American College of Radiology
ACR Appropriateness Criteria®
Imaging After Total Knee Arthroplasty

Variant 1: **Follow-up of symptomatic or asymptomatic patients with a total knee arthroplasty. Initial imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
Radiography knee	Usually Appropriate	☢
US knee	Usually Not Appropriate	O
Fluoroscopy knee	Usually Not Appropriate	☢
Image-guided aspiration knee	Usually Not Appropriate	Varies
MRI knee without and with IV contrast	Usually Not Appropriate	O
MRI knee without IV contrast	Usually Not Appropriate	O
CT arthrography knee	Usually Not Appropriate	☢
CT knee with IV contrast	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
CT knee without IV contrast	Usually Not Appropriate	☢
3-phase bone scan knee	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢
WBC scan and sulfur colloid scan knee	Usually Not Appropriate	☢☢☢☢

Variant 2: **Suspected infection after total knee arthroplasty. Additional imaging following radiographs.**

Procedure	Appropriateness Category	Relative Radiation Level
Image-guided aspiration knee	Usually Appropriate	Varies
US knee	May Be Appropriate	O
MRI knee without and with IV contrast	May Be Appropriate	O
MRI knee without IV contrast	May Be Appropriate	O
CT knee with IV contrast	May Be Appropriate	☢
3-phase bone scan knee	May Be Appropriate	☢☢☢
WBC scan and sulfur colloid scan knee	May Be Appropriate	☢☢☢☢
Fluoroscopy knee	Usually Not Appropriate	☢
CT arthrography knee	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
CT knee without IV contrast	Usually Not Appropriate	☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢

Variant 3: **Pain after total knee arthroplasty. Infection excluded. Suspect aseptic loosening or osteolysis or instability. Additional imaging following radiographs.**

Procedure	Appropriateness Category	Relative Radiation Level
MRI knee without IV contrast	Usually Appropriate	O
CT knee without IV contrast	Usually Appropriate	☢
3-phase bone scan knee	May Be Appropriate	☢☢☢
US knee	Usually Not Appropriate	O
Fluoroscopy knee	Usually Not Appropriate	☢
MRI knee without and with IV contrast	Usually Not Appropriate	O
CT arthrography knee	Usually Not Appropriate	☢
CT knee with IV contrast	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢
WBC scan and sulfur colloid scan knee	Usually Not Appropriate	☢☢☢☢

Variant 4: **Pain after total knee arthroplasty. Suspect periprosthetic or hardware fracture. Additional imaging following radiographs.**

Procedure	Appropriateness Category	Relative Radiation Level
CT knee without IV contrast	Usually Appropriate	☢
MRI knee without IV contrast	May Be Appropriate	O
3-phase bone scan knee	May Be Appropriate	☢☢☢
US knee	Usually Not Appropriate	O
Fluoroscopy knee	Usually Not Appropriate	☢
MRI knee without and with IV contrast	Usually Not Appropriate	O
CT arthrography knee	Usually Not Appropriate	☢
CT knee with IV contrast	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢
WBC scan and sulfur colloid scan knee	Usually Not Appropriate	☢☢☢☢

Variant 5: **Pain after total knee arthroplasty. Measuring component rotation. Additional imaging following radiographs.**

Procedure	Appropriateness Category	Relative Radiation Level
CT knee without IV contrast	Usually Appropriate	☢
MRI knee without IV contrast	May Be Appropriate	O
US knee	Usually Not Appropriate	O
Fluoroscopy knee	Usually Not Appropriate	☢
MRI knee without and with IV contrast	Usually Not Appropriate	O
CT arthrography knee	Usually Not Appropriate	☢
CT knee with IV contrast	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
3-phase bone scan knee	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢
WBC scan and sulfur colloid scan knee	Usually Not Appropriate	☢☢☢☢

Variant 6: **Pain after total knee arthroplasty. Suspect periprosthetic soft-tissue abnormality unrelated to infection, including quadriceps or patellar tendinopathy (quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues). Additional imaging following radiographs.**

Procedure	Appropriateness Category	Relative Radiation Level
US knee	Usually Appropriate	O
MRI knee without IV contrast	Usually Appropriate	O
Fluoroscopy knee	Usually Not Appropriate	☢
MRI knee without and with IV contrast	Usually Not Appropriate	O
CT arthrography knee	Usually Not Appropriate	☢
CT knee with IV contrast	Usually Not Appropriate	☢
CT knee without and with IV contrast	Usually Not Appropriate	☢
CT knee without IV contrast	Usually Not Appropriate	☢
3-phase bone scan knee	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢
Fluoride PET/CT whole body	Usually Not Appropriate	☢☢☢☢
WBC scan and sulfur colloid scan knee	Usually Not Appropriate	☢☢☢☢

IMAGING AFTER TOTAL KNEE ARTHROPLASTY

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Summary of Literature Review

Introduction/Background

Total knee arthroplasty (TKA), primarily used to treat pain and improve function in patients with symptomatic advanced knee osteoarthritis, is the most commonly performed joint replacement procedure in the United States [1,2]. In 2012, >670,000 knee replacement procedures were performed in the United States [3], which represents an increase of 86% since 2003 [4]. It is estimated that 4 million patients in the United States are currently living with a knee replacement [5]. By 2030, it is estimated that the annual demand for primary TKA will grow by 673% to 3.48 million [6]. Factors contributing to the rising number of TKAs include population growth; aging and increased longevity of the population; expanded indications for performing TKA, especially in individuals >65 years of age; obesity; decline in postprocedure complications; and increased patient demand [7].

The patient satisfaction rate for TKA is relatively high, ranging from 75% to 89% [8]. Around 10% to 30% of the patients report ongoing pain or are not satisfied with the result [9]. Factors, which contribute to patient dissatisfaction, include unmet expectations, functional limitations, and postoperative complications including pain [10]. Most TKA patients experience improved outcomes and long implant survival, with long-term TKA failure rates of <1% per year [5]. The growth in the number of primary TKA procedures has been accompanied by increased rates of TKA revision procedures [1]. Revision procedures for TKAs have increased by 5.4 procedures per 100,000 persons per decade over the period from 1990 to 2002, with a mean revision burden of 8.2% [11]. Nearly 1.5 million of those with primary knee replacement are 50 to 69 years of age, underscoring a large population at risk for revision surgery and long-term complications [5]. Sharkey et al [12] reviewed 781 revision TKAs and found the most common failure mechanisms were loosening (39.9%), infection (27.4%), instability (7.5%), periprosthetic fracture (4.7%), and arthrofibrosis (4.5%). Infection was the most common reason for early revision (<2 years after the initial TKA), and aseptic loosening was the most common reason for late revision. Compared with a review performed by the same author in 2002 [13], polyethylene wear is no longer the major cause of failure, and the percentages of revisions for polyethylene wear, instability, arthrofibrosis, malalignment, and extensor mechanism deficiency have all decreased. Identifying the cause of a painful TKA before surgery is critically important because "in cases of unexplained pain, reoperation is unwise and frequently associated with suboptimal results" [14].

Special Imaging Considerations

In some patients with knee arthroplasties, repeated hemarthroses are caused by synovial hyperemia or true arteriovenous malformations. These patients can be successfully diagnosed with angiography and treated with embolization. In rare instances, geniculate and popliteal vessel injuries may occur during surgery [15].

A recent study reports single-photon emission CT (SPECT)/CT arthrography with Tc-99m sulfur colloid has a high diagnostic accuracy (97%) in the evaluation of loosening of both hip and knee arthroplasties in patients with persistent postprocedural pain [16]. Barnsley et al [17] also found arthrography with SPECT/CT to be an accurate means of identifying aseptic prosthetic joint loosening.

