Multichannel CT Imaging of Orthopedic Hardware and Implants

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ABSTRACT

The introduction of multichannel CT scanners provides both radiologists and surgeons with a new tool to image patients with orthopedic hardware. The key parameters that have made it possible to image the implants and the surrounding bone with multichannel CT are the higher available technical factors (kVp and mAs) coupled with the ability to acquire thin slices over a large scan region. These properties make it possible to produce high-quality multiplanar reformations that facilitate visualization of the orthopedic device and the surrounding bone. An important consideration for multichannel CT imaging of hardware is the reduction of cone beam artifacts caused by the geometry of multichannel CT scanners. This artifact is reduced by using a narrower x-ray beam collimation and a low pitch setting. This article discusses CT scan parameters and image postprocessing used at our institution and illustrates common clinical problems encountered when imaging implanted orthopedic devices. These include fracture healing, loosening of joint prostheses, evaluation of particle disease, and the use of CT for preoperative planning in revision arthroplasty.

KEYWORDS: X-ray computed tomography, CT, bone, joint prosthesis, prostheses and implants

Advances in imaging technology have resulted in the creation of multichannel computed tomography (CT) scanners. These powerful devices have revolutionized body imaging and provide new opportunities in musculoskeletal imaging. Techniques optimized for body imaging are not optimal for orthopedic imaging. It is important to be aware of the differences in scan techniques to produce high-quality images of bone structures. Metal hardware introduces additional artifacts and accentuates the need to minimize the artifacts introduced by the geometry of multichannel machines.

Imaging of patients with metal hardware is important in assessing fracture fixation and fracture healing. The bone around most hardware can be imaged successfully. The artifacts introduced by the hardware are related to the composition of the metal, the shape and orientation of the hardware, and the scanner setup.1 The most important scan parameter affecting image quality is pitch: low pitch settings should be used routinely when scanning patients with metal hardware. Other parameters such as kVp, mAs, and image reconstruction algorithm are important, too, and are discussed.

The principles used to image metal plates and intramedullary nails can be applied to imaging of joint implants. Failure of joint implants may have a variety of causes including mechanical failure or fracture of the metal components, fracture of the surrounding bone, infection, component wear, osteolysis, and particle disease. Most of these complications can be detected with CT images, particularly if high-quality multiplanar
reformations (MPR) are available for review. Because many of these patients can undergo revision arthroplasty, preoperative imaging is extremely helpful when radiography fails to demonstrate the relevant anatomy adequately. The techniques used to image implants with CT and illustrations of some pertinent complications are detailed in this article.

CT TECHNIQUE
An understanding of the CT scan parameters that affect image quality is crucial to the production of diagnostic images of bone structures. This is particularly relevant when imaging patients with implants and other hardware. Techniques optimized for body imaging do not produce optimal results when applied to imaging of patients with orthopedic devices. Body imaging typically is performed with intravenous contrast material during suspension of respiration requiring short (<20 second) scan times. These rapid scan times are achieved using the highest x-ray tube rotation times and the highest table feed velocities resulting in higher pitch settings. These scan parameters degrade visualization of detail by exaggerating cone beam artifacts, which are more conspicuous when metal hardware is present. Thus, standard body imaging protocols should be avoided when imaging patients with orthopedic hardware.

The factors affecting our ability to visualize the bone structures surrounding implanted hardware include the following: hardware composition, hardware geometry and location, pitch, kVp, mAs, and image reconstruction algorithm. Each of these factors is discussed in the following paragraphs.

