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

Variant 1: **Follow-up of the asymptomatic patient with a total knee arthroplasty.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray knee	9		☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee without IV contrast	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without IV contrast	1		O
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Aspiration knee	1		Varies
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 2: **Status post total knee arthroplasty. Measuring component wear.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray knee	9		☢
Fluoroscopy knee	5		☢
X-ray arthrography knee	1		☢
CT knee without IV contrast	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without IV contrast	1		O
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 3: **Pain after total knee arthroplasty. Periprosthetic infection not excluded. Initial imaging evaluation, including image-guided intervention.**

Radiologic Procedure	Rating	Comments	RRL*
Aspiration knee	9	This procedure is performed after reviewing the x-ray of the knee.	Varies
X-ray knee	8	This procedure should be obtained prior to joint aspiration, if not already performed.	☢
Fluoroscopy knee	4	This procedure is sometimes done to supplement radiography to aid in detection of radiographically occult periprosthetic loosening. It is not specific for infection.	☢
US knee	3		O
MRI knee without IV contrast	2		O
X-ray arthrography knee	1		☢
CT knee without IV contrast	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
Tc-99m 3-phase bone scan knee	1	SPECT/CT is optional and dependent on the findings of the 3-phase bone scan.	☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1	SPECT/CT with subtraction imaging is optional and dependent on the findings of the WBC/sulfur colloid planar images.	☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 4: **Pain after total knee arthroplasty. Joint aspiration cultures positive for infection. Additional imaging following radiographs.**

Radiologic Procedure	Rating	Comments	RRL*
MRI knee without and with IV contrast	5		O
CT knee with IV contrast	4		☢
MRI knee without IV contrast	4		O
US knee	4		O
CT knee without IV contrast	2		☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee without and with IV contrast	1		☢
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 5: **Pain after total knee arthroplasty. Joint aspiration culture(s) negative or inconclusive. Suspect infection. Additional imaging following radiographs, including image-guided intervention.**

Radiologic Procedure	Rating	Comments	RRL*
Aspiration knee	9		Varies
Tc-99m 3-phase bone scan and In-111 WBC scan knee	6	Sulfur colloid may be needed if congruent in the area of concern. Perform SPECT/CT as needed.	☢ ☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	6	SPECT/CT with subtraction imaging is optional and dependent on the findings of the WBC/sulfur colloid planar images.	☢ ☢ ☢ ☢
MRI knee without and with IV contrast	5		O
CT knee with IV contrast	4		☢
MRI knee without IV contrast	4		O
Tc-99m 3-phase bone scan knee	4	SPECT/CT is optional and dependent on the findings of the 3-phase bone scan.	☢ ☢ ☢
In-111 WBC scan knee	4		☢ ☢ ☢ ☢
US knee	3		O
CT knee without IV contrast	2		☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee without and with IV contrast	1		☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 6: **Pain after total knee arthroplasty. Negative studies for infection. Suspect aseptic loosening. Additional imaging following radiographs.**

Radiologic Procedure	Rating	Comments	RRL*
CT knee without IV contrast	7		☢
Fluoroscopy knee	6		☢
Tc-99m 3-phase bone scan knee	6	SPECT/CT is optional and dependent on the findings of the 3-phase bone scan.	☢ ☢ ☢
MRI knee without IV contrast	3		O
FDG-PET/CT whole body	3		☢ ☢ ☢ ☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 7: **Pain after total knee arthroplasty. Negative studies for infection. Suspect granulomas/osteolysis. Additional imaging following radiographs.**

Radiologic Procedure	Rating	Comments	RRL*
CT knee without IV contrast	8		☢
MRI knee without IV contrast	6		O
Fluoroscopy knee	5		☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 8: **Pain after total knee arthroplasty. Clinical concern for instability.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray knee	9	Radiographs are always taken first.	☢
Fluoroscopy knee	7	After radiographs, this procedure is useful for viewing abnormal motion.	☢
CT knee without IV contrast	5	This variant is for standard instability. See Variant 11 for rotational instability.	☢
MRI knee without IV contrast	5		O
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 9: **Pain after total knee arthroplasty. Suspect periprosthetic fracture.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray knee	9	Radiographs are always taken first.	☢
CT knee without IV contrast	8		☢
MRI knee without IV contrast	5		O
Tc-99m 3-phase bone scan knee	4	SPECT/CT is optional and dependent on the findings of the 3-phase bone scan.	☢ ☢ ☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 10: **Status post total knee arthroplasty. Suspect complications related to the patella or the patellar liner (subluxation, dislocation, fracture, component loosening or wear, impingement, and osteonecrosis).**

Radiologic Procedure	Rating	Comments	RRL*
X-ray knee	9		☢
CT knee without IV contrast	6		☢
MRI knee without IV contrast	5		O
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 11: **Pain after total knee arthroplasty. Measuring component rotation.**

Radiologic Procedure	Rating	Comments	RRL*
CT knee without IV contrast	9		☢
MRI knee without IV contrast	6		O
X-ray knee	5		☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
US knee	1		O
Tc-99m 3-phase bone scan knee	1		☢ ☢ ☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢ ☢ ☢ ☢
FDG-PET/CT whole body	1		☢ ☢ ☢ ☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 12: **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).**

Radiologic Procedure	Rating	Comments	RRL*
MRI knee without IV contrast	7	This procedure is equivalent to US.	O
US knee	7	This procedure is equivalent to MRI.	O
X-ray knee	5		☢
CT knee without IV contrast	2		☢
Fluoroscopy knee	1		☢
X-ray arthrography knee	1		☢
CT knee with IV contrast	1		☢
CT knee without and with IV contrast	1		☢
MRI knee without and with IV contrast	1		O
Tc-99m 3-phase bone scan knee	1		☢☢☢
In-111 WBC and Tc-99m sulfur colloid scan knee	1		☢☢☢☢
FDG-PET/CT whole body	1		☢☢☢☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

IMAGING AFTER TOTAL KNEE ARTHROPLASTY

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Summary of Literature Review

Introduction/Background

Total knee arthroplasty (TKA), which is primarily used to treat pain and improve function in patients with symptomatic advanced knee osteoarthritis, is now 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], 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]. Moreover, 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 rise in 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].

