



# MR Imaging of Infectious Processes of the Knee

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Infectious processes about the knee can result from the hematogenous spread of infection from remote sources, spread from a contiguous source of infection, direct implantation of pathogens, and prior surgery [1]. Soft tissues, joints, and bones are infected most commonly by bacteria, although a few cases are caused by fungi, parasites, or viruses. MR imaging is useful in identifying cellulitis, abscess, septic arthritis, and osteomyelitis. MR imaging is particularly useful in the setting of chronic posttraumatic osteomyelitis and in prior surgical procedures, such as arthroscopy, anterior cruciate ligament (ACL) reconstruction, and amputation.

## Soft-tissue infection

Soft-tissue infection about the knee can occur either primarily (with or without secondary extension to the bone or joint) (Fig. 1) or secondarily, from extension of an intraosseous or intra-articular infection. Cellulitis is a term denoting infection localized to the subcutaneous tissues. MR imaging will demonstrate a reticulated pattern of abnormal signal intensity in the subcutaneous tissue on both T1-weighted and fluid-sensitive sequences (see

Fig. 1). If intravenous contrast is administered, the subcutaneous tissues will have a reticulated pattern of enhancement. In comparison, noninfective edema may have similar signal characteristics but will fail to enhance.

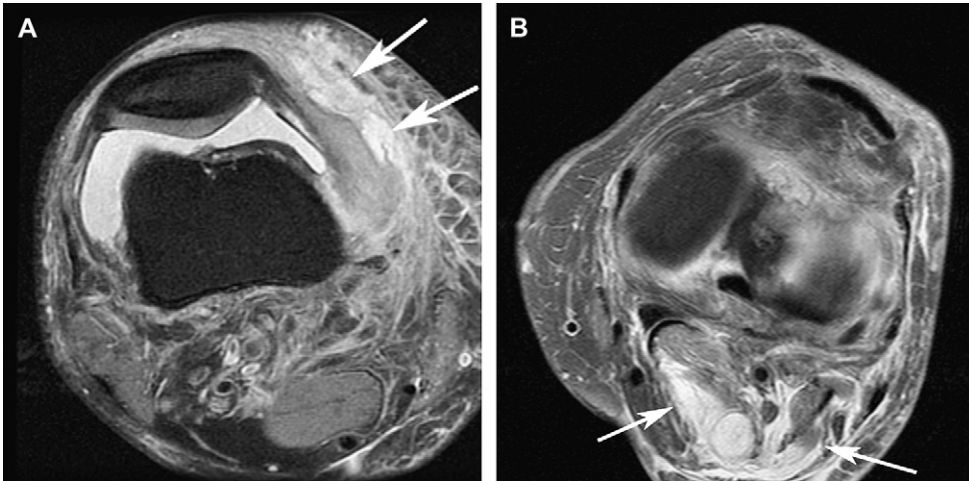
Fasciitis occurs when infection involves the deep or superficial fascia. Soft-tissue gas is a useful radiographic and CT imaging feature that is suggestive of necrotizing fasciitis. However, MR imaging is less sensitive than CT for the detection of soft-tissue gas. Hyperintense T2-weighted signal within deep fascial planes and muscle, with or without enhancement, can be seen in necrotizing soft-tissue infection and other conditions [2].

Pyomyositis tends to involve the large muscles of the lower extremity, and is caused by *Staphylococcus aureus* in about 90% of cases [3]. Patient factors that increase the risk of pyomyositis include diabetes mellitus, HIV, chronic steroid use, connective tissue disorders, malignancy, and multiple hematologic disorders [3]. Pyomyositis may also occur as a result of iatrogenic inoculation from various surgical procedures or contiguous spread of infection from adjacent soft tissues, bones, or joints. MR imaging demonstrates increased signal intensity in the