Metal hardware attenuates the x-ray beam and alters the spectral characteristics of the radiation causing beam hardening. There are three major types of metal alloys used in orthopedic devices: cobalt-chrome based, iron based, and titanium based. Tantalum is another material used occasionally for some prosthesis components. Cobalt-chrome alloys and stainless steel (iron based) attenuate the x-ray beam significantly, resulting in major artifacts. Conversely, titanium and titanium alloys produce minimal artifacts. Cobalt-chrome alloys are encountered commonly in hip and knee prostheses. Stainless steel is used often for fracture plates and screws. Titanium is used in the stems of newer hip prosthesis and for some intramedullary nails. Because it is impractical to identify the specific metal alloy used in an implant prior to the CT examination, evaluation of the opacity of the metal on the CT scout image is a helpful indicator of the density of the metal; dense cobalt-chrome implants are white on the scout image, whereas the less dense titanium devices are gray to gray-white on the scout image. These are guidelines that can be used to adjust technical factors at the time of the examination.

As might be expected, thicker portions of the metal hardware cause more attenuation and more artifacts than thinner portions of the hardware. Many intramedullary nails and prosthesis stems are symmetric in cross section and the attenuation of the x-ray beam is relatively uniform, dispersing the artifacts across the entire image (Fig. 1). In contrast, fracture plates are

Figure 1  (A) Axial CT image through midtibia. Artifacts from intramedullary nail are dispersed relatively uniformly throughout image. (B) Coronal reformation through posterior tibia of the same patient shows persistent fracture line. Intramedullary nail used to stabilize the fracture causes no visible artifacts. (C) Sagittal reformation, same patient. Healing is incomplete as there is no bone bridging at the fracture site.
rectangular in cross section and artifacts usually are most severe in the direction of the greatest cross section (Fig. 2A). Because fracture plates are placed along the outer margin of the affected bone, one can predict that the most severe artifacts will propagate tangentially to the surface of the bone and that the adjacent bone will be visualized adequately (Fig. 2B). Thus, a successful examination can be anticipated when lateral fixation plates are present.

Because artifacts are most severe immediately adjacent to the hardware, the farther the hardware is located from the region of interest, the less it interferes with visualization. For example, a patient with a unilateral hip prosthesis can undergo a detailed examination of the contralateral hip with little or no artifact. An exception to the proximity rule is the patient with bilateral hip prostheses. In this circumstance, the attenuation from both prostheses coupled with the overlying lateral soft tissues can produce severe artifacts. Except for the smallest of patients, the density of the two prostheses overwhelms the ability of the x-ray beam to penetrate the tissues in the horizontal direction, resulting in left-to-right streaking.

Metal produces artifacts only when the x-ray beam traverses the metal object; consequently, it may be possible to reorient the body part containing metal to reduce or avoid the x-ray beam entirely. For example, patients with bilateral knee prostheses may be positioned so that a cushion or pillow is placed behind the unaffected knee, displacing this knee so that the densest portions of the prostheses are not simultaneously traversed by the x-ray beam, improving visualization of the affected knee, which remains straight (Fig. 3A).

Perhaps the most important parameter affecting image quality is pitch. One definition of pitch is the table increment divided by the detector element width for each complete revolution of the x-ray beam. Thus, high pitch settings represent rapid table motion relative to x-ray beam revolution, quickly covering a large portion of the patient’s anatomy. Rapid scanning is useful to follow a contrast bolus or to facilitate motion-free imaging during suspended respiration, but the higher pitch settings exaggerate image artifacts. These artifacts are worse for hard edges such as the bone–soft tissue interface and are even worse when metal is present. Despite the deployment of cone beam correction software, the artifacts cannot be avoided. The cause of these artifacts is related partly to the geometry of multichannel scanners, which introduces cone beam effects.

The cone beam artifacts become worse as the detector elements become more numerous. Thus, cone beam artifacts are minimal on a 4-channel machine but can become severe on 16- and higher channel devices, which have wider detector arrays. The remedy is twofold. First, the use of lower pitch settings can reduce dramatically the cone beam artifacts and improve overall image quality. For four-channel scanners, pitch settings of 0.6 to 0.9 are recommended. If pitch cannot be changed, alter the table feed speed; slower table feeds correspond to lower pitch settings. For 16-channel and
higher channel scanners, a pitch setting of 0.3 works well if your equipment permits; otherwise, use the lowest possible setting. The second remedy is the use of the narrower detector element collimation. For 16-channel machines, the choices of array elements are 16 x 0.75 (12 mm collimation) or 16 x 1.5 (24 mm collimation) for Philips and Siemens CT scanners and 16 x 0.625 (10 mm collimation) or 16 x 1.25 (20 mm collimation) for GE scanners. Some investigation into protocol setup may be required to select the thinner collimation setting. Both the thinner collimation setting and the lower pitch setting are necessary for optimal results.