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Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

- There are complementary procedures (ie, more than one procedure is ordered as a set or simultaneously where each procedure provides unique clinical information to effectively manage the patient's care).

Discussion of Procedures by Variant

Variant 1: Follow-up of symptomatic or asymptomatic patients with a total knee arthroplasty. Initial imaging.

3-Phase Bone Scan Knee
There is insufficient evidence to support the use of 3-phase bone scan for the initial evaluation of TKA.

CT Arthrography Knee
There is insufficient evidence to support the use of CT arthrography for the initial evaluation of TKA.

CT Knee With IV Contrast
There is insufficient evidence to support the use of CT with intravenous (IV) contrast for the initial evaluation of TKA.

CT Knee Without and With IV Contrast
There is insufficient evidence to support the use of CT without and with IV contrast for the initial evaluation of TKA.

CT Knee Without IV Contrast
There is insufficient evidence to support the use of CT without IV contrast for the initial evaluation of TKA.

FDG-PET/CT Whole Body
There is insufficient evidence to support the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT for the initial evaluation of TKA.

Fluoride PET/CT Whole Body
There is insufficient evidence to support the use of fluoride PET/CT for the initial evaluation of TKA.

Fluoroscopy Knee
There is insufficient evidence to support the use of fluoroscopy for the initial evaluation of TKA.

Image-Guided Aspiration Knee
There is insufficient evidence to support the use of image-guided aspiration for the initial evaluation of TKA.

MRI Knee Without and With IV Contrast
There is insufficient evidence to support the use of MRI without and with IV contrast for the initial evaluation of TKA.

MRI Knee Without IV Contrast
There is insufficient evidence to support the use of MRI without IV contrast for the initial evaluation of TKA.

Radiography Knee
Radiographs can demonstrate abnormal bone and hardware alignment, periprosthetic lucencies and osteolysis [18-24], reactive bone formation and periostitis, periprosthetic fractures, evidence of polyethylene liner wear, and cement and heterotopic bone about the knee. Radiographs can often delineate effusion, soft-tissue swelling, foreign bodies, soft tissue emphysema, heterotopic bone, and cement or metal in the soft tissues. Radiographs are useful as the initial evaluation for symptomatology or follow-up. Radiographs are often limited in terms of sensitivity, and further imaging may be required.

Routine immediate postoperative radiographs are considered unnecessary unless the surgery is complicated or there are specific clinical indications warranting imaging evaluation [25,26], because several studies have indicated that the rate of complications identified in the immediate postoperative setting is low. Ververeli et al [27] compared recovery room radiographs with additional predischarge radiographs and found no change in the postoperative management of 124 consecutive patients with TKAs and suggested eliminating the predischarge radiographs. Novack et al [25] retrospectively reviewed 4,830 consecutive patients following cemented or uncemented TKAs and concluded routine recovery room radiographs after an uncomplicated primary TKA are not a reliable mechanism for preventing mechanical complications and did not alter patient care.

Although radiographs are an integral part of the workup for suspected periprosthetic infection, they are neither sensitive nor specific for diagnosing infection [28,29]. The radiographic appearance of an infected TKA can range from "normal" to subtle periprosthetic lucency to advanced bone destruction. Joint effusion and soft tissue swelling are often noted as well. It is often not radiographically possible to distinguish infection from loosening or particle disease [21]. Duff et al [18] found radiographs unhelpful because loosening, periostitis, focal osteolysis, and radiolucent lines were seen in both infected and noninfected knees. Because minor differences in positioning can greatly alter the appearance of the periprosthetic lucencies, the use of oblique or fluoroscopically positioned images may provide improved visualization of the prosthesis-bone interface, especially with uncemented prostheses [30].

Serial follow-up radiographs are more directed toward identifying postoperative complications related to loosening and are important for identifying subtle changes [31,32]. Although follow-up radiographs are commonly performed, the frequency of assessment has not been standardized. A survey of 682 active members of the American Association of Hip and Knee Surgeons in 2003 found that 80% of responders supported annual or every-other year orthopedic and radiographic examinations and more frequent follow-up if there were signs of failure, decreased periprosthetic bone quality, or a history of prior revision [33]. The routine annual or every other year radiographic examination for TKA evaluation consists of standing anteroposterior (AP) and lateral and a tangential axial view of the patellofemoral joint. Some practitioners also use standing long-leg (hip-to-ankle) views to provide for optimal assessment of alignment [4]. Skytta et al [34] compared standing hip-to-ankle radiographs and AP knee radiographs for assessment of alignment and found that the standard AP knee radiograph was a valid alternative to the hip-to-ankle radiograph for determining coronal plane alignment at the knee, but that the longer hip-to-ankle radiograph alone provided accurate information on the weightbearing mechanical axis in patients with suspected lower limb malalignment. They suggested that after acquisition of a baseline hip-to-ankle radiograph, further follow-up could be based on targeted knee radiographs. Kosashvili et al [35] compared assessment of alignment on AP radiographs taken in cadaveric TKAs and found that interpretation of varus and valgus alignment was improved on AP views obtained in 10° of internal rotation compared with neutral AP views and with those obtained in 10° of external rotation.

Radiographic evaluation of wear is based on weightbearing AP and lateral radiographs and on axial radiographs. Liner wear is seen as joint space narrowing, varus or valgus deformity, or patellar tilt. An effusion may be present. Findings can be subtle and annual weightbearing radiographs are suggested for detecting subclinical wear [21]. Collier et al [36] found that 87% of measurements performed on standing frontal knee radiographs (on the basis of the minimum distance from the metallic femoral condyle to a line through the top surface of the baseplate at its widest dimension) were within 1 mm of the known implant thickness, but the accuracy decreased for evaluating polyethylene thickness in patients with wear requiring revision.

Instability is evaluated on radiographs obtained in extension-flexion position, under varus-valgus stress, and during anterior and posterior drawer maneuvers. In contrast, malalignment refers to suboptimal alignment of the prosthesis components relative to each other (although it is occasionally used to describe alignment of the bones in relation to each other and to the joint) [37] and is evaluated on full-length standing radiographs of the lower extremity [21].

Radiographs including the entire prosthesis are the initial examination for assessment of suspected periprosthetic fractures. Radiographs are also usually satisfactory for assessment of patellar complications [20] and helpful in guiding treatment [38]. Axial radiographs demonstrate the degree of patellar tilt or subluxation [21]. Baldini et al [39] proposed a weightbearing axial radiograph to better assess patellofemoral kinematics.

Although axial radiographs may be used to determine axial rotation of the femoral component [40], CT is most commonly used for this purpose. Leon-Munoz et al [41] have noted CT-scan-based 3-D models and, therefore, supine CT scan, underestimate the degree of deformity at the knee joint, both in varus and valgus; therefore

preoperative full-leg standing radiographs should be performed for patient-specific instrumentation assisted TKAs, as a complementary study, to analyze the position of the load-bearing axis.

Radiographs cannot directly image post-TKA periprosthetic soft-tissue abnormalities. However, radiographic signs of extensor mechanism tendon tears include patella alta, patella baja, localized soft-tissue swelling, posterior subluxation of the tibia, bony avulsions, and dystrophic calcifications within the tendon [21,42].

US Knee
There is insufficient evidence to support the use of ultrasound for the initial evaluation of TKA.

WBC Scan and Sulfur Colloid Scan Knee
There is insufficient evidence to support the use of white blood cell (WBC) scan and sulfur colloid scan for the initial evaluation of TKA.

Variant 2: Suspected infection after total knee arthroplasty. Additional imaging following radiographs.