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**Fig. 1.** Periarticular soft-tissue infection. (A) Axial proton density fat-suppressed image in a 38-year-old diabetic man demonstrates fluid (arrows) superficial to the vastus medialis, diffuse cellulitis, and a small joint effusion. Culture of the drained abscess revealed *Staphylococcus aureus*. (B) Axial proton density fat-suppressed image in a 71-year-old woman demonstrates complex fluid in the popliteal fossa (arrows) that insinuates throughout the posterior compartment musculature around the neurovascular bundle. Aspiration revealed *Streptococcus viridans* and patient subsequently developed septic arthritis.

muscle on fluid-sensitive sequences. If an intramuscular abscess is present, it is hyperintense on fluid-sensitive sequences, and the rim can be increased in signal on T1-weighted images and decreased on T2-weighted images, and can enhance with intravenous gadolinium (Fig. 2) [3]. Pyomyositis also may be associated with cellulitis, which can help differentiate pyomyositis from other benign or malignant soft-tissue masses [3]. Knee joint effusions distal to, and separate from, the site of muscle infection may be sympathetic and not septic [3].

### Septic arthritis

Septic arthritis indicates an infectious process localized to the joint. Although no single MR imaging feature can differentiate septic from nonseptic arthritis, the presence of several abnormal findings can increase the probability of infection. Concomitant bone erosions and marrow edema are highly suggestive of septic arthritis, and the added presence of synovial thickening, synovial edema, soft-tissue edema, or bone marrow enhancement is even more suggestive of infection (Fig. 3) [4]. Joint effusions are nonspecific findings, and can be present in both septic and nonseptic joints. Furthermore, up to one third of patients who have septic arthritis can lack a joint effusion [5]. Abnormal marrow signal is worrisome for concomitant osteomyelitis, especially if diffuse and identified on T1-weighted images [5].

