Evaluating the postoperative patient is integral to the practice of musculoskeletal radiology. Most of the subsets of musculoskeletal pathology, including trauma, neoplasia, arthritis, sports medicine, and congenital and developmental maladies, encompass many diagnoses and entities that lead to surgical intervention. The radiologist must combine knowledge of normal and abnormal reparative processes with understanding of the pathology, surgical procedures, and various implants and devices to render adequate service to referring surgeons. This chapter provides a general overview of basic principles of fixation and reconstruction with comments on general hardware, complications, and imaging in specific post-operative situations. A special focus will be the continuing evolution of fixation techniques and newer implants. Certainly, all available implants will not be reviewed but the devices contained herein are a representative sample of the devices used by musculoskeletal surgeons.

**PLATES AND SCREWS**

Plates and screws are central in the armamentarium of any surgeon who operates on bones. They are used not only in open and percutaneous fixation of fractures but also to
aid osteosynthesis in cases of osteotomies, fusions, and tumor resection. Basic principles of plates and screws apply across all these uses, but are probably easiest to understand in the setting of fracture fixation. Certainly, many types of fractures are best treated with closed techniques, but plate osteosynthesis is central to the treatment of many types of fractures.

*Cortical Plates*: Plate and screw technology, though seemingly simple at first glance, is an apt example of the evolution of principles of orthopedic surgery. As our knowledge of physiology, pathology, and material science has progressed, plates and screws have become more sophisticated and individualized for specific tasks. The first plates were simple cortical plates, often referred to as flat plates. While plates have variable functions of compression, stabilization, tension, neutralization, buttressing, and bridging, they all provide at least some stability and serve to hold bones in apposition to allow healing to occur. Cortical plates create their stability by being tightly screwed to the surface of the bone, with friction at the bone surface performing the work. The screws achieve this tight application of the plate to the bone. To accomplish this, the screws for most cortical plates are bicortical, crossing both the near and far cortex.

The simple cortical plate has undergone a remarkable evolution, incorporating designs for specific anatomic sites and designs to satisfy different physical and physiologic principles, to the point that today it is difficult to find a simple flat rectangular plate with round holes. Many plates have been manufactured to fit certain anatomic sites. The one-third tubular plate (see Figure 1) is primarily used to fix distal fibular fractures and
osteotomies. Its short axis is an arc, though curiously not one-third of a tube or 120°. It is also a relatively thin plate. These features make it an ideal design for the distal fibula, which is so small that its cortex is noticeably curved, not flat, and which is nearly subcutaneous in all but the largest people, requiring a thin plate. In this same family of plates are the smaller one-quarter tubular plate, occasionally used in metacarpals and metatarsal, especially in children; and larger semitubular plate, which is rarely used today.

Figure 1: One-third tubular plate fixing a prior distal fibular fracture. The plate is slightly curved to match the surface of the fibula, and is very thin.

Other cortical plates are contoured for specific sites also. This feature is especially common in buttress plates. The term buttress plate is generally applicable to any plate near a joint that flares out or widens as it nears the articular surface. They perform a buttress function, in that they provide a broad surface to support and bolster a
comminuted fracture where the cortex is thin. This situation is especially common in fractures involving the distal radius, femur, and tibia, and the tibial plateau. Each of these sites has several buttress plates specific to it. Buttress plates are often named by their shape and appearance (see Figure 2).

![Figure 2: Buttress plates. Postero-anterior (PA) view of the wrist (A) demonstrates a distal radial T-plate. Lateral view of the knee (B) shows a L-plate securing a tibial osteotomy.](image)

Another specialized plate is the reconstruction plate. Sometimes called malleable plates, these plates are manufactured with notches along the sides, in between each screw hole. When viewed en face, these plates have wavy margins (see Figure 3). This notching weakens the plate enough to allow it to be contoured to fit the exact shape of the bone at the time of implantation. Because these plates require tools to be shaped, they are better termed contoured plates instead of malleable plates, which might imply flimsiness in situ.
Reconstruction plate is the preferred term, as these plates are employed to provide significant structural support to fracture sites, most commonly in the pelvis.

Figure 3: Reconstruction plate fixing a proximal ulnar fracture in the forearm. Notching allows the plate to be contoured in the operating room.

Another modification of some plates is to use them to apply compression across a fracture. Appropriate compression of fracture margins augments healing. Whether this effect is due to the function of keeping the two ends in constant, close apposition, even in the face of resorption of the fracture margins; or due to actual acceleration of the healing response, remains uncertain. Either way, compression techniques allow more rapid
healing when used appropriately. Several fracture characteristics would obviate the use of compression: these include fractures with more than minimal comminution; fractures involving the metaphysis, osteoporotic bone, or otherwise weak cortex; pathologic fractures; and fractures involving an articular surface. Hence, the ideal fracture in which to use compression is a diaphyseal traumatic fracture in a younger adult patient. Fracture compression can be achieved in several ways. First, human anatomy and physiology provide several sites where stabilization of a fracture naturally creates tension on one side of a bone but resultant compression on the other side. The classic example of this is the femur, in which the lateral musculature is stronger than the medial, and placement of a plate on the lateral side converts the tension there to compression on the medial side. This is truly a dynamic compression whenever the muscles are in use. Another way to provide compression is to use axial loading from weight bearing and gravity to compress a fracture that is not fully fixed in the axial plane, such as femoral neck fractures secured by a dynamic compression screw, spine fusions with plates that allow some craniocaudal translation, and long bone fractures stabilized by nails or rods without locking screws (all discussed later). Compression also may be applied with special devices at the time of open reduction. A plate then secures the fragments in static compression.