Infection is a serious complication of joint arthroplasty and is reported in 0.8% to 1.9% of TKAs [43]. The frequency of infection is increasing as the number of primary arthroplasties increases [44]. Infection may be acute or delayed, with delayed infection defined as occurring at least 3 months postoperatively [45]. In a series, infection was responsible for 37.6% of early revisions and 21.9% of revisions performed >2 years after the initial operation [12]. *Staphylococcus aureus* and coagulase-negative *Staphylococcus* species, including *Staphylococcus epidermidis*, are the most common organisms associated with these infections [46]. Both clinical findings and laboratory tests may serve useful in addition to imaging studies. Low-grade or chronic TKA infections may be difficult to diagnose preoperatively. Duff et al [18] noted that diagnosis of infection was not obvious in 53% of knees before revision arthroplasty. Pain is the most common presenting symptom of infection, but pain is a nonspecific finding [47]. In acute infection, findings such as pain, swelling, warmth, erythema, and fever are common, whereas chronic infections may be manifested by pain alone [44]. Night pain or pain at rest is characteristic of infection, whereas pain on weightbearing is more characteristic of mechanical loosening. Some authors suggest that infection needs to be excluded in all patients with pain persisting >6 months after joint replacement [18].

Laboratory findings in the setting of TKA infection are often nonspecific. Peripheral leukocyte counts are not elevated in most patients with infected prostheses. Erythrocyte sedimentation rates (ESRs) are abnormal in patients with infection, but this finding may also be seen in uninfected patients, limiting the usefulness of the test [48]. A retrospective review of 68 patients undergoing hip and knee revision surgery indicated that C-reactive protein (CRP) was significantly higher in patients with infection compared with those with loosening (sensitivity of 79% for all prostheses); however, a normal CRP level did not exclude infection [49]. CRP has a sensitivity of 73% to 91% and a specificity of 81% to 86% for the diagnosis of prosthetic knee infection when a cutoff of ≥13.5 mg/L is used [44]. Although CRP can be elevated after surgery, under normal circumstances it generally returns to baseline within 2 months [44]. A large multicenter study found CRP and joint aspiration to be the most useful tools to diagnose infection [50]. In an attempt to construct an algorithm for evaluating TKA infection, Savarino et al [51] found that abnormal results for at least 2 of 3 tests (CRP [cutoff 0.93 mg/L], ESR [cutoff 27 mm/h], and fibrinogen [cutoff 432 mg/dL]) led to accurate results for the diagnosis of infection (sensitivity, 93%; specificity, 100%; accuracy, 97%). More recently, interleukin-6 has also shown promise for diagnosing infection, with higher predictive values than most other serologic markers [52], and has shown excellent sensitivity for detecting infection after TKA when combined with CRP [53]. The American Academy of Orthopaedic Surgeons (AAOS) guidelines strongly recommend the use of ESR, CRP, and serum interleukin-6 testing for patients being assessed for periprosthetic joint infection [54]. Serologic tests can be hard to interpret when underlying inflammatory arthropathy is present [28]. More recently, the use of an alpha-defensin laboratory test has been described for the diagnosis of periprosthetic joint infection. Alpha-defensin is an antimicrobial peptide that is naturally released by neutrophils responding to a pathogen in the synovial fluid. Used as a biomarker for infection in synovial fluid, it has been demonstrated to be highly accurate in the diagnosis of prosthetic joint infection, nearly matching the Musculoskeletal Infection Society definition for prosthetic joint infection [55-57]. In a study by Deirmengian et al [56] of 149 synovial fluid aspirates, synovial fluid alpha-defensin tests alone demonstrated a sensitivity of 97% and a specificity of 96% for the diagnosis of periprosthetic joint infection, and the combination of synovial fluid alpha-defensin and CRP tests demonstrated a sensitivity of 97% and a specificity of 100% for the diagnosis of periprosthetic joint infection. A recent review suggests the preoperative workup for periprosthetic infection should include serum ESR rate and CRP, serum D-dimer, synovial fluid culture, cell count, and differential, leukocyte esterase, alpha-defensin, and synovial fluid ESR [58].

3-Phase Bone Scan Knee
Tc-99m bone scintigraphy is more sensitive than radiographs in the detection of osteomyelitis [59]. However, periprosthetic uptake on bone scan is a nonspecific finding and cannot differentiate infection from aseptic loosening [60] and can be seen because of normal remodeling after prosthesis surgery (for up to 1-2 years or longer) [61], infection, aseptic prosthesis loosening [62], and/or periprosthetic fracture. Normal bone scans have a high negative predictive value (NPV) and indicate that infection, loosening, or fracture is unlikely. It is usually stated that bone scintigraphy is useful for excluding osteomyelitis and hence is useful as a screening study [30,59,63]. A 3-phase versus single-phase (a delayed-only skeletal acquisition) bone scan does not improve the accuracy of the test [64]. The accuracy of bone scans, either single phase or 3-phase, for diagnosing complications of lower extremity prosthesis is approximately 50% to 70% with a normal study, excluding a prosthetic complication as the cause of the patient's symptoms [65]. The classic finding for an infected TKA is increased uptake on all 3 phases in the same location (a positive 3-phase bone scan) [30]. However, increased uptake is a nonspecific finding and may persist on a bone scan even as a postsurgical finding in the absence of infection and >1 year after surgery, and it can also be seen with aseptic loosening [59]. In fact, Duff et al [18] reported persistent bone scan activity in the absence of infection 2 years after surgery. This activity is not likely to be 3-phase positive. Bone scans can potentially be negative with loosening at the cement–prosthetic interface, which does not incite new bone formation [66]. Although Love et al [64] report that the use of 3-phase bone scintigraphy does not improve the accuracy of the test, Smith et al [60] found that infection is more likely than aseptic loosening if there is increased uptake on both blood-pool and delayed images. Their analysis of 80 bone scans in patients with postoperative pain found that no patient with infection had a negative 3-phase bone scan [60]. Given the limited specificity of this test, patients with abnormal bone scans and suspected infection should undergo additional assessment to help in characterizing the bone scan abnormality [64]. Overall, 3-phase bone scans may be useful, even though their accuracy is lower than that of the WBC or FDG-PET/CT scan [63].

CT Arthrography Knee
CT joint arthrography can assess for lucency with contrast accumulation at the bone/cement/hardware interface. These areas of lucency are not specific for infection versus mechanical loosening.

CT Knee With IV Contrast
CT has a limited role in the workup of periprosthetic infection. CT with IV contrast could help demonstrate periprosthetic fluid collections and fistulae. Advances in metal artifact reduction may expand the potential role of CT.

CT Knee Without and With IV Contrast
CT has a limited role in the workup of periprosthetic infection. Noncontrast CT can demonstrate the size and extent of osteolysis, periprosthetic lucencies, intraosseous or soft-tissue gas, and reactive bone formation that might not be evident on radiographs [20,67]. CT with IV contrast could help demonstrate periprosthetic fluid collections and fistulae. Advances in metal artifact reduction may expand the potential role of CT.

CT Knee Without IV Contrast
CT has a limited role in the workup of periprosthetic infection. Noncontrast CT can demonstrate the size and extent of osteolysis, periprosthetic lucencies, intraosseous or soft-tissue gas, and reactive bone formation that might not be evident on radiographs [20,67]. Advances in metal artifact reduction may expand the potential role of CT.

