forces Med J 4:1633–1636, 1953.
128. Yang, R.S.; Liu, H.C.; Liu, T.K. Supracondylar fractures of the femur. J Trauma 30:315–319, 1990.
129. Zehntner, M.K.; Marchesi, D.G.; Burch, H.; Ganz, R. Alignment of supracondylar/intercondylar fractures of the femur after internal fixation by AO/ASIF technique. J Orthop Trauma 6:318–326, 1992.
130. Zickel, R.E. Nonunions of fractures of the proximal and distal thirds of the shaft of the femur. Instr Course Lect 37:173–179, 1988.
131. Zickel, R.E.; Fietti, V.G., Jr.; Lawsing, J.F., III; Cochran, G.V. A new intramedullary fixation device for the distal third of the femur. Clin Orthop 125:185–191, 1977.
132. Zickel, R.E.; Hobeika, P.; Robbins, D.S. Zickel supracondylar nails for fractures of the distal end of the femur. Clin Orthop 212:79–88, 1986.