Another method of fracture compression involves a specific design feature of some plates. These plates contain oval screw holes. The holes have sloped margins. If the surgeon places the screw eccentrically in the hole, farthest from the fracture, the rounded head of the screw will contact the slope of the hole, forcing the screw (and the bone it is entering) toward the fracture. When this eccentric screw placement technique is carried
out on either side of the fracture, the fracture margins are brought into compression (see Figure 4). Despite the fact that this compression is static, these plates are called dynamic compression (DC) plates.

![Dynamic Compression Plate](image)

Figure 4: Anteroposterior (AP) view of a dynamic compression plate in place, demonstrating eccentric placement of screws away from the original fracture site, creating the compression force.

The latest advances in plate designs have been based more on biological principles. These plates are occasionally grouped under the term biological plates. The first significant improvement based on biology was to limit the surface contact of the plate. Cortical plates pressed onto the surface of bones create a zone of devitalization, primarily involving the periosteum. Optimal fracture (or osteotomy) healing requires maximum vascularity, but cortical plates reduce vascularity. The concept that improving vascularity would improve bone healing and reduce infection rates led to the design of cortical plates that only contact bone where they must, adjacent to the screw holes.

Unlike reconstruction plates, these plates are notched or cut out along the deep surface, not the sides. This creates an undulating profile to these plates when one views them from the side (see Figure 5). This plate design is termed limited contact or low contact. This feature is often present in dynamic compression plates, creating the low contact
dynamic compression (LCDC) plate.

Figure 5: AP view of a tibial low-contact plate showing the undulating deep surface, limiting the amount of the plate that contacts the surface. Note obvious pullout of the screws and plate liftoff, termed catastrophic failure.

Locked Plates: The most recent advances in plate technology that take biological principles into account are the locked plates. The primary differing feature of locked
plates is that some or all of their screws are locking screws. A locking screw has a threaded head, which locks the screw into place in the plate, which has threaded holes (see Figure 6). This design feature is helpful in that it makes locking screws into rigid, fixed-angle devices, which will not toggle or back out of the plate. As such, locking plates should markedly reduce the incidence of loss of fixation and plate-screw failure. On radiographs, one can recognize locking screws because their threads are very shallow, meaning they take a small “bite” into the bone; and the thread pitch, or spacing between each thread, is quite narrow. Standard cortical and cancellous screws have a wider pitch and deeper threads (see Figure 7). Plates that use locking screw technology include LISS plates, combination plates, and locked condylar plates.

Figure 6: Locking screws have threads on their heads, which lock them into the plate’s threaded holes. Image courtesy of Synthes, West Chester PA. Used with permission.
There are a couple other important features of these plates. Because locking screws are fixed into the plate, they cannot compress the plate down on the periosteum and cortex. Their main principle of fixation and stabilization, then, is not friction of the plate on the
cortex, as with cortical plates, but is along the shanks of the screws. These locking
screws act like pins from external fixators, and this whole class of plates is often referred
to as internal fixators. The fixation they provide is quite rigid. Many of these plates are
inserted in a minimally invasive fashion; the surgeon makes a short incision and then
attaches a guide to assist in sliding the plate into its final, submuscular position. The
guide is also a template for inserting the screws percutaneously. When the surgeon can
choose a minimally invasive insertion, tissue damage is minimized and the local healing
environment at the fracture is improved. LISS plates are best able to take advantage of
minimally invasive techniques, but all locking plates have smooth, tapered, rounded ends
to allow minimally invasive insertion, rather than open fixation, when appropriate.

Less Invasive Stabilization System (LISS) plates are specialized locking plates available
only for the distal femur and proximal tibia. They are contoured to fit the shape of the
lateral margins of these bones and they come in three lengths and right and left versions.
LISS plates are designed for intra-articular fractures about the knee with significant
comminution, especially when there is diaphyseal involvement. The rigid fixation and
fixed-angle locked screws resist the tendency of these fractures to fall into varus
malalignment. These plates are especially beneficial in patients with osteoporosis, in
whom fracture fixation about the knee is otherwise fraught with hardware pullout and
failure of fixation. One can recognize these plates by three features (see Figure 8): they
are used only in the distal tibia and proximal femur; the screws are locking screws; and
the holes in the plate are all single, circular, locking holes (unlike the combination holes
described below). Also, because these plates are inserted in a submuscular fashion and act as internal fixators, there is a gap between most of the plate and the underlying cortex.

Combination (combi) plates have hybrid screw holes. These holes are usually shaped like the number 8. The smaller half of the hole is a locking hole. The larger half is a hole for a regular (cortical or cancellous) screw. These holes allow the surgeon flexibility regarding when to place locking screws. If locking screws are in place, the surgeon cannot use the screw and plate to manipulate and further reduce a fracture, because the locking mechanism rigidly fixes the bone and plate in place. Similarly, locking screws won’t allow the application of “dynamic” compression. Using a combi plate, surgeons may use regular screws to achieve a DC configuration and further reduce the fracture, and then place the final locking screws to fix everything in place. These plates are used
in diaphyseal fractures and are recognized by the 8-shaped combi holes (see Figures 7, 9).

Figure 8: AP and lateral view of a LISS plate, demonstrate its characteristic features: only locking screws are used; the holes are all circular; the location is the distal femur; and there is a gap between much of the plate and the underlying bone.
Figure 9: AP and lateral views of the left ankle demonstrating a combi plate. The lowest two screws demonstrate the characteristic profile of locking screws, while the remainder are bi-cortical screws. The combi holes are 8-shaped.