Technical factors such as the use of a higher kVp setting and higher mAs may be helpful in addressing some of the metal artifacts. The use of the filtered back projection algorithm in CT image reconstruction is responsible for the streak artifacts encountered in images containing metal hardware. The metal attenuation of the x-ray beam may be severe, resulting in imperfect CT projections. For less dense metal, the use of a higher kVp setting (e.g., 140 kVp) may result in more photons passing through the hardware, improving the quality of the image reconstructions. Similarly, higher mAs factors can be employed. Both of these strategies are recommended when dense hardware is present. The downside of this approach is an increase in dose to the patient. In fact, if all other parameters remain unchanged (i.e., pitch, slice width, mAs), the patient experiences 30 to 40% higher dose when the kVp is raised from 120 to 140.

If the region of interest is remote from radiation-sensitive tissues, such as the knee or ankle joint, increased dose should not be a serious issue. Similarly, if the region of interest is the wrist and can be positioned overhead, the unnecessary radiation of other body parts...
can be avoided. To obtain a diagnostic examination in an older patient past childbearing years, the use of higher technical factors should be considered an acceptable risk. If at all possible, minimal exposures are advised when dealing with pediatric and young adult patients.

Although it may seem paradoxical when imaging bone, the use of a smoother image reconstruction algorithm such as a standard or soft tissue filter rather than a sharper reconstruction algorithm such as a bone filter may assist in reducing some of the fine streak artifacts seen in the soft tissues surrounding metal hardware. This strategy works well when dense metal, such as a hip prosthesis, is present. The trade-off is a reduction in the spatial resolution of the surrounding bone. For large devices such as a hip prosthesis, a typical field of view (FOV) used to reconstruct the image would be 20 cm; with a 512 image matrix, pixel size is about 0.4 mm. Using liberal approximations, this corresponds very roughly to a 13 lp/cm spatial resolution, which is close to the resolution limits of a standard CT reconstruction filter. Thus, spatial resolution is not compromised significantly when using the smoother reconstruction filter. In addition, the absence of significant streak artifact may reveal details that would otherwise be obscured when using a sharper reconstruction filter.

When limited hardware such as screws and pins is present in small joints like the ankle and wrist, images are reconstructed using submillimeter slice width at 50% overlap (e.g., 0.8 mm thick at 0.4-mm increments). A sharp reconstruction filter is employed because metal artifacts are usually minimal. For more substantial hardware such as a fixation plate, hip, or knee prosthesis, images are reconstructed using 1- to 1.5-mm-thick slices at 50% overlap. Depending on the density of the metal and the location or amount of surrounding soft tissues, a standard or soft tissue algorithm should be used.

**IMAGE POSTPROCESSING**

For most orthopedic imaging, frontal and lateral projection radiographs are the conventional way to review joints and hardware implants. These projections correspond to sagittal and coronal multiplanar reformations generated from the source axial CT images. Thus, interpretation of CT studies of patients with orthopedic implants is dependent on the availability of high-quality multiplanar reformations and other forms of image postprocessing.

The development of highly integrated powerful postprocessing software and workstations makes it possible to generate multiplanar reformations rapidly and easily. Sagittal, coronal, and true axial (if necessary) planes are created routinely. For each plane, a set of 24 to 36 images is generated; more are necessary when evaluating a large region such as an extensive pelvic fracture. When reviewing images with dense hardware, it is beneficial to increase the thickness of the multiplanar reformations. The reformations are created using 1- to 2-mm-thick slices. Although thicker reformations increase the likelihood of introducing partial volume artifacts and image blurring, these undesirable effects are offset by a significant reduction in image streaking induced by the averaging effects of the thicker slice. In general, the default thickness for multiplanar reformations is set by the workstation software to the in-plane pixel size, so the slice thickness of the reformations must be increased manually.