FDG-PET/CT Whole Body
FDG-PET/CT scans may be useful for detecting infection after joint replacement. FDG-PET images reflect relative levels of glucose uptake and thus reflect the localized level of increased metabolic activity. Zhuang et al [68] reported that elevated glycolytic activity causes inflammatory cells such as neutrophils and activated macrophages to be FDG avid at sites of inflammation and infection. Some periprosthetic uptake may occur because of marrow activity, and adding marrow scanning can increase specificity [69]. In these instances, the marrow study would be performed the next day using a different camera type because the marrow scan relies on lower energy photons (PET, 511keV; Tc-99m, 140 keV). Zhuang et al [68] studied 36 painful knee prostheses using FDG-PET and identified 10 of 11 infected cases but had false-positive results in 7 cases (sensitivity of 90.9%, specificity of 72%, and accuracy of 77.8% for detecting infection). This was a lower accuracy than found in assessment of hip prostheses. The cause for the large number of false-positives was not known. Aksoy et al [70] found a positive predictive value (PPV) of 28% (15 of 54) for infection in 54 patients with painful joint prosthesis (24 knee, 48 hip) using FDG-PET. Manthey et al [71] reported that, by analyzing intensity and periprosthetic uptake patterns on FDG-PET, accurate differentiation among aseptic loosening, synovitis, and infection is possible. Kwee and Kwee [72] reports FDG

uptake at the bone-prosthesis interface has been consistently reported as diagnostic criterion for knee prosthetic joint infection. Kwee et al [73] in a meta-analysis reported that the specificity of FDG-PET for diagnosing infection was significantly lower for knee prostheses (74.8%) than for hip prostheses (89.8%). Delank et al [74], in a series of both hip and knee prostheses, found that a negative PET scan excluded infection (100% sensitivity). If the scan was positive, differentiation between wear and infection was not possible. Prandini et al [75] performed a meta-analysis of the diagnostic performance of different radiotracers in peripheral osteomyelitis and prosthetic joint infections, yielding results for FDG-PET with a sensitivity of 94%, a specificity of 87%, a PPV of 87%, an NPV of 94%, and an overall accuracy of 92%. Although metal artifacts have very little impact on nuclear medicine examinations (except as photopenic defects) and create negligible scatter [68,76,77], high PET attenuation coefficients in the area of metal can lead to an overestimation of the PET activity in that region and thereby to a false-positive PET finding. Nonattenuated PET images, which do not manifest this error, can be used in these cases to aid the interpretation of these metal-induced artifacts.

Synovitis and aseptic loosening (in hip prostheses) may cause increased FDG uptake [69]. Sterner et al [78] examined 14 patients with painful TKA to detect early aseptic loosening. Overall accuracy was 71% (sensitivity, 100%; specificity, 56%). In addition, Stumpe et al [79] found diffuse synovial and focal extrasynovial FDG uptake in patients with component malrotation. They concluded that this test is noncontributory in individual patients with persistent pain. Studies in patients with hip prostheses have shown that postoperative remodeling can result in artifactual periprosthetic FDG uptake for up to 6 months after implant insertion [80]. Noting the lack of specificity for detection of periprosthetic infection on conventional FDG-PET, Aksoy et al [70] explored the use of FDG-labeled leukocyte PET/CT for imaging patients with painful joint prostheses and found a sensitivity of 93%, a specificity of 97%, a PPV of 93%, and an NPV of 97%. However, this examination is not in general use. Basu et al [81] found the sensitivity, specificity, PPV, and NPV of FDG-PET in knee prostheses were 94.7%, 88.2%, 69.2%, and 98.4%, respectively, in 87 patients with knee prostheses suspected of being either infected or experiencing noninfectious loosening. Van Acker et al [82] investigated the use of FDG-PET in combination with bone scans and showed no advantage over HMPAO-labeled WBC and bone scans. Comparison of FDG-PET with In-111-labeled leukocyte/Tc-99m-labeled sulfur colloid marrow imaging showed that FDG-PET was less accurate than the leukocyte/marrow scans and could not replace that combination of tests [69].

Fluoride PET/CT Whole Body

There is insufficient evidence to support the use of fluoride PET/CT for the initial evaluation of TKA.

Fluoroscopy Knee

Fluoroscopically positioned radiographs provide optimal visualization of the prosthesis–bone interface to help in demonstrating evidence of bone resorption about the prosthesis, especially in uncemented prostheses [30]. However, this finding by itself is nonspecific for distinguishing between infection, osteolysis, and mechanical loosening.

Image-Guided Aspiration Knee

Knee joint aspiration, often with fluoroscopy or ultrasound guidance, has been found to be extremely useful in diagnosing joint infection after TKA [45,47,83]. This can be performed on fluid aspirated either preoperatively or intraoperatively. Some authors prefer intraoperative aspiration because of better control of contaminants. The synovial fluid is usually evaluated with Gram stain, total and differential cell counts, and aerobic and anaerobic cultures [30,44], although Gram stain has a relatively poor sensitivity and specificity [84]. There are discrepancies in the literature with regard to the optimal cutoff levels for determining the WBC and percentage of polymorphonuclear leukocytes in the aspirated joint fluid that best distinguish infected from noninfected fluid [85,86]. Toms [87] proposed obtaining three samples, including one tissue sample, at the time of aspiration, with the test then considered positive when two specimens grow out the same antibiogram. An absence of fluid (ie, "dry tap") at the time of aspiration does not necessarily indicate the absence of infection [88]. Duff [18] found sensitivity, specificity, and accuracy of 100% for aspiration in a series of 43 knees with pain, instability, loosening, or suspected infection undergoing surgical revision. In contrast, radiographic findings did not separate infected from noninfected patients. Virolainen [49] found joint aspiration to be 100% specific and 75% sensitive for diagnosing infection and to be the best test for diagnosing infection in a group of 68 total hip and knee replacement patients. Bach [45] found that early aspiration led to a significant reduction in the duration of treatment and a better outcome. In 16% of patients, more than three aspirations were necessary to obtain a positive culture. Barrack [89] noted that false negative aspirations may occur in patients who have had preaspiration antibiotic treatment. At least 2 weeks off antibiotics is supported before an aspiration is performed (with careful clinical monitoring for sepsis), but as long

as a month may be necessary for cultures of aspirated fluid to become positive [30]. Weekly repeat aspirations may be needed if the first aspiration is negative and clinical suspicion for infection remains high. Even with a negative preoperative aspiration, intraoperative tissue may indicate infection. Bernard [50], after literature review and a multicenter trial, advocated CRP and joint aspiration as the best tools for diagnosing prosthetic joint infection. When the CRP level is >10 mg/L, repeat joint aspiration or biopsy is suggested. Della Valle [90] also found the combination of ESR and CRP to be a good screening tool for infection, with only one infected knee having negative results on both tests. These authors suggest preoperative aspiration if the ESR or CRP is elevated or if clinical suspicion is high, combined with intraoperative frozen section analysis of the periprosthetic synovial tissue [90]. The AAOS gives a moderate strength of recommendation for synovial fluid testing including leukocyte count and neutrophil percentage, aerobic and anaerobic bacterial cultures, leukocyte esterase, alpha-defensin, CRP, and nucleic acid amplification testing (eg, polymerase chain reaction) for bacteria [54]. A recent manuscript advises intraoperative synovial fluid re-cultures are necessary even if the preoperative aspiration culture is positive and any discordance between preoperative aspiration culture and intraoperative synovial fluid culture should be noted [91]. If the joint aspirate culture is positive on the basis of both cell count with differential and positive cultures, then infection is considered likely and treatment is initiated [54,92]. In that setting, no further imaging is supported for the diagnostic workup of the infection. Berbari [46] studied 897 cases of periprosthetic joint infection and found that approximately 7% were associated with negative cultures. If the preoperative synovial cultures remain negative, multiple intraoperative periprosthetic tissues should be submitted for aerobic and anaerobic bacterial culture [54].