Locked condylar plates, also called locked peri-articular plates, are for fixation of intra-articular and juxta-articular fractures. These plates flare out as they near the articular surface. In this, they resemble buttress cortical plates, but they often provide no
significant buttressing function because of their locking screws and limited contact. The peri-articular, wider portion of the plate only uses locked screws, with circular holes. In the diaphyseal portion, there are combi holes, allowing the surgeon to choose to place locking or regular screws. These design features allow easy recognition of these plates, which are now available in designs for the ends of most of the long bones (see Figure 10).

*Figure 10*: AP fluoroscopic image and lateral radiograph demonstrating a locked proximal humeral plate. All of the proximal screws are locking, but some of the distal ones, passing through 8-shaped holes, are cortical screws.

Locking screw technology has revolutionized the techniques of internal fixation of numerous types of fractures. While they have not supplanted cortical plates for all uses,
the improved healing and reduced complication rates afforded by locking plates has brought them quick and widespread acceptance in the surgical community. Locking screw technology has even been applied to some old stand-bys, such as the one-third tubular plate.

**SCREWS:**

A working knowledge of fixation hardware includes familiarity with screw types. Locking screws are described in the section above. The other basic screws in use are cortical and cancellous screws. Cortical screws have shallower threads and a narrower thread pitch relative to cancellous screws (see Figure 11), although both are wider and deeper than a locking screw. The thread design of cortical screws takes advantage of the dense bone of the cortex for fixation, while the thread design of cancellous screws allow them to achieve fixation in the relatively porous center of a bone. Cortical screws are usually placed across the near and far cortex of a bone, and are termed bi-cortical.
Figure 11: Oblique view of the calcaneus demonstrates the narrower pitch of the threads of a cortical screw (red arrow) and the wider pitch of a partially threaded cancellous screw (blue arrow).

The term lag screw, derived from carpentry, refers to the function of a screw, not one specific design. A screw performs a lagging function when it is placed across two fragments of bone and the threads in the distal piece pull it and compress it against the proximal piece. There are several ways to achieve this function. One is to use a partially threaded screw, with no threads on the proximal shank. As one inserts the screw and the screw head contacts the near piece of bone, progressive turning of the screwdriver advanced the threads into the distal piece, drawing it toward the proximal piece and creating compression. The same effect can be achieved with a fully threaded screw, if
one over-drills the screw hole in the proximal fragment such that the screw threads do not engage it. Again, the distal threads pull the distal piece toward the proximal one.

Another way to achieve a lag function is with headless variable compression screws. The most familiar of these is the Herbert screw, but the Acutrak screw has supplanted the Herbert screw for many purposes. These screws do not have heads, but they are slotted for screwdrivers. The threads on the distal portion of these screws have a wider pitch than the proximal threads. As the screw is driven, the wider pitch of the distal threads draws the distal fragment toward the proximal one. These screws are most common in fixation of scaphoid waist fractures and fractures and osteochondral lesions of the femoral condyles (see Figure 12).
Figure 12: Headless variable compression screws: Herbert screw fixing a scaphoid waist fracture (A) and Acutrak screw fixing a femoral osteochondral fragment (B) demonstrate the variable thread pitch that provides the unique function of these screws.
One implant that has features of plates, screws, and intramedullary devices is the dynamic compression screw (DCS). These are most commonly seen in the proximal femur for fixation of some femoral neck and peri-trochanteric fractures (dynamic hip screw—DHS), but there also is a version for the distal femur intercondylar fractures (dynamic condylar screw). In the DHS, a wide-bore, partially threaded cancellous screw is driven up into the femoral head via the neck. This screw slides into a sleeve that is connected to a side plate, placed along the lateral cortex of the proximal femur (see Figure 13). As the patient begins to bear weight on the extremity, the femur fracture compresses along the shaft of the screw. Invariably, there is progressive impaction of the
fracture as healing progresses and the screw telescopes into the sleeve.

Figure 13: Dynamic hip screw (DHS): as the femoral fracture heals, it may subside. The screw will telescope into the sleeve.

**INTRAMEDULLARY DEVICES**

Nails, rods, pins, and wires fit into this category. There is some overlap in these terms, leading to some confusion when reporting on these devices. Nails are used for
diaphyseal fractures of long bones and fill the medullary cavity at its narrowest point. They are typically tapped into place from the proximal (anteade) or distal end of the bone. Large bore nails are usually implanted with proximal and distal interlocking screws (see Figure 14). This adds rotational and axial stability to the construct, but eliminates the possibility of fracture compression. When nails are implanted without interlocking screws or if the screws are removed, known as dynamizing the nail, the fracture margins will compress against each other, similar to the mode of the dynamic compression screw. Most nails seen in daily practice are the large bore nails that are used in the adult femur and tibia. The treatment for children 5-15 years old with long bone diaphyseal fractures is often the elastic intramedullary nail, which is moderately flexible but is curved in its native state (see Figure 15). The prototype of this nail was the Ender nail, and that name usually is still applied to these nails. Although one of these nails rarely fills the medullary cavity in the long bone of even a young (normal) child, with application of two or three of these nails in concert will fill the marrow space and provide extra stability. The proximal and distal ends are anchored through the cortex of the bone, adding rotational stability.
Figure 14: AP view of the distal aspect of a retrograde interlocking intramedullary nail.
Figure 15: AP view of the forearm demonstrating the flexible Ender nail crossing the radial shaft fracture. Also note the one-third tubular plate on the distal radius.