Sometimes it is valuable to demonstrate the global relationships of hardware and bone. If radiographs are not available, this relationship is best illustrated using a volume rendering technique. Volume rendering allows the simultaneous display of different density objects such as metal (very dense) and bone (less dense). If the threshold for bone is lower than that of metal, the metal hardware can be visualized through the less dense bone. The volume rendering technique is relatively powerful and can be used to assign different colors to the bone and the metal, amplifying the differences between the objects. In addition, volume rendering techniques are more robust than shaded surface display (three-dimensional) techniques, valuable when moderately severe streak artifacts are present.

**ORTHOPEDIC HARDWARE**

One of the most common indications for hardware placement is fracture fixation. Long bone fractures may be spanned by intramedullary nails or lateral side plates (Figs. 1, 2). When fractures occur in irregularly shaped bones such as the ilium or ischium, malleable plates may be used to secure fixation (Fig. 4). It is important to consider imaging the full extent of the implanted hardware because the hardware alters the mechanical properties of the bone and complications such as loosening may begin proximal or distal to the original fracture site (Fig. 3). Also, it is advisable to include the nearest joint within the scanned volume to provide anatomic cues about general orientation on subsequent multiplanar reformations and to demonstrate the relationship of a known landmark to the fracture site. This is particularly important if revision surgery is under consideration.

When imaging occurs soon after surgical repair, the goal of postoperative fracture imaging is the assessment of joint alignment or the assessment of the proximity of hardware to sensitive soft tissue structures such as nerves or articular surfaces. When imaging occurs weeks to months after surgical repair, the goal is usually the evaluation of fracture healing by assessing the presence of bone bridging (Figs. 1, 2, 5). Because immature osteoid is less dense than ordinary bone, very early healing may not be evident at imaging. In addition,
the determination of delayed union, malunion or non-union is a complex issue requiring a comprehensive assessment of the patient’s clinical state. Furthermore, the terms malunion and nonunion have negative connotations and should probably be avoided in the radiographic report because some of these patients pursue litigation. It is much better to focus on the presence or absence of bone bridging in the report and avoid the negative terminology altogether.

**HIP IMPLANTS**

Implantation of a hip prosthesis is an effective way to treat patients with debilitating joint disease. A properly implanted prosthesis can have a life span of decades. However, some prostheses fail and need to be removed or revised. There are a variety of reasons for failure including mechanical failure of the prosthesis components, mechanical loosening, stress fracture, particle disease, and infection. The reason for failure is not always clear. Most patients can undergo revision arthroplasty, and these patients may benefit from preoperative imaging to assist in surgical planning.

Some knowledge about the hip components is useful when interpreting CT studies of patients with hip prostheses. Placement of a hip prosthesis can involve a simple femoral arthroplasty with implantation of a unipolar or bipolar femoral component or a complete hip replacement that includes an acetabular implant as well. The femoral stem can be cemented in place or may be an ingrowth component. In the latter case, the stem is often coated with tiny metal spheres sintered to the metal stem. Because of their small size (50–200 μm), these spheres are difficult to appreciate when they are in their normal location adjacent to the metal, but micromotion and wear may cause the spheres to dislodge, referred to
as “bead shedding.” Aggregate clumps of beads can be visible in the pseudocapsule surrounding the implant as high-density irregularly shaped material. This is one helpful finding when searching for signs of prosthesis failure on CT examinations.

In the case of a unipolar hip prosthesis, the stem and femoral head are usually one monolithic unit. For a variety of reasons, this type of implant has fallen out of favor. The composition of a bipolar hip prosthesis is more complicated, consisting of a femoral stem, a head, a plastic liner, and a hollow hemisphere that accommodates the liner and the head of the femoral component. The outer surface of the hemisphere articulates with the cartilage of the native acetabulum. These modular components are designed to enable future revision arthroplasty to a total hip with the addition of an acetabular cup; the femoral stem is preserved, simplifying the revision.