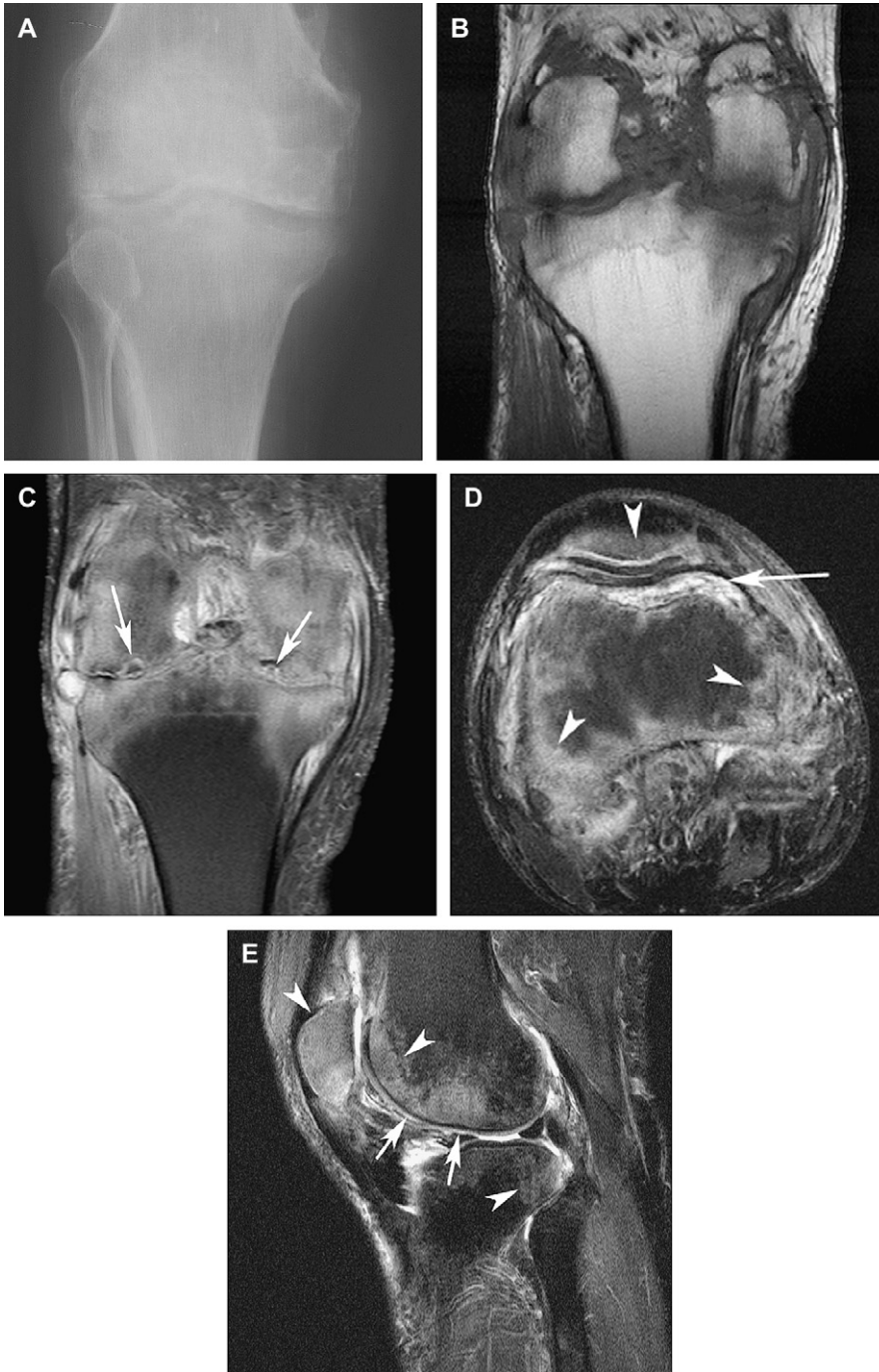
### Osteomyelitis

Osteomyelitis is an infection of the bone and marrow that is usually the result of a bacterial infection, although it may be caused by fungi, parasites, and viruses [1]. Resnick [1] uses the term infective (suppurative) osteitis to indicate isolated contamination of cortical bone, which can occur separately from, or, more commonly, in conjunction with, osteomyelitis. Infective (suppurative) periostitis indicates involvement of the periosteum only [1].

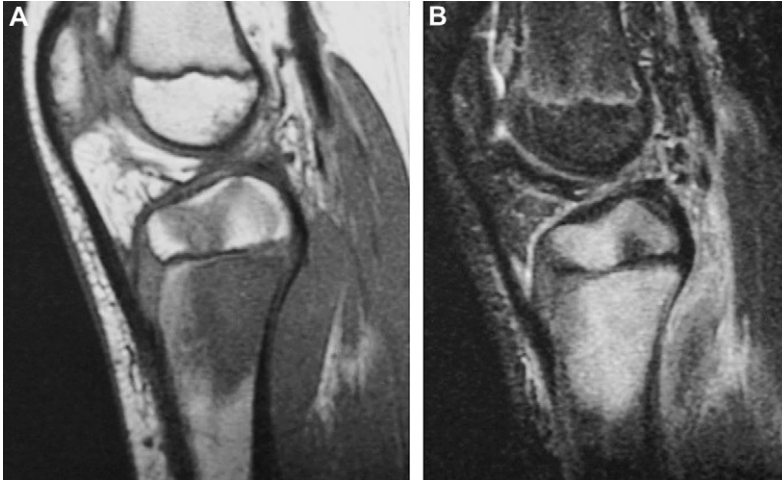
Osteomyelitis is caused by the hematogenous spread of infection or is spread from a contiguous source, including direct implantation (eg, puncture wound, surgery) or extension from an adjacent infection (eg, skin, soft tissue, joint) [6]. Hematogenous osteomyelitis typically affects the metaphysis of tubular bones [1,7]. Direct penetration or implantation (contiguous-focus) is now the most common cause of osteomyelitis in the United States [7]. Osteomyelitis is classified as acute, subacute, or chronic, depending on the rate of onset and the intensity of the associated symptoms [1,6].