One of the recent advances in this arena is the development of cephalomedullary nails. These are modifications of standard femoral nails, with the addition of a blade plate,
screw, or pins passing up the femoral neck into the head. The common example of this is
the trochanteric fixation nail (TFN), which is inserted through the greater trochanter and
has a large bore screw (akin to a DCS screw) or blade plate passing up into the femoral
head (see Figure 16). These devices are designed to be implanted for proximal femur
fractures involving the intertrochanteric region but with complicating features, such as
extensive comminution, reverse obliquity, or extension into the diaphysis. Piriformis-
starting nails are nearly identical devices except the insertion site is different, slightly
medial to the trochanter on an anteroposterior radiograph. There are other examples of
the cephalomedullary technology, and it has even been applied to the proximal humerus
in the form of a proximal humeral spiral blade nail.

Figure 16: AP view of the hip shows a short trochanteric fixation nail. This model uses a spiral blade to achieve stabilization across the femoral neck.

Rods are also used to stabilize long bone fractures, but they are narrower devices.

Because a single Ender nail is a narrow device, it is sometimes referred to as an Ender rod. The classic rod in use for the last few decades is the Rush rod. This implant is
straight except for a tight curve on the end, resembling a crochet needle (see Figure 17). The curved portion may serve as an anchor and allows for easy retrieval. These rods are often the best device to stabilize fractures of narrower long bones such as the fibula or the pediatric radius, and they play an important part in stabilizing long bones of patients with osteogenesis imperfecta.

Figure 17: AP view of the led with a Rush rod securing tibial osteotomies. The patient suffers from osteogenesis imperfecta.
Pins are narrow, shorter devices that have their pointed, often threaded, end buried in bone across a fracture site. The back end of the pin protrudes out of bone, sometimes just through the cortex and sometimes outside the whole body. It is common to speak of pinning fractures, in which the surgeon inserts or screws the device across the fracture percutaneously. Some pins are threaded and are essentially screws, while others are pointed on the end but not threaded (see Figure 18). When threads are present on pins, the width of the threads often does not exceed that of the unthreaded shank.

Figure 18: AP view of the hip demonstrates prior pinning of the femoral head in a child with slipped capital femoral epiphysis. This pin is a cannulated, partially threaded cancellous screw.
There are two types of wires.  Kirschner wires (K-wires) are relatively rigid, straight devices that are typically employed in the mode of a pin (see Figure 19).  They are rigid enough to provide stability in fracture fixation, but are often bent and truncated in the operating room with tools.  The other type of wire is malleable wire provided on a spool.  This type of wire is commonly seen as cerclage wires around hip prostheses, tension band wires at the olecranon, and in association with posterior spine instrumentation, especially Luque instrumentation.  Cable, in which smaller strands of wire are pre-braided together, also serves these purposes.

*Figure 19: PA view of the wrist shows multiple K-wires pinning a complex fracture-dislocation.  The external ends of the wires have been curved to limit unnecessary contact.*
Fractures: Because of the ability of younger bones to remodel significant displacements and modest angular deformities and because of the rapid healing of children’s bones, most pediatric fractures are reduced in a closed fashion and treated with casts, splints, or slings. There are several exceptions to this concept in routine pediatric fracture treatment. First, the weight bearing long bones will often be treated with one or more elastic intramedullary nails if the child is 5-15 years old and the fracture is transverse, oblique, or a simple spiral fracture. Second, plate and screw fixation is reserved for older teenagers and overweight children. Third, while displacement is of lesser concern in diaphyseal fractures, adequate reduction is critical in epiphyseal and trans-physeal fractures, to ensure a functional articular surface and to ward off growth disturbances resulting from growth plate disruption. These fractures are often fixed with K-wires; the classic example is the Salter-Harris IV lateral condyle fracture of the distal humerus. Fourth, markedly unstable lower extremity fractures are often best served by external fixation.

External Fixators: External fixators are used in both pediatric and adult patients, for fracture treatment and stabilization of rotational osteotomies, lengthening, and bone transfer. Unilateral external fixators consist of half-pins (penetrating one side of the extremity but not exiting the other) connected by graphite or metal rods on one side of the extremity (see Figure 20). Planar external fixators use the same building blocks but occupy more than a 90 degree arc around the extremity. Ring fixators, first developed
by Ilizarov, consist of a series of rings that surround the extremity and are connected to each other by rods. The whole construct is anchored into the bone by wires or fully threaded pins (see Figure 21). External fixators that cross a joint are termed spanning fixators (versus non-spanning) and they often will be constructed with angular capability across the joint. Similar angulation, which can be changed over time, is used when external fixators are employed to gradually rotate an osteotomy to overcome a pre-existing angular deformity.

Figure 20: AP view of the forearm reveals an external fixator across the distal radial osteotomy. The child had a prior fracture which had resulted in premature arrest of growth of the radius.
Several decades ago, Ilizarov pioneered the first effective and reliable system for lengthening long bones. These techniques continued to be refined, but the principles are largely ones that he developed. Lengthening is often employed in patients with limb length discrepancy due to childhood trauma, infection, or congenital/developmental deformity. Another use is limb lengthening for dwarfs. The basic steps of the technique include creating a corticotomy, which is a careful osteotomy in which the periosteum is left largely intact, with placement of a ring external fixator; an initial 5-10-day latency
period to start the healing process; gradual distraction of the corticotomy in tiny
increments totaling no more than 1 mm per day; and a consolidation phase at least as long
as the distraction phase, to allow new bone to fill the defect while the extremity is
protected by the fixator. Radiographs usually are obtained every 7-14 days (see Figure
22). The radiologist should scrutinize the images to describe the amount of interval
lengthening, document the presence and increasing consolidation of new bone in the gap
after lengthening, and alert the surgeon to complications, such as fracture through the
new bone, progressive angular deformity or buckling, or infection along the pin tracks.
Similar processes now are employed to correct some angular long bone deformities and
to achieve bone transfer to fill a bone gap left behind after fracture, infection, or
congenital pseudoarthrosis.
Figure 22: Proximal femoral lengthening site demonstrate moderate new bone developing in the gap, secured by a unilateral external fixator.