MRI Knee Without and With IV Contrast

MRI may have a role in the workup of periprosthetic infection. Advances in metal artifact reduction may expand the potential role of MRI. Using metal reduction techniques, Potter and Foo found that infected synovium has hyperintense laminar appearance, distinct from the appearance of particle disease [22,93]. They noted that, in selected cases, MRI may be helpful in detecting extracapsular spread of infection and abscess formation. IV contrast may provide additional benefit in this regard [93]. On the basis of their findings, Plodkowski [94] examined 28 patients with proven infected TKAs and 28 controls with noninfected TKA. They found a sensitivity of 86% to 92% and a specificity of 85% to 87%, with almost perfect interobserver agreement, when using the appearance of lamellated hyperintense synovitis to classify infected versus noninfected TKA. Li [95] also reported a different lamellated and hyperintense appearance of the synovium in infected joints, which can be differentiated from frond-like and hypertrophied synovium associated with particle-induced synovitis and from homogeneous fluid-signal intensity effusion associated with a nonspecific synovitis. MRI with metal artifact reduction technique has also been shown to detect osteolysis that is not visible on radiographs [96,97]. Contrast may provide additional benefit in detecting extracapsular spread of infection and abscess formation when compared to noncontrast MRI.

MRI Knee Without IV Contrast

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US Knee

US has a limited role in the workup of periprosthetic infection, but it can be readily used to assess soft tissues, including the presence of edema, hyperemia, and fluid collections about the knee joint in patients with TKA. This may be beneficial in certain situations (eg, practices that may perform fluoroscopy-guided aspiration).

WBC Scan and Sulfur Colloid Scan Knee

Leukocyte scanning using In-111 was introduced in the 1980s [98]. WBCs may be radiolabeled in vitro with In-111 oxine or Tc-99m exametazime (Tc-99m hexamethylpropyleneamine oxime [HMPAO]) [99]. Labeling leukocytes in vitro requires that the patient's venous blood sample be drawn and the WBCs isolated and radiolabeled [100]. The radiolabeled WBCs are then reinjected into the patient, with imaging performed 18 to 24 hours after

injection of the radiolabeled WBCs [63]. Comparison of activity on the WBC image with activity on a bone scan (usually a 3-phase bone scan) has been advocated. A positive study for infection generally requires focal increased activity on the WBC study in the same location and distribution as the positive 3-phase bone scan [100]. Using a sequential combination of bone and In-111-labeled leukocyte scans in patients with loose or painful knee prostheses found a sensitivity of 88%, a specificity of 78%, a PPV of 75%, and an NPV of 90% for diagnosis of infection. They noted an area of potential utility for leukocyte scans, specifically that a negative indium leukocyte scan might support the absence of infection in otherwise equivocal cases and in situations in which a musculoskeletal pathologist is not available to interpret an intraoperative frozen section [100]. A small sample of indium scans in uncomplicated postoperative TKA patients has shown that inflammation can persist around the operative site in the absence of infection [100]. Bernard et al [50] reported a multicenter trial of various methods for diagnosing hip and knee infections. Scans using tagged WBCs or radiolabeled immunoglobulin demonstrated a sensitivity of 74% and a specificity of 76% for diagnosing infection. A literature review indicates sensitivities of 40% to 96% and specificities of 76% to 100% for WBC scans of joint prostheses [49,50,99-104]. Therefore, these studies are not useful as routine for differentiating mechanical failure from occult infection in painful loose total knee prostheses. Filippi and Schillaci [105] applied SPECT/CT using a hybrid camera to conventional planar Tc-99m-HMPAO-labeled leukocyte scintigraphy in patients with suspected infection. SPECT/CT was able to differentiate soft-tissue involvement from bone involvement. The authors argued that SPECT/CT might eliminate the necessity for a correlative bone scan with labeled leukocyte scans. WBC scans also have a decreased sensitivity with low-grade infection [66] and a limited neutrophilic component. Labeled leukocyte imaging may lead to a high false-positive rate because leukocytes accumulate in reactive bone marrow as well as in infection and it is not always possible to differentiate between the two [64,106].

The addition of Tc-99m-labeled sulfur colloid bone marrow scanning has been investigated to reduce this confusion. Palestro et al [107] reported that sequential combined leukocyte/marrow imaging was 95% accurate for diagnosing prosthetic knee infection and was superior to bone scans alone or to bone scans in combination with labeled leukocyte imaging. Joseph et al [106] found that low sensitivity and the potential for false-negative results made this combination of scans of limited utility for diagnosing prosthetic infection, and therefore it is no longer used at their institution. In that group of 22 total knee prostheses evaluated and later operated upon, there was a sensitivity of 66%, a specificity of 100%, a PPV of 100%, an NPV of 88%, and an accuracy of 91%. Blanc et al [108] did a retrospective review of 168 patients. They determined Tc-99m-HMPAO labeled leucocyte scintigraphy was more sensitive for knee (84%) than hip prosthesis (57%) but was less specific for knee (52% versus 75%). The addition of blood-pool and flow scans was investigated to determine if hyperemia led to a match of bone marrow-labeled leukocyte uptake (and therefore a false-negative scan). These additional scans decreased the number of false-negative findings (sensitivity, 83%; specificity, 94%; PPV, 83%; NPV, 94%). Overall, the performance of the labeled leukocyte marrow scan protocol was nonetheless thought to be of limited clinical utility [106]. In contrast, Love et al [69] found the combination of In-111-labeled leukocyte/Tc-99m-labeled sulfur colloid marrow scanning to be the reference standard for diagnosing periprosthetic infection. The authors found the combination of labeled WBC and marrow scanning to be 100% sensitive and 100% specific for diagnosing infection in TKA [69]. Semiquantitative assessment of WBC scans using a combination of early and delayed imaging as a substitute for bone marrow imaging produced a >90% sensitivity and specificity in one series [99]. Love et al [109] examined 150 failed joint prostheses with histopathologic correlation and found that leukocyte/marrow imaging yielded a sensitivity of 96%, a specificity of 87%, and an accuracy of 91%. They found that leukocyte/marrow imaging was significantly more accurate than bone scan (50%), bone/gallium scan (66%), and leukocyte/bone imaging (70%) in their population.

WBC scan and sulfur colloid scan may have a role in the workup of suspected infection in knee arthroplasty.

Variant 3: Pain after total knee arthroplasty. Infection excluded. Suspect aseptic loosening or osteolysis or instability. Additional imaging following radiographs.

Imaging of rotational instability of a TKA is discussed in greater detail under Variant 5. If a patient has undergone a full workup and infection has been excluded, then loosening should be considered as the potential cause of knee pain and periprosthetic lucency. In multiple studies, aseptic loosening has been found to be a common cause of TKA failure [13,110-112]. Sharkey et al [13] found aseptic loosening to be the major cause of late stage (>2 years) TKA failure. Aseptic loosening may occur either because of inadequate primary fixation or because of failure after successful fixation. It is thought to result from mechanical stresses, osteolysis secondary to particle debris, or poor bone stock [21]. Loosening may be closely related to other forms of mechanical failure such as osteolysis,

instability, polyethylene liner wear, and periprosthetic fracture. Osteolysis is a leading cause of late TKA revision. Osteolysis, also known as particle disease and aggressive granulomatosis, occurs secondary to macrophage phagocytosis of particle debris. Debris originating from polyethylene, cement, and metal can all be causes of cell-mediated inflammatory response and osteolysis [113], but typically polyethylene is the most common cause. Areas of osteolysis contain granulation tissue with phagocytosed particulate debris [21]. The incidence of osteolysis is higher for cementless, compared with cemented TKA [114]. Osteolysis can occur anywhere but is more common in the region of the femoral condyles near the attachment of the collateral ligaments, along the periphery of the component, and along the access channels to the cancellous bone of the tibia, including screw holes [114,115]. Patients with osteolysis may be asymptomatic early on but can go on to develop pain, swelling, and acute synovitis.