### Acute osteomyelitis

Acute osteomyelitis is an acute, suppurative infection [1,6]. Typically, acute hematogenous osteomyelitis is considered a disease of children, usually between 3 and 15 years old [1,7]. Hematogenous osteomyelitis most commonly involves the



**Fig. 2.** Septic arthritis in a 58-year-old man currently treated with antibiotics. (A) Anteroposterior radiograph of the knee demonstrates generalized joint space narrowing, subchondral sclerosis, and erosions. (B) Coronal T1-weighted image demonstrates extensive changes of septic arthritis, with diffuse chondrolysis, subchondral erosions, hypointense marrow signal intensity in the subarticular tibia and femur, and abnormal periarticular soft tissue. (C) Coronal FSE T2-weighted fat-suppressed image demonstrates fluid within the osteochondral defects (*arrows*) and multiple subcortical erosions. (D) Axial FSE proton density fat-suppressed image delineates the extent of marrow edema-like signal throughout the patella and femur (*arrowheads*), and the thickened synovium (*arrow*). (E) Sagittal FSE T2-weighted fat-suppressed image delineates the chondrolysis (*arrows*) and periarticular marrow edema-like signal (*arrowheads*).



**Fig. 3.** Osteomyelitis in the proximal tibial metaphysis with spread across the physis in an 8-year-old girl. (A) T1-weighted sagittal image demonstrates abnormal hypointense signal intensity, predominantly in the proximal tibial metaphysis, with transphyseal extension into the epiphysis. (B) Fast short tau inversion recovery (STIR) sagittal image demonstrates abnormal hyperintense signal intensity in a slightly larger distribution than the T1-weighted images, consistent with marrow edema-like signal from osteomyelitis.

metaphyses of tubular bones in children, but it can involve flat or irregularly shaped bones in up to 25% of cases [1]. An adjacent joint effusion is present in about 60% of cases [6]. Extensive involucrum formation is also characteristic of osteomyelitis in infants because the periosteum can be separated easily from the adjacent bone [1].

MR imaging can identify the presence of osteomyelitis and determine the degree of involvement. The affected marrow shows poorly marginated areas of abnormal signal intensity, with decreased signal intensity on T1-weighted images and corresponding increased signal intensity on fluid-sensitive images (see Fig. 3) [8]. Cortical signal is preserved in early cases [8]; however, with time, abnormal signal will extend into the cortex, the periosteum, and soft tissue. Erdman and colleagues [8] found MR imaging to be 100% sensitive for bacterial osteomyelitis, with a specificity of 75% to 82%; the specificity was decreased because of other causes of abnormal signal intensity, such as septic joint, fracture, or infarction. Abnormal signal on short tau inversion recovery (STIR) sequences typically overestimates the true extent of the infected marrow [9]. Before abscess formation, involved tissue shows enhancement following contrast administration, reflecting the inflammatory nature of the underlying process, with almost all-enhancing marrow reflecting areas of active infection [9]. An abscess may also show more well-defined margins on T2-weighted images, and a rind of decreased signal [10]. Contrast-enhanced imaging is especially helpful in differentiating an abscess from diffuse

inflammation, both of which may show increased signal intensity on fluid-sensitive sequences.

### Subacute osteomyelitis

Brodie's abscess, also referred to as "cystic" osteomyelitis, is a specific form of osteomyelitis that can occur in either subacute or chronic infection (Fig. 4) [7,11]. Typically, it is seen in young men, with 75% of patients under 25 years old [7]. The cause of this form of osteomyelitis is unknown, but it may arise spontaneously in association with a focal inflammatory episode, or after hematogenous infection [7]. Radiographically, Brodie's abscess is a geographic lesion with a well-defined sclerotic margin, located in the metaphysis. A radiolucent channel, representing a sinus tract, may be seen, which can communicate with the physis [1,7].

MR imaging demonstrates a Brodie's abscess as a well-defined lesion that is hypointense to marrow on T1-weighted images and hyperintense on fluid-sensitive sequences. The margin of the abscess may be either hypointense or hyperintense. The penumbra sign is a characteristic MR imaging feature of subacute osteomyelitis that represents a thin layer of granulation tissue that lines the abscess cavity [12,13]. The penumbra sign is identified on unenhanced T1-weighted images as a discrete peripheral zone of slightly increased signal intensity, relative to the central abscess cavity and the surrounding hypointense reactive new bone and edema [12], and is often present about the knee in either the distal femur or proximal tibia.