Osteotomies and Epiphysiodesis: Osteotomies are used in both children and adults to correct angular deformities and to allow surgeons to re-set malunited fractures (see Figure 17). The osteotomy is secured by internal hardware or an external fixator. The most common use of osteotomies in children is in the setting of developmental dysplasia of the hip. In these children, the femoral head is laterally subluxated or dislocated and
the acetabulum develops abnormally as a result. To provide improved coverage of the femoral head, the child may undergo one of a number of peri-acetabular osteotomies, usually fixed with several pins (see Figure 23), or a varus derotational osteotomy of the proximal femur, secured by an angled blade plate.

Figure 23: Two K-wires pin the site of the previous supra-acetabular osteotomy, performed to correct developmental dysplasia of the hip.

The paragraphs above allude to a number of situations in which adults undergo osteotomy. One of the classic adult osteotomies is the opening wedge osteotomy of the proximal tibia. This is performed in young or middle aged adults with isolated medial compartment arthrosis of the knee. These patients and their surgeons wish to avoid total knee arthroplasty (TKA) as long as possible. By realigning the proximal tibia, the surgeon recreates the normal mild valgus at the knee and unloads the degenerated medial compartment by shifting the mechanical axis laterally. This may buy some time before
the patient’s first total knee replacement, but the procedure is falling out of favor as
techniques evolve. Many of these patients now undergo a medial unicompartmental
arthroplasty (see Figure 24). This procedure had been largely abandoned for awhile, but
is gaining popularity again with improved devices and techniques. These implants are
proving nearly as durable as total knee prostheses, yet the operation and recovery are
much less rigorous and it does not preclude the patient from undergoing standard TKA in
the future.

![Image](image_url)

**Figure 24:** AP and lateral views of the knee show a medial unicompndylar prosthesis.

Another reconstructive procedure for children is epiphysiodesis. This procedure is for
children with open growth plates and either limb length discrepancy or developing
angular deformity across a growth plate, often due to injury of the epiphysis. The
surgeon disrupts the growth plate cartilage and secures it with a staple, plates and screws,
or a bone dowel (see Figure 25).
Figure 25: AP view of both knees demonstrates plate and screw devices in place in child who has undergone epiphysiodesis.

**ARTHROPLASTY AND ARTHRODESIS**

These topics are only covered in general here, without joint-specific attention.

Arthroplasty is the replacement of a native joint. One usually thinks of replacing the joint with hardware, especially in the hip and knee. However, other types of arthroplasty include interposition arthroplasty, in which a tendon or man-made spacer takes the place of a joint; and resection arthroplasty, in which some or all of the articular surfaces are removed but not replaced. An example of interposition arthroplasty is the resection of the trapezium in cases of severe first carpometacarpal joint arthrosis with interposition of a tendon to maintain appropriate length in the first ray (see Figure 26). Alignment is
initially maintained by a K-wire. The classic example of resection arthroplasty is the
Girdlestone procedure, in which the femoral head and neck are resected but not replaced.
Initially developed to treat tuberculous septic arthritis, occasional patients still undergo
this procedure for multiply failed hip prostheses and in some cases of fracture in which
the patient is too unstable for a full joint replacement procedure.

![Figure 26: Oblique wrist image in a patient who has undergone resection of the trapezium for arthritis. There has been tendon interposition and two K-wires temporarily stabilize alignment and position.](image)

A total joint replacement requires replacement of all the surfaces that are within the
synovial cavity of the joint. A hemiarthroplasty is a procedure in which only half the
joint is replaced; the most common examples are the proximal femur and the proximal
humerus (see Figure 27). Limited joint resurfacing is also occasionally a choice. This is
another arena for evolution of hardware and techniques. Femoral head resurfacing had been abandoned some time ago due to high complication rates and low patient satisfaction. However, improved devices and techniques, including adding a medullary peg to stabilize the femoral head resurfacing, and additional resurfacing of the acetabulum, have revived this procedure. Due to the lack of long-term follow-up studies and the lingering skepticism regarding this procedure, it should be several years before it gains widespread use.

**Figure 27:** AP view of a bipolar hemi-prosthesis, with a femoral stem and head covered by a cup, but with acetabular cortex intact.
Additional evolution continues in other joints. Improved devices and techniques have brought both total elbow and total ankle arthroplasty off the trash heap and made them viable options for patients suffering pain and/or stiffness due to degenerative or post-traumatic arthrosis or inflammatory arthritis. Both of these joints exhibited dismal results in the early days of arthroplasty. The physiology and function of each joint were poorly understood. Hinged elbow prostheses had a high rate of pullout, and 1970s-era ankle replacements often experienced loosening of the tibial component or subsidence of the talar component. Just recently, improved understanding of the normal motion and function of these joints, in combination with improved materials and techniques, has allowed some patients to have these joints replaced rather than fused or ignored (see Figure 28).

Figure 28: Total ankle arthroplasty has been performed in this patient. Polyethylene tibial insert is radiolucent.
There has been continual evolution regarding how best to treat the severely symptomatic wrist and the joints of the hand and foot. The smaller joints are typically made of silicone or silastic, sometimes with metal grommets or backing. Swanson has contributed a number of designs, and some of these remain popular. However, relatively high rates of failure continue to encourage new designs (see Figure 29). Wrist prostheses have progressed from Swanson’s initial silicone single-piece implant to metal and polymer joint replacements. Still, fusion of the wrist (arthrodesis) remains a common choice, as does resection arthroplasty, in which the proximal carpal row is removed. Arthrodesis remains the mainstay of treatment of recalcitrant painful degenerative joint disease of the hindfoot and midfoot, as there are no suitable prostheses for these sites. In fact, ankle arthrodesis (see Figure 30), typically a very effective salvage procedure to palliate pain, is still more common than the resurgent arthroplasty techniques.