A modern total hip prosthesis consists of a femoral stem, a head, a plastic liner, and a metal acetabular cup (Fig. 6). The plastic liner is made of high-density polyethylene and may be held in place by a circumferential clip placed near the rim of the metal cup. Most of the acetabular cups we encounter have an ingrowth coating and are secured to the native acetabulum with one or two screws. Another design, the gap cup prosthesis, has a U-shaped flange that fits under the acetabular tear drop and one or two tabs that are screwed to the lateral margins of the iliac wing. Occasionally, a simple plastic cup is cemented in place to the native acetabulum.

The polyethylene liner of the acetabular cup wears over time, and the head of the femoral component can migrate superiorly. Early evidence of this finding is best appreciated on radiographs (Fig. 7A). More significant wear can be detected on sagittal and coronal reformations of the CT examination, and wear is easy to detect because the head is normally centered symmetrically in the acetabular cup (Fig. 6). In some patients, the polyethylene debris incites a granulomatous reaction in the adjacent bone. This “particle disease” can result in erosion of bone resulting in cyst-like changes in the periprosthetic bone, weakening the bone and contributing to failure of the prosthesis (Fig. 7). The erosions can occur around the acetabular cup as well as the proximal femur. In addition, patients can develop pseudomembranes in the soft tissues surrounding the pseudocapsule of the prosthesis. These pseudomembranes are cyst-like regions of fluid or soft tissue density material that protrude into the periacetabular region and communicate with the hip joint (Fig. 7F). The cysts can extend superiorly for many centimeters, and it is important to extend the scan to the superior pelvic brim routinely to identify the full extent of the pseudomembrane formation. There remains some controversy about the etiology of the periprosthetic erosions and pseudomembrane formation: particle disease is not the sole cause.

In an effort to address the polyethylene wear problem, some manufacturers of orthopedic implants produce ceramic femoral heads designed to work in conjunction with ceramic acetabular liners. On CT images, the ceramic composite is homogeneous in appearance and relatively high in density, although less dense than metal (Fig. 8). The acetabular liners may have a metal backing and are secured to a conventional metal acetabular cup. The ceramic components are precisely machined and the interface between components should
Figure 6  (A) Coronal reformation of an uncomplicated right total hip prosthesis; only right side was replaced in this patient. The acetabular component has an ingrowth coating and the femoral component is cemented in place. Full extent of femoral stem was scanned but is not illustrated. Plastic polyethylene liner separates head of femoral stem from acetabular cup. Femoral head should be symmetrically located within cup. (B) Sagittal reformation, anterior to the left, same patient. Two screws secure cup to acetabulum. Trabecular bone can be seen extending directly to peripheral margin of cup, indicating integration of component into host bone.

Figure 7  (A) AP radiograph of pelvis of an 81-year-old woman with bilateral total hip prostheses. Liner wear has resulted in cephalad migration of both femoral heads. Medial right acetabulum is absent and right acetabular cup has migrated medially. Large radiolucent zone noted lateral to right acetabular cup. Proximal right femur has resorbed. (B) Close-up of right hip prosthesis shows medial wall fracture (arrow). Innumerable faint radiopaque beads are present in right inferior acetabular region. New beads visualized after initial postoperative radiographs often signal loosening of implant. (C) Coronal reformation of same patient shows liner wear with asymmetric location of femoral head in cup. Large medial acetabular wall deficiency readily identified. (D) Sagittal reformation, same patient, anterior to the left of image. Large posterior acetabular defect (*) indicates severe bone stock loss. Radiopaque beads are faintly visible (arrows). (E) Coronal reformation, more posterior than image in C, shows posterior cup is floating without support in a large osteolytic zone. (F) Coronal reformation, same location as E, narrower window to emphasize soft tissue details. Large cyst-like pseudomembrane (arrowheads) arises from medial acetabulum and extends into inner pelvis.
be barely visible at CT imaging. Wear between these components should be minimal over the life of the prosthesis. If there is asymmetry, there may be a mismatch between the femoral head and the acetabular cup or a manufacturing defect.