**Fig. 4.** Subacute osteomyelitis with a Brodie's abscess. Coronal T1-weighted (A) and STIR (B) images demonstrate extension of a Brodie's abscess (arrow) across the physis, into the metaphysis. Note the prolonged T1 and T2 relaxation time in the mid- and lateral epiphyseal marrow (arrowhead) and the distal femoral metaphysis, consistent with edema-like signal from osteomyelitis. (C) Axial STIR image through the distal femoral metaphysis demonstrates the hyperintense Brodie's abscess (arrow), diffusely abnormal metaphyseal marrow signal, and marked periosteal thickening (arrowhead).

### Chronic osteomyelitis

Chronic osteomyelitis occurs when there is a residual nidus of infection and a refractory clinical course [1,6]. Chronic osteomyelitis is the result of continuous infection or reactivation, usually by a low-virulence organism [7]. After a period of inactivity, lesions may become active. Chronic osteomyelitis is frequently the result of long-standing indolent infection, often as a result of inappropriate or inadequate treatment, and has a predilection for the metaphyses of long bones [7].

MR imaging of chronic osteomyelitis often reveals a thickened cortex with a sharp interface between involved and uninvolved marrow, and well-

defined, associated soft-tissue abnormality [8,14]. A rim of decreased signal, presumably representing fibrous tissue, may also surround areas of chronic active infection (Fig. 5) [8]. Usually, osseous remodeling is identified, and disruption of cortical bone and sinus tracts may be seen also [8]. Sinus tracts typically extend to cutaneous ulcers, and often are seen overlying weight-bearing prominences [9]. On MR imaging, metaphyseal disease may be obscured by adjacent hematopoietic marrow on T1-weighted images [15]. T2-weighted images and STIR images usually show less signal intensity in normal hematopoietic marrow than in marrow infiltrated by infectious exudate [15]. Although usually present, bone marrow edema may not be



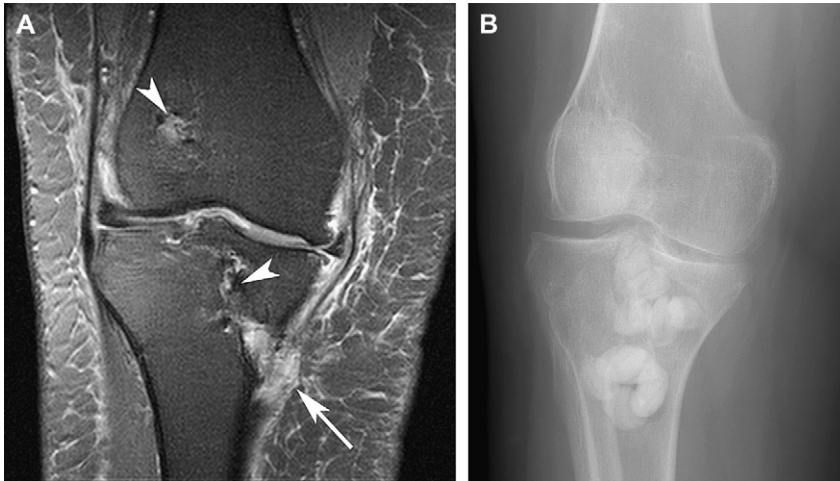
**Fig. 5.** Chronic osteomyelitis and septic arthritis in a 60-year-old diabetic woman. (A) Anteroposterior radiograph demonstrates a large defect within the lateral tibial plateau, with a well-marginated contour and extensive sclerosis. Coronal images through the knee demonstrate extensive changes of chronic osteomyelitis and septic arthritis, with areas of marrow edema that are nearly isointense to muscle on T1-weighted image (B) and slightly hyperintense to muscle on FSE T2-weighted fat-suppressed image (C). Note that the large lateral tibial defect is filled with joint fluid, and the complex fluid tracking medial and lateral to the knee joint. Surgery showed gross pyarthrosis, which cultured group B *Streptococcus*.

detected if sclerosis is surrounding a bone abscess [16]. Fast inversion-recovery sequences may be more sensitive than fast spin-echo (FSE) sequences for the detection of abnormal marrow [17].