Figure 29: Two-part silicone metacarpophalangeal joint prostheses are in place.
Figure 30: Oblique and later views of the ankle demonstrate solid arthrodesis of the ankle joint. Three cancellous screws were used for stabilization while the fusion healed.

SPINE HARDWARE

Neck and back pain are ubiquitous in humans, and there are numerous non-operative and operative treatments for maladies of the spine. Although complication and failure rates of spine surgery are relatively high, many patients find themselves resorting to this option, sometimes multiple times. As with extremity operations, the imperfect outcomes of spine surgery continue to drive innovation in hardware and techniques. This section simply provides an overview of the advancements, without specifics regarding individual procedures and devices.
The first effective posterior instrumentation to augment correction and fusion in scoliosis consisted of the Harrington distraction rods, soon to be coupled with Harrington compression rods (see Figure 31). Luque instrumentation, with rods secured to the vertebrae by sublaminar wires, and Cottrell-Dubousset rods, anchored by laminar hooks, have been joined by the Texas Scottish Rite Hospital (TSRH) and Isola systems, and current instrumentation often is a hybrid of these designs. Long-segment anterior fusion systems, such as Dwyer instrumentation and Zielke instrumentation, are no longer widely used.
Lessons learned from long-segment thoracic and lumbar fusions have been adapted to shorter segments, and there is a strong trend towards posterior instrumentation to augment fusion to accompany spinal canal decompressions (see Figure 32). As understanding of normal spine mechanics and physiology improves, some innovations attempt to preserve or restore motion or anatomy. For instance, it is thought that many
people suffering from painful degenerative disc disease have multiple causes for pain. While the degenerated disc may be painful, abnormal motion there worsens pain. Moreover, the loss of height across the disc space and posterior elements contributes to radiculopathy. A relatively recent approach to this combination of problems has been to perform a diskectomy but then restore disc height with two threaded interbody cages. If the cages are tapered, with the narrower aspect placed posteriorly, this will also restore natural lordosis at the site (see Figure 33). The X-stop interspinous spacer (see Figure 34) is a new device that restores height and decompresses the neural foramina. Its ease of implantation and good short term results suggest it may be a helpful first option for patients with positional claudication. To restore natural motion and hopefully lessen the risk of adjacent segment degeneration, effective intervertebral disc prostheses have been developed. A number of these devices for the lumbar and cervical spine are in various stages of the FDA approval process, and early and intermediate results are promising (see
Figure 32: AP and lateral views of the lumbar spine in a patient who has undergone posterior decompression supplemented by posterior fusion from L3 through the sacrum. Note the adjacent segment degeneration at the L2/3 disc, which was new in the last year.
Figure 33: AP and lateral views of a pair of tapered, threaded LT interbody cages at the L4/5 level. Note the restoration of disc space height and lordosis at this level.

Figure 34: AP and lateral views of the lower lumbar spine reveal an X-stop interspinous spacer placed between the spinous processes of L5 and S1. The S1 vertebra is anomalous and has a larger spinous process than is typical.
Cervical spine procedures also have undergone recent evolution. Cervical disc arthroplasty mirrors the development of lumbar disc prostheses. Plate and screw technology for anterior fusion have made vast improvements since the early 1990s. There are several plates available now that have captured screw technology. In these plates, the screws will not back out or extrude. Flat plates without captured screw technology, such as the Caspar plate, are an anachronism. Additionally, some of these plates allow variable angling or translation of their screws, permitting some natural subsidence of the spine as there is resorption of the ends of interbody bone grafts, a common part of the normal healing process. Another advance has been the development of laminoplasty for patients with long-segment cervical canal stenosis. In this procedure,
the canal is decompressed by hinging the posterior elements and opening up the canal without removing the posterior elements. Osteotomies are secured with small plates or suture in this procedure.

**BIOLOGICAL IMPLANTS**

There is a growing trend toward using devices and substances that are biodegradable and/or augment bone healing and fusion.

*Bone Graft Substitutes:* Bone graft is extremely useful in filling voids, providing structural support, and augmenting osseous fusion. However, allograft (from another person) is in limited supply and brings on the consequences of using allogeneic material, while harvesting autograft from the patient often leaves donor site morbidity. The search for substitutes has resulted in a number of options. Three of the most popular are Bone Morphogeneic Protein (BMP-2 and -7 are in use), which primarily serves to hasten osseous fusion; and calcium phosphate and calcium sulfate putty. The latter two are used to fill osseous voids, commonly in depressed calcaneal and tibial plateau fractures (see Figure 36). Both resemble polymethylmethacrylate bone cement but are eventually absorbed by the body and replaced by bone marrow, with calcium sulfate remaining in place for just a few months, as opposed to a few years for calcium phosphate. Calcium sulfate also may be formed into bioabsorbable antibiotic impregnated beads and joint spacers for the treatment of chronic osteomyelitis or septic arthritis.
Figure 36: Bone graft substitute: lateral view of the calcaneus (A) and AP view of the knee (B) show dense calcium phosphate filling osseous defects after reduction of fractures.
**Bioabsorbable Hardware:** There have been great advances in the development of bioabsorbable devices. These are implants that are used to stabilize bone or soft tissue defects until the body heals the injury. With time, the body breaks down and absorbs these devices. As such, these implants need to be stable long enough to ensure healing of the defect and strong enough to withstand the considerable forces that daily activities put on many body parts. Yet their chief advantage is in their eventual disappearance and the lack of a need to be retrieved. Additionally, because of their dissolution, they will not generate stress shielding in the bone. Another touted advantage is their marked reduction in artifact generation on post-operative CT and MRI. Their imaging characteristics are a mixed blessing for radiologists, though, because they may be unaware that one of these radiolucent devices is even present!