Imaging of patients with hip prostheses using CT is relatively straightforward. All imaging is performed using the highest 140 kVp setting. For most patients with a single hip prosthesis, 350 to 450 mAs produces good images; when bilateral hip prostheses are present, 450 to 600 mAs produces good images. We use a small focal spot; however, depending on equipment vendor, it may not be possible to achieve the recommended high technique settings using a small focal spot. Higher mAs settings can be used in larger patients, but results may not be as consistent and there are diminishing returns to increased technical factors. The metal of the implants can confound x-ray beam dose modulation software, so it is best to turn this feature off. Most patients with hip implants are past childbearing years and, although care should be taken to avoid excessive radiation, it is less of an issue in these patients. To minimize the cone beam artifacts, the smaller detector array configuration is selected (for 16 slice scanners: 16 × 0.75 mm for Philips and Siemens; 16 × 0.625 for GE) and a very low pitch setting (0.3, if possible).

Scanning begins just above the top of the iliac crests and continues through the tips of the femoral stems and any associated cement. The entire scan volume is reconstructed with both sides in the FOV (350 mm) using a standard image reconstruction filter (C on Philips) creating 3-mm contiguous images. It is important to survey the entire pelvis as the patient may have another reason for symptoms such as a sacral or pubic insufficiency fracture. In addition, the full extent of pseudomembrane formation can be imaged when it is encountered. Despite the fact that one can bill legitimately only for the symptomatic side, it is important to consider reconstruction of the asymptomatic hip for several reasons. If the hip has been replaced, it is not uncommon to encounter particle disease or signs of loosening in the contralateral hip. If the hip has not been replaced, one can look for degenerative joint disease or findings of osteonecrosis, both of which may be important to the orthopedic surgeon.

Additional reconstructions can be made of each hip from the raw data. For the side containing an implant, images are reconstructed using a 160- to 220-mm FOV with 1- or 1.5-mm-thick slices at 50% overlap using a soft image reconstruction filter (B on Philips). These images are reconstructed from the midpelvis level to the end of the scanned volume. More cephalad slices are reconstructed if metal components or screws extend superiorly. Using these axial source images, 24 to 36 MPRs are created in the sagittal and coronal planes using 1.5-mm-thick slices. Two sets of MPRs are created in each plane: one set contains the entire series of images to illustrate the full length of the femoral stem; the second set is limited to the acetabular cup and the proximal femoral stem. This additional set of reformations is important because the majority of periprosthetic bone loss occurs in this region. A native hip is reconstructed with a 160-mm FOV with 0.8-mm-thick slices at 0.4-mm increments using a standard (Philips C) or bone filter (Philips D), depending on the patient’s size. The native hip series is reconstructed from just above the level of the acetabulum to just below the lesser trochanter. A single set of 1-mm-thick sagittal and coronal MPRs are created from these axial source images.

Lucencies or erosions surrounding the prosthesis may be an indicator for loosening or failure of the components. A normal metal cup closely approximates the reamed acetabulum. Trabecular bone should be visible to the level of the cup and any associated screws (Fig. 6). If the cup has an ingrowth coating, there should be no bead shedding. If the cup is cemented, there should be close approximation between the cement mantle and the underlying bone. A radiolucent zone more than a few millimeters surrounding the cement is suggestive of linear osteolysis and may indicate loosening of the acetabular component. For noncemented cups, smaller cyst-like lucencies can be encountered normally at unoccupied screw holes, possibly related to egress of pressurized synovial fluid between the liner and the metal. Preexisting degenerative cysts account for some of the smaller lucencies encountered elsewhere. Larger lytic zones surrounding an acetabular component may indicate particle disease. When present, a search for associated pseudomembrane formation in the adjacent soft tissues is recommended. For noncemented cups, the
most important finding of stability is trabecular bone at the rim. Large radiolucent zones in the non peripheral
zone of the cup may be tolerated if fixation is secure at the periphery. The radiologist’s report should indicate
the location and approximate size of lytic zones. Osteolysis is not always caused by particle disease, so it is best to
term these zones of lysis “bone stock loss.”