Umans and colleagues [18] reported the usefulness of intravenous gadolinium for the differentiation of osteomyelitis from bone infarction in patients who were at risk for both processes. Patients who have osteomyelitis have more geographic and irregular marrow enhancement on enhanced MR imaging, compared with the thin, linear rim enhancement associated with acute bone infarcts [18]. In addition, osteomyelitis may demonstrate subtle cortical defects with abnormal signal traversing marrow and soft tissue [18].

### Chronic post-traumatic osteomyelitis

The evaluation of active osteomyelitis in the setting of chronic posttraumatic osteomyelitis can be difficult; however, acute activity in chronic osteomyelitis can be excluded with high likelihood if the MR imaging findings are negative [19]. Pitfalls occur because reparative fibrovascular scar tissue in the bone marrow and traumatized soft tissue can persist for up to a year after surgical intervention [19,20]. In addition, heterogeneously hypo- and hyperintense osseous signal can be evident on fluid-sensitive sequences after trauma, limiting the detection of superimposed infection. Ledermann and colleagues [20] reported 63% specificity and 100% sensitivity



**Fig. 6.** Infected ACL graft requiring removal in a 43-year-old woman. (A) Coronal T1-weighted enhanced fat-suppressed image through the knee demonstrates abnormal enhancement (*arrow*) surrounding the intact ACL graft (*arrowheads*). (B) Anteroposterior radiograph of the knee demonstrates antibiotic-laden cement in the ACL tunnel, after infected graft removal.

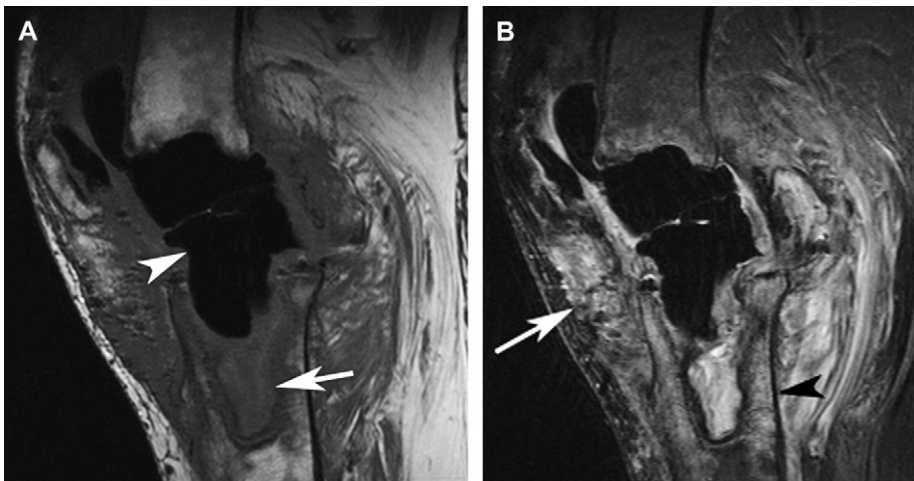
of enhanced MR imaging for the diagnosis of relapsing, active osteomyelitis in the setting of chronic posttraumatic osteomyelitis. In chronic posttraumatic osteomyelitis, the presence of soft-tissue sinus tracts increases the likelihood of infection [20]. However, cutaneous ulcerations and cortical irregularities are not specific for the presence or absence of infection in the setting of prior trauma [19,20]. Gadolinium may be helpful in differentiating abscess from diffuse inflammatory

change, and fibrovascular scar from infectious foci, in the setting of chronic posttraumatic osteomyelitis [19,20].