The longest standing and most widely used devices in this category are absorbable sutures, such as PDS. Just in the last few years, bioabsorbable implants have been developed and approved for a wide range of applications, including darts and tacks to repair tears of the knee menisci and glenoid labral tears; suture anchors, most widely used in rotator cuff reattachments; numerous small and even a few large plate and screw devices, mostly used in craniofacial surgery; lumbar intervertebral cage devices; and a variety of small nails and tacks for securing small fracture fragments and osteochondral lesions (OCL). Current polymers in use in this field are mostly polymers of polylactic acid (PLA) and polyglycolic acid (PGA). These are lucent on radiographs. On CT, they usually have attenuation in the range of soft tissue. At MR, these devices are uniformly
low signal on all sequences, and do not exhibit susceptibility artifact (blooming) on
gradient recalled echo sequences unless there is adjacent micro-metallic debris. The
main imaging findings of concern with these devices are failure of fixation, which should
be obvious; dislodgement, such as with rotator cuff anchors and Smart Nails securing
knee OCLs; and aggressive synovitis, more commonly seen with the more rapidly
resorbing PGA than with PLA.

**POST-OPERATIVE IMAGING AND COMPLICATIONS**

*Post-Operative Imaging:* In most settings, radiographs will be the first and only imaging
study needed to evaluate a patient’s post-operative status. Even when there are specific
complaints raising questions of complications, radiographs are usually indicated first and
may provide all the necessary information. Ultrasound is a powerful tool in certain
situations, but is not broadly applicable for most radiologists. Various scintigraphic
techniques are sometimes quite helpful; these topics are discussed below.

For many years, the literature has been replete with statements that CT and MRI are poor
choices to evaluate patients with significant metallic implants, due primarily to beam
hardening (CT) and susceptibility (MR) artifacts. That has been the mantra of
radiologists and our referring colleagues until recently. However, with recent advances
in CT technology and MR sequences and knowledge, many metallic implants can be
imaged without significant loss of relevant information. One excellent review of this
topic is the article by White and Buckwalter listed in the Suggested Readings section of this chapter. Most of the suggestions are summarized here.

With the development and evolution of modern multi-detector CT scanners and improved multiplanar reformat capability, current CT scanners produce much less beam hardening artifact than prior generations of scanners. For CT scanning, geometry of the implant matters. The less metal in any one axial image, the less artifact there will be. Therefore, positioning an implant with its long axis perpendicular to the axial plane will reduce artifact. Unfortunately, most implanted hardware allows little leeway regarding patient positioning. An additional consideration to reduce scatter artifact at CT is to increase the exposure factors. This is achieved better with significantly increasing the mAs than the kVp. It is also known that using a soft tissue/standard reconstruction algorithm, and then viewing in bone windows, will diminish beam hardening artifact. In fact, widening the windows will aid further in inspecting the regions nearest the metal implant. Finally, reviewing the multiplanar reformatted images that are routine with modern multi-detector scanners helps to evaluate even the tissues closest to an implant.

For MR imaging of metallic implants, positioning again affects the scan. The longitudinal axis of the device should be aligned with the direction of $B_0$, the main magnetic field. Gradient-recalled echo sequences markedly enhance susceptibility artifact and should be avoided when hardware is in the field. Fast or Turbo Spin Echo sequences are superior to Spin Echo, and T2-weighted sequences suffer more than T1. Frequency selective fat suppression worsens susceptibility artifact, so one should use
Inversion Recovery to serve as a fluid sensitive sequence with fat suppression.

Misregistration artifact propagates in the direction of the frequency encoding axis but not the phase encoding axis, so switching these axes may allow inspection of tissues near an implant. Increasing the receiver bandwidth is another parameter adjustment that may be helpful. These hints for limiting artifacts on MR and CT are certainly useful, but some portions of bone and soft tissues adjacent to metallic implants may be impervious to advanced imaging and may require the implant to be removed before adequate images are possible.

*Infection:* Osteomyelitis next to an implant often looks like osteomyelitis in an unoperated bone, except for associated artifact on CT or MR imaging. However, infection can behave differently when it is associated with hardware. When an implant or other foreign body is colonized by microbes, they change their phenotype and create a biofilm. This biofilm offers a protective effect against natural host defenses and creates additional barriers to penetration by antimicrobial medications. These features render eradication of the organism difficult. This is compounded by the typical reduced vascular supply in close proximity to implants. These effects are the reason that most implants must be removed to eliminate an established infection.

Infection around an implant occasionally is fulminant and will give obvious systemic clues to the process. More often, these infections are relatively indolent and cause modest alterations in laboratory values and low fevers at most. Likewise, local bone destruction around orthopedic implants is often relatively mild and the appearance
seemingly innocuous. Diagnosis of these infections remains difficult at times. Certainly, sampling the local environment with microbiological analysis is usually preferred. However, joint aspirations and bone and tissue biopsies are complicated by false negative results, an occasional false positive from a skin contaminant, reduced sensitivity in the setting of recent antibiotics, and occasional difficulty accessing the site. Of note, any time a joint aspiration is performed, some of the fluid should be submitted for cell count and differential. In an undiluted specimen, greater than 2500 white cells, especially with a majority of granulocytes, indicates infection and will require removal of the prosthesis or implant regardless of the microbiological results.