Although small areas of osteolysis may be monitored, the presence of large areas of osteolysis suggest component loosening and may require revision surgery [116]. Imaging can also help evaluate available bone stock in preparation for revision surgery. Instability refers to abnormal and excessive displacement of the articular surfaces of the prosthesis [21]. Instability usually occurs because of surgical error and/or poor prosthesis selection and often results in revision surgery an average of 4 years after the primary arthroplasty [21]. Severe instability can result in dislocation. In a 2014 review of 781 cases of prosthesis failure, Sharkey et al [12] found that instability represented the third most common cause of prosthesis failure overall, accounting for 7.5% of all cases. The concepts of instability, malalignment, and loosening in TKA are closely interrelated [117]. When malalignment of the joint is created at the time of surgery, minor degrees of instability can become a significant problem. By the same token, instability, ongoing over time, can give rise to malalignment, which, in turn, can lead to loosening. Although ligamentous balance/imbalance plays a role in joint instability, it is not the only factor accounting for stability [118].

3-Phase Bone Scan Knee

There is insufficient evidence to support routine use of Tc-99m 3-phase bone scans for the assessment of instability.

Bone scintigraphy may be helpful in diagnosing loosening, especially when obtained many years after surgery [62]. This delay in maximum utility is because of the observation that positive bone scans are noted in 20% of asymptomatic knees 1 year after surgery and in 12.5% of individuals 2 years after surgery [61]. Serial bone scans may be more helpful than a single examination [119]. Generally, increased uptake on the delayed images but not on the blood-pool phase is thought to be due to loosening rather than to infection [60]. Normal scans are most helpful and are characterized by a high NPV, indicating that loosening or infection is unlikely. A potential false negative; however, may occur if there is loosening at the cement–prosthetic interface that does not incite new bone formation [66]. Smith et al [60] evaluated 80 bone scans in patients with symptomatic TKA, classifying even mildly increased activity on either blood-pool or delayed images as abnormal, and found a high sensitivity (92.3%) for distinguishing abnormal (ie, those with either loosening or infection) from normal TKA. The test was not specific in that it was unable to distinguish between aseptic loosening and infection [60]. If infection is excluded by other studies, loosening of the tibial component may be detected using quantitative analysis of bone scintigraphy, with a sensitivity of 90% and a specificity of 100% [120]. The 3-phase bone scan is moderately sensitive (76%) in identifying the failed joint prosthesis but with a specificity of only 51% and an accuracy of 50% to 70% [121]. A positive 3-phase bone scan demonstrates increased periprosthetic uptake in both focal and diffuse patterns, but even with SPECT/CT it can still be difficult to distinguish between infection and aseptic loosening, the latter of which is due to either inadequate initial fixation, mechanical loss of fixation over time, or biologic loss of fixation caused by particle induced osteolysis around the implant. Murer et al [122] reports that the sensitivity and specificity for detection of tibial component loosening was 96.0% and 100%, respectively, and the sensitivity and specificity for detection of femoral component loosening was 95.0% and 100%, respectively. The bone scan; however, can be useful as a screening test, with a high NPV with 1 caveat. Math et al [20] reported that increased periprosthetic uptake along the tibial or femoral stem was more indicative of loosening than uptake along the tibial tray. The authors also commented on the benefit of a contralateral asymptomatic TKA as a comparative control. Periprosthetic TKA uptake was also reported in more than 60% of femoral and nearly 90% of tibial components in asymptomatic patients for several years after surgery [123]. With a positive 3-phase bone scan, WBC and marrow imaging may be needed to delineate between infection and aseptic loosening, the latter of which can be related to particle disease.

CT Arthrography Knee

CT joint arthrography can assess for lucency with contrast accumulation at the bone/cement/hardware interface. These areas of lucency are not specific for infection versus mechanical loosening.

CT Knee With IV Contrast
CT with IV contrast is not useful for the assessment of aseptic loosening, osteolysis, or instability.

CT Knee Without and With IV Contrast
CT without and with IV contrast is not useful for the assessment of aseptic loosening, osteolysis, or instability.

CT Knee Without IV Contrast
Particularly when metal artifact reduction techniques are used, CT can be used to show the extent and width of lucent zones that may be less apparent on radiographs [20]. MRI and CT have both been shown to be more sensitive for detection of osteolysis than radiographs [116]. CT can be used to detect osteolysis and to determine the total volume of osteolytic lesions, particularly when metal reduction techniques are used [124]. CT is supported by Math et al [20] to look for osteolysis in patients with painful knee prostheses who have normal or equivocal radiographs and increased uptake on all 3 phases of a bone scan. Reish et al [67] found that only 17% of 48 lesions visible by CT were detected on radiographs. They suggested multidetector CT in cases in which osteolysis is expected, such as when there is aseptic loosening and gross polyethylene wear.

CT allows the assessment of rotational positioning of the prosthesis components, which can affect patellofemoral tracking and varus/valgus ligamentous stability in flexion [125]. Imaging of rotational instability of a TKA is discussed in greater detail under Variant 5.

FDG-PET/CT Whole Body
Sterner et al [78] examined 14 patients with painful TKA using FDG-PET to detect early aseptic loosening. Overall accuracy was 71% (sensitivity, 100%; specificity, 56%). Delank et al [74], in a series of both hip and knee prostheses, found that a negative PET scan excluded infection (100% sensitivity). If the PET scan was positive, then differentiation between wear and infection was not possible. Soft-tissue inflammation begins before prosthetic osteolysis, both of which are often asymptomatic until the need for surgery. Metallic artifact also hinders CT and MRI assessment of this osteolysis at the prosthetic-bone interface. FDG accumulates in cells with high glucose uptake. Other than tumor cells, FDG accumulates in areas of inflammation and infection because of activated lymphocytes, neutrophils, and macrophages. Jansen et al [66] reported that postoperative remodeling can be seen as nonspecific periprosthetic uptake in the first six months after arthroplasty. A negative FDG study has a high NPV for loosening related to particle disease, which incites a granulomatous response. Similar to bone scan, a false-negative scan may be seen if loosening occurs at the cement–prosthetic interface [66]. Increased FDG activity is sensitive but cannot differentiate between TKA infection and loosening [121].

There are varying reports on FDG sensitivity, specificity, and accuracy, which are likely in part related to nonuniform interpretation criteria and PET techniques. One overall estimate of FDG sensitivity, specificity, and accuracy in TKA is 96%, 77%, and 83%, respectively [126]. Although FDG is reportedly limited in evaluating patients with chronic knee pain after TKA [66,127], further advancements in FDG-PET may potentially be a promising tool in identifying prosthetic osteolysis [126]. Its exact role in the failed joint prosthesis; however, has yet to be determined. There is insufficient evidence to support routine use of FDG-PET/CT for assessment of instability.

Fluoride PET/CT Whole Body
Koob et al [128] noted a sensitivity of 95.00%, a specificity of 87.04% and an accuracy of 89.19% for the diagnosis of periprosthetic loosening of total hip and knee prosthesis with fluoride PET/CT. There is insufficient evidence to support routine use of fluoride PET/CT for assessment of instability.

Fluoroscopy Knee
There is no recent evidence supporting the routine use of fluoroscopy for the assessment of aseptic loosening, osteolysis, or instability. Fluoroscopy may be useful to see lucent lines in profile that could be obscured on standard AP radiographs [20,129,130] and can also be useful for demonstrating loosening under real-time manipulation. It can be useful in optimally positioning the joint for detection of radiographic osteolysis [129,130] and facilitates dynamic assessment of the knee under stress. In older studies, this procedure was determined to be useful, but it has been supplanted by other modalities and is now infrequently performed.

MRI Knee Without and With IV Contrast
MRI without and with IV contrast is not useful for assessment of osteolysis or instability. The use of IV contrast for assessing loosening has not been described.