### Postoperative knee infection

#### *Anterior cruciate ligament reconstruction*

Postoperative infection of the knee is uncommon after arthroscopy, ACL reconstruction, or arthroplasty



**Fig. 7.** Cement spacer after removal of chronically infected total knee arthroplasty in a 76-year-old woman. (A) Sagittal T1-weighted image demonstrates an intra-articular signal void (*arrowhead*), corresponding to antibiotic-impregnated cement spacer placed after removal of infected total knee arthroplasty. Note the proximal tibial defect (*arrow*) previously occupied by the knee arthroplasty, and the abnormal hypointense signal throughout the adjacent soft tissues. (B) Sagittal FSE T2-weighted image redemonstrates the articular spacer, the complex fluid within the tibial defect, and the abnormally increased signal within the proximal tibia marrow (*arrow*), consistent with osteomyelitis. Note the extensively abnormal extraosseous soft tissues (*arrow*), consistent with soft-tissue infection.



**Fig. 8.** Myocutaneous flap coverage for tibial osteomyelitis in a 45-year-old woman. (A) Lateral radiograph demonstrates pretibial soft tissue coverage corresponding to the myocutaneous flap (arrow), which was placed for soft-tissue coverage after osteomyelitis, complicating the anterior tubercle elevation performed for patellofemoral arthritis (Maquet's procedure). Sagittal proton density (B) and axial proton density fat-suppressed (C) images demonstrate the rotated medial head of the gastrocnemius (arrows) into the pretibial soft-tissue defect. Note the healed tibial tubercle elevation (arrowheads).

[21]. The incidence of postoperative infection after all arthroscopic procedures is reported to be between 0.1% to 0.4% [22]. The incidence of infection after arthroscopic ACL reconstruction ranges between 0.3% and 1% [22–25]. When autologous patellar or quadriceps tendons are used for graft reconstruction, the grafted portion of the knee and the donor site may become infected. Strict quality measures are maintained at licensed donor banks, which severely limit the incidence of transmittable bacteria and viruses in ACL autografts. However, undetected contamination can occur while harvesting, storing, or manipulating the graft before implantation. Diaz-de-Rada and colleagues [26] reported that 13% of 118 patients who had cadaveric-bone-patellar-bone allografts had positive cultures, but no clinical signs of infection.

Although arthrocentesis is required to diagnose infection, MR imaging may be helpful in the diagnosis or exclusion of infection (Fig. 6). Because the ACL graft is avascular, it normally does not demonstrate enhancement. An infected ACL graft may be focally or diffusely hyperintense, likely because of fibrinous exudate on its surface [23]. However, noninfected periligamentous tissues are normally higher in signal intensity, and can enhance because of their vascularity and developing granulation tissue or immature collagen [27].

Although nonspecific for infection, joint effusion, synovitis, and edema of the adjacent soft tissue and bone marrow can occur in the setting of infection after ACL grafting [23,28]. Osseous erosions, sinus tracts, and soft-tissue abscesses are more specific signs of musculoskeletal infection



**Fig. 9.** Recurrent abscess and development of osteomyelitis after below-knee amputation in an 80-year-old woman with peripheral vascular disease. Sagittal T1-weighted (A) and FSE T2-weighted fat-suppressed (B) images demonstrate a well-defined fluid collection (\*) with a thick border distal to the tibial stump, which proved to be an abscess. The underlying bone maintains its hypointense margin and normal marrow signal intensity. Patient underwent debridement of the abscess. (C) Anteroposterior radiograph obtained 13 months later depicts new periosteal reaction about the stump (arrowheads) and soft-tissue ulceration about the medial, distal soft tissues (arrow). (D) Coronal T1-weighted image defines the depth of the ulceration (white arrow) and new, abnormal, hypointense marrow signal (black arrow) within the tibial centimeter of the stump. (E) FSE T2-weighted fat-suppressed image demonstrates myonecrosis and progressive abscess (\*) within the distal stump. Note the marrow edema-like signal within the stump (arrow). (F) Enhanced T1-weighted fat-suppressed image demonstrates communication of the abscess with the distal stump (black arrow), leading to contiguous spread of infection to the bone (white arrow).

on MR imaging. Osteomyelitis should be suspected when MR imaging shows replaced marrow fat-signal on T1-weighted images and more intense marrow enhancement. However, intra-tunnel ganglia, cysts, and surrounding bone marrow edema-like signal may be present in the setting of noninfected ACL reconstructions [27,29].