Radiographs are the first line of radiologic investigation. They are frequently negative for any signs of infection. When positive evidence is present, it usually is fairly unimpressive, consisting of mild degrees of lucency around the implant at its interface with bone (see Figure 37). While extensive areas of osteolysis and aggressive periosteal reaction, or any periosteal reaction, for that matter, are strong indicators of infection, they rarely are present. When local tissue sampling is not an option due to difficult access, patient instability, or ongoing antimicrobial treatment, and the radiographs are not illuminating, scintigraphy can be very helpful. Currently the best tool in nuclear medicine remains an Indium-111 labeled white cell scan, although investigations into the
use of PET to evaluate for infection are showing promise.

*Figure 37:* Infection: the acetabular component is clearly too vertical and is obviously loose, but the picture is not an aggressive one, and could be due bland loosening or particle disease. Cultures at the time of revision were positive.
Loosening: Loosening of an implant carries different implications based on the nature of the device. Loosening of plates, screws, and other fixation devices will often portend a lack of effective osteosynthesis at the site. A cardinal rule of hardware is that all hardware that bears a load or stress will eventually fail unless the body fuses or heals at the site. Fixation hardware is rarely intended to be a permanent solution. Instead, it provides stability and apposition of structures until they can heal. As such, when loosening of devices is discovered, one should assume that the fracture, osteotomy, or other defect is ununited or malunited.

On radiographs, loose implants are recognizable by a lucency surrounding them. This is especially true when the lucency exceeds 2 mm or increases in size after the first year (see Figure 38). Loose screws will often gradually retract and may eventually become expelled from the bone entirely. One of the most dramatic examples of this is cutout of a dynamic hip screw, in which the screw within the femoral head migrates through the head and into the hip joint (see Figure 39). Certainly, any motion of hardware between images, other than intended effects such as settling of a DHS, indicates loosening.
**Figure 38:** Coned-down AP view of the ankle demonstrates failure of fixation, with lucency surrounding the syndesmotic screws, which are pulling out, and widening of the syndesmosis.

**Figure 39:** AP view of the hip shows nonunion of the intertrochanteric fracture with failure of fixation. The DHS screw has cut out of the femoral head.

**Catastrophic Failure:** When an implant grossly breaks or the device becomes largely dissociated from the underlying bone, it is termed catastrophic failure (see Figure 5). The findings in these cases are obvious and merit little discussion. However, there are two significant points in this situation. First, liftoff of a plate, gross breakage of an implant, dissociation of spine fusion rods from the spine, and other such catastrophic hardware
failures should raise strong suspicion for lack of fusion or fracture nonunion. The
surgeon should assume such is the case and take appropriate corrective action. Second,
one should at least suspect infection when there is a remarkable hardware failure.

*Complications of Joint Replacements*: Complications related to prostheses will be
discussed in their respective anatomic chapters below, but because prostheses are so
ubiquitous, they deserve some general comments here.

Peri-prosthetic fractures are most common at the distal femur, just above a knee
prosthesis (see Figure 40). Nevertheless, because of implant-related stress shielding and
the advanced age of many patients who have joint replacements (implying higher rate of
osteoporosis), fractures occasionally occur around almost all types of joint replacements.
They are more common at certain sites because of the inherent stresses involved and at
times the surgical technique. For instance, many distal femoral peri-prosthetic fractures
occur because the anterior femur is inappropriately notched at the time of surgical
implantation, creating a stress riser that later fractures.

Figure 40: AP and lateral views of the knee demonstrate a fracture just above the knee prosthesis. This is the most common site of all peri-prosthetic fractures.

Loosening of joint prostheses typically causes lucency, just as is seen around other types of implants. However, loosening can also be manifest as breakage of polymethylmethacrylate (PMMA) cement, which is never normal; gross subsidence of the implant; change in alignment of the implant; or shedding of tiny metallic beads that
are part of an uncemented device’s porous coating (see Figure 41).

*Figure 41: Lateral view of a revision knee prosthesis demonstrates tiny metallic beads that have been shed from the porous coating of the original device and now lie posterior to the tibial tray. These beads portend loosening.*

Infection of arthroplasty hardware most often looks normal on radiographs or resembles bland loosening. Thus, if one observes abnormal lucencies around a device on a radiograph, infection should remain in the differential with loosening.

Particle disease and osteolysis are two terms applied to a foreign body granulomatous reaction that occurs around prostheses. A whole prosthesis does not incite these chronic inflammatory responses. Instead, the culprit is microscopic debris, including PMMA
particles, particles of polyethylene, and small particles of metal. Again, this reaction may manifest only with radiographic signs of loosening. However, this process often leads to more focal, large granulomas, which appear as multifocal, bubbly lucencies around a device. Eventually, particle disease leads to failure of the prosthesis, requiring surgical revision. Because the osteolysis creates large defects that complicate revision arthroplasty, and because the size of the lucencies is underestimated by radiographs, surgeons often resort to cross-sectional imaging to find and characterize known or suspected osteolysis (see Figure 42). With modern equipment and techniques, both CT and MR have been shown to be accurate at this task, with CT slightly better at accurate measurement of the defects and MR slightly better at demonstrating smaller lesions.

Figure 42: AP radiograph and coronal reformatted CT of the left hip: there is extensive osteolysis in the acetabulum deep to the prosthesis. Despite the hardware, the CT images are exquisite.
**Implant-Related Sarcoma:** Numerous metals have been shown to be carcinogenic when implanted into humans. Still, the occurrence of implant-related sarcoma is a true rarity. When these neoplasms occur, they are most commonly malignant fibrous histiocytomas and osteosarcomas. These sarcomas are usually quite aggressive locally and often metastasize. They must be differentiated from other aggressive but benign processes, such as infection and extensive particle disease.
SUGGESTED READINGS