MRI Knee Without IV Contrast

The literature regarding MRI in the detection of implant loosening is evolving, and the available evidence supports its use. Using metal artifact reduction techniques, Fritz et al [93] described what they posited are distinct appearances for an intact periprosthetic interface (direct contact of the implant or cement with the surrounding bone), a periprosthetic fibrous membrane that indicates limited implant fixation that may or may not progress to loosening (1- to 2-mm thick layer with smooth margins surrounding the prosthesis along the bone interface) and frank bone resorption (a periprosthetic layer >2-mm thick with irregular margins). They reserve the use of the term loosening for cases in which MRI demonstrates circumferential osseous resorption together with signs of implant displacement, subsidence, or rotation. In a study of 116 knees in 114 patients that evaluated the interface type (normal, fibrous membrane, fluid, or osteolysis), percent integration (<33%, 33%-66%, or >66%), and presence of bone marrow edema. They determined MRI had higher sensitivity (84% versus 31%) but lower specificity (85% versus 96%) for patellar component loosening than did radiography [131].

MRI and CT have both been shown to be more sensitive for detection of osteolysis than radiographs [116]. MRI with metal artifact reduction techniques can detect osteolysis that is not visible on radiographs, even around the femoral component [96]. An MRI investigation of 11 TKA suspected of osteolysis on radiographs (and subsequently confirmed by surgery) found 10 cases with osteolysis at MRI and confirmed at surgery, 5 cases with additional osteolytic lesions detected on MRI, and 9 cases in which lesions were larger on MRI than on radiographs [97]. MRI can also show synovial changes due to particle disease before osteolytic lesions become apparent [22].

When effective, metal suppression can be used, and MRI can allow direct visualization of ligaments and tendons about the knee [93].

US Knee

US has no significant role in assessing for aseptic prosthesis loosening and is not typically used for the assessment of osteolysis. US can be used to evaluate synovitis and soft tissues about the joint and to guide joint aspiration [132]. US is not typically used for assessment of instability but can be used to visualize and assess the medial and lateral collateral ligaments in the setting of TKA [133].

WBC Scan and Sulfur Colloid Scan Knee

In-111 WBC, Tc-99m labeled WBC, and Tc-99m sulfur colloid knee scans are not useful for evaluation of aseptic knee prosthetic loosening. WBC/marrow studies are used to differentiate prosthetic loosening from acute infection and can be performed without or with a corresponding bone scan, the latter without altering the WBC/marrow results [127]. A negative WBC scan negates an acute neutrophilic infection but may be falsely negative in chronic infection [101]. Love et al [109] reported WBC/marrow sensitivity, specificity, and accuracy as 96%, 87%, and 91%, respectively, for 150 total hip and knee replacements. Joseph et al [106] reported preoperative WBC/marrow imaging in 58 total hip and knee replacements with a sensitivity, specificity, and accuracy of 46%, 100%, and 88%, respectively. Palestro et al [107,134] described >90% accuracy and a specificity with a high sensitivity for WBC/marrow studies in the assessment of prosthetic joints. In the setting of chronic infection, differentiating chronic prosthetic infection from loosening can be more challenging, given that, in comparison with acute infections, chronic infections tend to have significantly fewer neutrophils, which are the predominant type of WBC labeled in an In-111 or Tc-99m-HMPAO WBC study, and radiolabeled WBCs are predominantly neutrophils. A decreased WBC sensitivity in osteomyelitis has also been attributed to a bacterial protective membrane or biofilm and to the effect of antibiotics [66]. Nonetheless, WBC/marrow scans to include SPECT/CT appear to be the imaging procedures of choice, with a high degree of accuracy for the failed joint prosthesis in the setting of a positive 3-phase bone scan because a negative WBC/marrow study does not include aseptic loosening [66]. In-111 WBC and Tc-99m sulfur colloid studies are not useful for assessment of instability.

Variant 4: Pain after total knee arthroplasty. Suspect periprosthetic or hardware fracture. Additional imaging following radiographs.

Periprosthetic fractures may occur either during or after surgery and can involve the femur, tibia, or patella. Among periprosthetic fractures, supracondylar distal femur fractures are most common, whereas patellar fractures are rare [135,136]. Supracondylar fractures occur in 0.3% to 2.5% of TKA, usually within 2 to 4 years after surgery, and often occur in the setting of low-energy trauma [136]. Tibial fractures are associated with loose components and malalignment. Patellar fractures are associated with rheumatoid arthritis, steroid use, osteonecrosis, and malalignment. Most patients with periprosthetic fractures are elderly, having poor bone stock. Treatment depends

on fracture classification, which often includes information regarding fracture location, degree of comminution, and position and stability of the prosthesis.

3-Phase Bone Scan Knee
Radionuclide 3-phase bone scans can demonstrate increased activity at a site of periprosthetic fracture and can show fractures that are radiographically occult [137,138]. In older osteopenic individuals with low rates of bone remodeling, it may take 48 to 72 hours for the development of increased radionuclide activity at the site of fracture. Within 1 to 2 years after prosthesis surgery, the differential diagnosis for increased periprosthetic activity would include postoperative change; however, with serial imaging, this postoperative activity should decrease over time, whereas activity increasing over time would be suggestive of a prosthetic complication, such as a periprosthetic fracture, aseptic loosening, or infection. Therefore, no conclusion should be drawn on an isolated bone scan unless it yields a normal study.

CT Arthrography Knee
There is no benefit to intraarticular contrast.

CT Knee With IV Contrast
IV contrast is not helpful for CT assessment of periprosthetic fracture.

CT Knee Without and With IV Contrast
IV contrast is not helpful for CT assessment of periprosthetic fracture.

CT Knee Without IV Contrast
Radiographically occult fractures may be detected on CT when metal artifact reduction techniques are used [20].

FDG-PET/CT Whole Body
There is insufficient evidence to support the use of FDG-PET/CT for the assessment of periprosthetic fractures.

Fluoride PET/CT Whole Body
There is insufficient evidence to support the use of fluoride PET/CT for the assessment of periprosthetic fractures.

Fluoroscopy Knee
There is insufficient evidence to support the use of fluoroscopy for the assessment of periprosthetic fractures.

MRI Knee Without and With IV Contrast
IV contrast is not helpful for CT or MRI assessment of periprosthetic fracture.

MRI Knee Without IV Contrast
Radiographically occult fractures may be detected on MRI [22] when metal artifact reduction techniques are used.

US Knee
There is insufficient evidence to support the use of US for the assessment of periprosthetic fractures.

WBC Scan and Sulfur Colloid Scan Knee
There is insufficient evidence to support the use of In-111 WBC and Tc-99m sulfur colloid studies for the assessment of periprosthetic fractures.

Variant 5: Pain after total knee arthroplasty. Measuring component rotation. Additional imaging following radiographs.

Malposition of femoral and tibial components may affect patellar alignment [139]. Excessive combined internal rotation of tibial and femoral components has been shown to be associated with patellar complications [139]. Moreover, Berger and Rubash [140] found that the amount of excessive combined internal rotation is directly proportional to the severity of patellofemoral complications. Abdelnasser et al [141] noted an internal rotation of the tibial component in TKA can lead to postoperative extension deficit.

3-Phase Bone Scan Knee
There is insufficient evidence to support the use of bone scans for the assessment of rotational alignment of a TKA.

CT Arthrography Knee
Intraarticular contrast is not helpful in the CT assessment of rotational alignment.

CT Knee With IV Contrast
IV contrast is not helpful in the CT assessment of rotational alignment.

CT Knee Without and With IV Contrast
IV contrast is not helpful in the CT assessment of rotational alignment.