As the femoral neck is exposed to synovial fluid, erosion of the bone in this location is another finding encountered
in particle disease. Large lytic zones and fractures can occur in the greater trochanter region as well. Because most femoral stems transfer force to the
more distal bone, it is possible to encounter proximal osteopenia normally caused by stress shielding, and this
should not be confused with the osteolytic zones of particle disease. Other findings of failure include sub-
sidence (inferior migration of the femoral stem relative to the shaft) and, in the case of an ingrowth coated stem, bead shedding. In addition, lucency, erosion, and change
in position over time, particularly at the tip, are worrisome signs.8

Many common problems can be evaluated with standard radiography, and it is important to remember
that radiographs have spatial resolution that is superior to that of the most advanced clinical CT scanner. A host
of signs are used to assess stability of the prosthesis on radiographs.9 With the exception of a subtle fracture or
mild bone stock loss in the greater trochanter, the femoral portion of a total hip prosthesis can be evaluated
adequately with a simple frontal projection and Lauenstein lateral set of radiographs. The entire length of the
stem, including any cement, needs to be radiographed as some patients experience a fracture of the femur or
failure of the stem at or below the tip of the stiffer femoral stem. For this reason, inclusion of the entire stem is important for the CT technique.

**KNEE IMPLANTS**

There are various knee implants to accommodate the different requirements of knee arthroplasty. These include
an isolated patellofemoral prosthesis, a unicompartmental prosthesis, and a total knee prosthesis with or without a
patellar resurfacing component. The components of a total knee prosthesis can connect via a hinge mechanism
to provide additional support when the cruciate ligaments are absent. Long-stemmed prostheses are encoun
tered following a revision arthroplasty (Fig. 3). Regardless of the configuration, most total knee prostheses consist of a metal femoral component that articulates with a plastic liner affixed to the tibial component.
The plastic liner can be replaced after implantation, if necessary.

Because of the dense metal, it is extremely challenging to image the femoral portion of total knee implants and there is limited visibility of the condylar
region. The remainder of the prosthesis is usually visualized very well. In general, the components are
cemented in place, but ingrowth coating can be seen in some implants. When present, the patellar resurfacing
component consists of a plastic surface that is secured to the patella with cement. As with any hardware or im-
plant, it is advisable to examine the entire extent of both prosthesis components.

The CT examination of a knee prosthesis is very similar to that of the hip. Because some patients with
implants have bilateral prostheses, it is helpful if the technologist questions the patient prior to positioning. If
there is a contralateral prosthesis, the asymptomatic side
should be flexed and supported by a pillow or sponge to facilitate penetration of the x-ray beam; flexion of the
contralateral side prevents the undesirable simultaneous overlap of both condylar components by the beam
(Fig. 3A). As with the hip examination, 140 kVp and a high mAs technique are suggested (400–600 mAs). Images are acquired using the thinner detector array configuration and a low pitch setting. Images are recon-
structed using a soft tissue filter (Philips B) with 1- to
2-mm-thick slices at 50% overlap. These axial source images are subsequently reformatted into coronal and
sagittal planes using 1- to 2-mm-thick slices.

Signs of loosening and failure are similar to those for the hip. These include fracture, radiolucent zones
surrounding the cement mantle of the components, and osteolysis. As with the hip, it is possible to encounter
stress shielding around the tibial component of the knee prosthesis, which arises as bone atrophy at the
proximal margins of the tibial component. For the knee prosthesis, serial radiography remains the best means to
assess stability and CT should be considered an adjunct examination only.