### Periprosthetic infection

Multiple complications can occur after knee arthroplasty, including aseptic loosening, periprosthetic and patellar fracture, extensor mechanism

abnormalities, component failure, peroneal nerve palsy, prolonged serous drainage, and infection [30,31]. With the development of improved orthopedic techniques and antibiotics, the rate of deep infection after primary total knee arthroplasty is currently less than 1%, and wound infection after revision arthroplasty is less than 2% [32,33]. The diagnosis of infection is based most commonly on a combination of clinical findings (pain, redness, swelling, elevated erythrocyte sedimentation rate, C-reactive protein, and leukocytosis), radiographs, aspiration cultures, and scintigraphy. Radiography is not reliable in the diagnosis or

exclusion of infection after arthroplasty; however, endosteal scalloping, laminated periosteal reaction, sequestra, and intra-articular gas are fairly specific radiographic signs for infection [34]. Ill-defined periprosthetic resorption, acute periosteal reaction, and multiple foci of subacute periosteal reaction are also highly worrisome for osteomyelitis [35].

MR imaging is used rarely for the evaluation of periprosthetic infection. Distortion and image degradation related to the metallic prostheses can hinder significantly the evaluation of anatomic imaging with MR imaging, depending on the type of metal and MR imaging techniques used [36,37]. Titanium implants usually result in less metallic artifact than stainless steel, allowing more of the adjacent bone and soft tissue to be evaluated [37]. Prostheses that are fairly linear and uniform in their construction result in fewer artifacts than implants that are rounded or irregular [37]. The use of several MR imaging techniques also reduces the amount of field-inhomogeneity artifact generated by metallic implants. These techniques include designating the frequency-encoding direction along the long axis of the prosthesis, increasing the frequency-encoding gradient strength, using FSE sequences, increasing the echo train length and increasing readout bandwidth [37,38]. Furthermore, chemical fat saturation and gradient-echo imaging should be avoided because they result in greater artifact [37,39].

MR imaging can be useful in the evaluation of persistent infection after explantation because focal intraosseous and soft-tissue abscesses can be well visualized. Antibiotic-laden cement usually presents as a signal void with very little artifact on MR imaging (Fig. 7).

### **Myocutaneous flap**

In the event of infection, myocutaneous flaps may be required for adequate soft-tissue coverage after debridement of soft tissue or bone (Fig. 8) [40]. Flaps about the knee may be rotational flaps, commonly obtained from the gastrocnemius muscle, but can also be free flaps from distant sites. These autografts resemble muscle on MR imaging, but may have an edema-like signal within them. Myocutaneous flaps also develop progressive fatty atrophy on sequential MR imaging [40].

### **Amputation**

Patients requiring either above- or below-knee amputations for osteomyelitis may require further intervention because of either residual or recurrent soft-tissue or osseous infection. MR imaging can detect stump abscesses readily (Fig. 9), thereby facilitating either image-guided or surgical drainage. If the infection progresses to involve the osseous

stump, MR imaging is useful in delineating the extent of osteomyelitis before surgical debridement.

### **Summary**

MR imaging is useful in identifying cases of cellulitis, fasciitis, abscess, septic arthritis, and osteomyelitis about the knee. The inherent tissue contrast provided by MR imaging allows for the delineation of soft-tissue infection and osteomyelitis. Therefore, MR imaging is a useful tool in evaluating the extent of infection, and in facilitating adequate debridement and drainage. MR imaging can be particularly useful in complicated settings, such as chronic post-traumatic osteomyelitis, and in postsurgical patients after arthroscopy, ACL reconstruction, and amputation.

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