CT Knee Without IV Contrast
CT is the modality most commonly used for measuring axial malrotation of a knee prosthesis. Jazrawi et al [142] studied the accuracy of a CT method for evaluating femoral and tibial component rotation and found the coefficient of variation between CT and digital imaging of cadaver specimens to average 0.87. The rotation of tibial and femoral components on cross-sectional studies is most often evaluated using internal anatomic landmarks for reference [20,139,142]. Femoral component rotation may be assessed in relation to the transepicondylar axis [139,140], the Whiteside line [143], or the posterior femoral condyles [139,143]. Berger et al [139,140] constructed the transepicondylar axis from the lateral epicondyle to the trough in the medial epicondyle. Unfortunately, this trough is visible only in a little more than half of patients, and therefore measurement to the peak of the lateral epicondyle has also been used (known as the condylar twist angle) [40]. According to Berger and Rubash [140], the femoral component should be parallel to the transepicondylar axis, and the tibial component should be positioned in about 18° of internal rotation in relation to the tibial tubercle. Three-dimensional CT studies may also be used for assessing component rotation [144]. According to Saffi et al [145], 3-D CT is the reference standard for measuring tibial component rotational alignment.

FDG-PET/CT Whole Body
Stumpe et al [79] found diffuse synovial and focal extrasynovial FDG uptake in patients with component malrotation; however, FDG-PET/CT studies are not routinely used for the assessment of rotational alignment of a TKA.

Fluoride PET/CT Whole Body
There is insufficient evidence to support the use of fluoride PET/CT for the assessment of rotational alignment of a TKA.

Fluoroscopy Knee
There is insufficient evidence to support the use of fluoroscopy for the assessment of rotational alignment of a TKA.

MRI Knee Without and With IV Contrast
IV contrast is not useful for MRI assessment of rotational alignment.

MRI Knee Without IV Contrast
When adequate metal reduction techniques are used, MRI can be used to assess TKA component rotation [146]. Anatomic landmarks and axes required for measurement of rotational alignment parameters can be identified [147,148]. In a study of 50 patients with painful TKA and 16 controls, Murakami et al [148] found high interobserver agreement in all the relevant rotational alignment measurements and found statistically significant relative internal rotation of the femoral component in patients with a painful TKA. MRI literature is evolving, and the available evidence suggests MRI may be useful in the assessment of component rotation with adequate metal reduction techniques.

US Knee
There is insufficient evidence to support the use of US for the assessment of rotational alignment of a TKA.

WBC Scan and Sulfur Colloid Scan Knee
There is insufficient evidence to support the use of In-111 WBC and Tc-99m sulfur colloid studies for the assessment of rotational alignment of a TKA.

Variant 6: Pain after total knee arthroplasty. Suspect periprosthetic soft-tissue abnormality unrelated to infection, including quadriceps or patellar tendinopathy (quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues). Additional imaging following radiographs.

The incidence of quadriceps or patellar tendon tears after TKA is low, at 0.17% to 2.5% [149]. Sharkey et al [12] reported that the incidence of postoperative arthrofibrosis is also relatively low, accounting for 4.5% of failures in this series and 6.9% of failures where noted in the Lombardi et al [111] series. Of note, patients with keloids have increased odds risk of arthrofibrosis following primary TKA [150]. Additional periprosthetic soft-tissue causes of postoperative knee pain are also uncommon and include impingement of nerves or other soft tissues.

3-Phase Bone Scan Knee
There is insufficient evidence to support the use of 3-phase bone scan for the assessment of periprosthetic soft-tissue abnormalities.

CT Arthrography Knee
CT is not useful for assessment of periprosthetic soft-tissue abnormalities. Intraarticular contrast is not significantly helpful in the CT assessment of quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues.

CT Knee With IV Contrast
CT is not useful for assessment of periprosthetic soft-tissue abnormalities. IV contrast is not significantly helpful in the CT assessment of quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues.

CT Knee Without and With IV Contrast
CT is not useful for assessment of periprosthetic soft-tissue abnormalities. IV contrast is not significantly helpful in the CT assessment of quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues.

CT Knee Without IV Contrast
There is insufficient evidence to support the use of CT without IV contrast for the assessment of periprosthetic soft-tissue abnormalities.

FDG-PET/CT Whole Body
There is insufficient evidence to support the use of FDG-PET/CT for the assessment of periprosthetic soft-tissue abnormalities.

Fluoride PET/CT Whole Body
There is insufficient evidence to support the use of fluoride PET/CT for the assessment of periprosthetic soft-tissue abnormalities.

Fluoroscopy Knee
There is insufficient evidence to support the use of fluoroscopy for the assessment of periprosthetic soft-tissue abnormalities.

MRI Knee Without and With IV Contrast
There is no relevant literature documenting the additional benefit of contrast, relative to noncontrast MRI, in the assessment of impingement, tendon abnormalities, or intraarticular abnormalities. Information regarding the use of MRI knee in the setting of in neoplastic masses and inflammatory pseudotumors is documented in the ACR Appropriateness Criteria® topic on "Soft Tissue Masses" [151].

MRI Knee Without IV Contrast
MRI that uses robust metal reduction techniques can be used for evaluation of quadriceps or patellar tendinopathy in patients with TKA [152] and for evaluation of arthrofibrosis [93]. MRI can also demonstrate suprapatellar arthrofibrosis that can be associated with post TKA patellar clunk syndrome [147]. The presence of MRI measurable abundant thick fibrotic tissue in patients with a clinical diagnosis of knee fibrosis is of benefit to knee surgeons faced with patients with stiff TKA and can facilitate the decision to debride the knee, restore range of motion, and revise the implant [153]. MRI is beneficial for the workup of periarticular soft-tissue masses, including neoplastic masses and inflammatory pseudotumors [154].

US Knee
US can be used for evaluation of quadriceps or patellar tendinopathy [155-157], postsurgical arthrofibrosis [158], and periarticular soft-tissue masses in patients with TKA. One review discusses the use of dynamic US to look for causes of snapping knee, including patellar clunk, snapping popliteus, and snapping related to component/liner malposition [159]. A case report discussed the utility of using dynamic US for the workup of patellar clunk syndrome [160].

WBC Scan and Sulfur Colloid Scan Knee
There is insufficient evidence to support the use of In-111 WBC and Tc-99m sulfur colloid studies for the assessment of periprosthetic soft-tissue abnormalities.

Summary of Recommendations

- **Variant 1:** Radiography knee is usually appropriate for the initial imaging of symptomatic or asymptomatic patients with a total knee prothesis.
- **Variant 2:** Image-guided aspiration knee is usually appropriate as the next imaging study for suspected infection after TKA following radiography.
- **Variant 3:** In the setting of a painful knee prosthesis evaluated with radiography and when infection has been excluded, MRI knee without IV contrast or CT knee without IV contrast is usually appropriate as the next imaging study for aseptic loosening or osteolysis or instability. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 4:** In the setting of a painful knee prosthesis evaluated with radiography, CT knee without IV contrast is usually appropriate as the next imaging study for suspected periprosthetic or hardware fracture.
- **Variant 5:** In the setting of a painful knee prosthesis evaluated with radiography, CT knee without IV contrast is usually appropriate as the next imaging study for measuring component rotation.
- **Variant 6:** In the setting of a painful knee prosthesis evaluated with radiography, US knee or MRI knee without IV contrast is usually appropriate as the next imaging study for suspected periprosthetic soft-tissue abnormality unrelated to infection, including quadriceps or patellar tendinopathy (quadriceps or patellar tendon tears, postoperative arthrofibrosis, patellar clunk syndrome, or impingement of nerves or other soft tissues). These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document [161].

Relative Radiation Level Designations		
Relative Radiation Level*	**Adult Effective Dose Estimate Range**	**Pediatric Effective Dose Estimate Range**
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv
*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."		

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The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.