**SHOULDER IMPLANTS**

Shoulders are replaced less frequently than hips and knees and the mechanics are different because the
shoulder is a non-weight-bearing joint. Unlike those with hip and knee implants, patients undergoing
shoulder arthroplasty may not experience an increase in joint mobility following surgery. Reduction of pain is the
main purpose for shoulder arthroplasty. Analogous to the hip, a humeral head prosthesis may be placed alone
or in conjunction with a plastic glenoid cup. These components are usually cemented in place. Frictional
forces are minimal and wear of the glenoid cup is unusual.

The CT technique is similar to that for other joints. However, it is helpful to place the contr alateral arm overhead to reduce the thickness of tissue at the
level of the shoulder joint. The affected arm is placed by
the side of the body in mild external rotation. Scanning
should proceed from superior to inferior and technical
parameters should be adjusted to allow a 20-second scan time so that the respiration can be suspended. Images are acquired with technical factors similar to those of the hip. Sagittal and coronal multiplanar reformatations are created in oblique planes like the planes used for routine shoulder magnetic resonance imaging.

The humeral prosthesis is extremely dense, and visualization of the proximal bone surrounding the head of the prosthesis is limited. It is usually possible to see the full extent of the adjacent glenoid, with or without a glenoid component. It is not uncommon to perform the CT examination following a single contrast arthrogram to assess for loosening. This is challenging, particularly if a noncontrast examination has not been performed. It is advisable to consider digital subtraction arthrography in conjunction with the CT examination to increase the likelihood of detecting contrast flow around the cement of the components. Because the rotator cuff is interrupted when placing the humeral head prosthesis, a small perforation of the rotator cuff may be encountered as it is difficult to obtain a watertight seal following rotator cuff repair.

**IMPLANTS IN OTHER JOINTS**

Imaging of implants in the elbow, wrist, and ankle (Fig. 9) is less common than imaging of implants in the hip, knee, and shoulder. Serial radiography remains the main imaging method to assess for loosening and failure, although CT may provide additional information when radiography is inconclusive. Our experience to date is limited, but the imaging principles and CT technique are similar to those previously outlined with a few exceptions. When imaging the elbow or wrist, it is advisable to scan the patient with the affected arm.
overhead to limit the tissue traversed by the x-ray beam. Imaging of the ankle can be performed in the “toes up” position to facilitate positioning of the patient. Depending on the density of the metal, multiplanar reformations should be created with 1- to 2-mm-thick slices. Loosening or failure is predicated on the detection of radiolucent zones surrounding the cement mantle of the prosthesis components or on the detection of fracture lines.

CONCLUSIONS
The development of multichannel CT scanners provides us with new imaging opportunities in musculoskeletal radiology. The radiologist and the orthopedic surgeon should be aware that it is possible to image most patients with hardware with good results. The additional capabilities of the equipment allow us to image most patients with orthopedic hardware and joint implants. The key factors that enable us to image these patients are as follows: higher technical factors, low pitch settings, and high-quality multiplanar reformations. The key parameters that allow us to predict the likelihood of successful imaging of implants and hardware are composition of the hardware, shape (geometry) of the device, and physical location of the device relative to the region of interest.

The goal of most imaging following open reduction and internal fixation is the assessment of healing. Because the determination of delayed union or nonunion is based on imaging as well as clinical findings, the radiologist’s role is to document the presence or absence of bone bridging; when hardware is present, CT can be a useful tool to examine the underlying bone for bridging.

Multichannel CT is useful in examining patients with joint implants. Attention to technical details is essential to obtain high-quality images. When dense metal is present, such as a hip prosthesis, it is useful to review the images using coronal and sagittal multiplanar reformations created with thicker slices (1–2 mm). Prosthesis failure can be related to fracture, infection, particle disease, and osteolysis. Most of these complications can be detected with CT. Furthermore, these scans are useful for preoperative planning when revision arthroplasty is under consideration.

If there is a question about fracture healing or an implant that cannot be answered with conventional radiography, it is generally worthwhile to consider CT imaging.

REFERENCES