Patient satisfaction rates for TKA are relatively high, ranging from 75% to 89% [8]. TKA patients experience improved outcomes and long implant survival, with long-term TKA failure rates of <1% per year [5]. However, the growth in the number of primary TKA procedures has been accompanied by increased rates of TKA revision procedures [1]. In fact, revision procedures for TKAs have increased by 5.4 procedures per 100,000 persons per decade over the period 1990 to 2002, with a mean revision burden of 8.2% [9]. 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 [10] 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 [11], 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” [12].

Overview of Imaging Modalities

Radiography

Radiographs are the initial imaging modality for evaluation of a patient with a TKA. The typical examination consists of anteroposterior (AP), lateral, and axial views, with the AP view preferably obtained during weight bearing. Full-length (hip-to-ankle) weight-bearing views are used for the measurement of anatomic and mechanical axes for optimal assessment of alignment. Images should include the entire prosthesis [4,13,14].

Radiographs can demonstrate normal or abnormal bone and hardware alignment, periprosthetic lucency and osteolysis [15-21], reactive bone formation and periostitis, periprosthetic fractures, evidence of polyethylene liner wear, and cement and heterotopic bone about the knee. Radiographs are limited in terms of sensitivity. Subtle changes in bone mineralization or alignment may be obscured by overlying bone or hardware. Radiographs are also limited in terms of specificity; it is often not possible to distinguish infection from aseptic loosening.

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Radiographs can delineate effusion, overt soft-tissue swelling, foreign bodies, subcutaneous emphysema, heterotopic bone, and cement or metal in soft tissues, but they are quite limited for the depiction of soft-tissue structures, such as collateral ligaments, about the knee.

Several strategies to improve the sensitivity for detection of subtle findings include (1) fluoroscopy to optimally align radiographs for detection of subtle findings and to allow dynamic evaluation for either prosthesis loosening (motion of prosthesis within the surrounding bone or cement) or prosthesis instability (change in alignment of prosthesis components during fluoroscopic maneuvers) , (2) knee joint arthrography to assess for periprosthetic contrast as evidence of loosening, and (3) dedicated views to demonstrate additional bony surfaces. Fluoroscopy can be used for comparison of sequential radiographs when considered important to assess for changes in the bone surrounding the prosthesis or in the alignment of the arthroplasty components. However, this is predicated on obtaining sequential images with comparable positioning and technique.

The optimal schedule for obtaining postoperative radiographs has not been standardized, but the use of immediate postoperative radiographs in routine circumstances has been questioned because of suboptimal quality of perioperative images and their limited contribution to patient care [22,23].

CT

The use of computed tomography (CT) for the assessment of TKA is limited by metal (beam-hardening) artifact, which can obscure surrounding bone and soft tissue. Nonetheless, CT can reveal changes in the surrounding bone that might not be apparent on radiographs and thus, in some cases, can reveal radiographically occult evidence of loosening, osteolysis, fracture, and reactive bone formation. CT arthrography has been used to outline periprosthetic lucency and demonstrate displaced polyethylene within the joint. Intravenous (IV) contrast-enhanced CT can demonstrate effusions, fluid collections, and abscesses. CT is the main modality used to assess rotatory alignment of prosthesis components [24]. New CT technology and new techniques for suppression of metal artifact will likely expand the utility of CT for evaluation of TKAs [25-31].

MRI

Magnetic resonance imaging (MRI) has higher intrinsic soft-tissue contrast resolution compared to CT and therefore is generally superior for assessing soft-tissue complications of knee arthroplasty. However, MRI is not typically used for the evaluation of patients with suspected TKA complications because of metallic susceptibility artifacts as well as cost considerations. Evolving MRI methods for metal artifact reduction suggest a more robust future role for MRI, not only in the evaluation of surrounding soft-tissue pathology such as extensor tendinopathy, fluid collections, masses, and muscle edema and atrophy, but potentially also in the diagnosis of component loosening, osteolysis, infection, and malrotation [27,32-40]. A recent retrospective study (n = 108) suggested that using MRI metal artifact reduction techniques, qualitative differences in the appearance of the synovium in TKA patients could be observed that would allow distinction among particle-induced synovitis, infection, and nonspecific synovitis [41]. In general, prostheses composed of conventional cobalt/chrome/molybdenum alloy have more pronounced metal artifact than those composed of titanium or zirconium, even when metal reduction techniques are used, and are therefore less amenable to MRI evaluation [42].

US

Ultrasound (US) cannot be used to evaluate the prosthesis itself or the surrounding bone but can be very useful for problem solving about a knee arthroplasty. On US images, unlike CT scans or MRI, metal artifact does not obscure the soft tissues surrounding the joint. Therefore, US can be used effectively to interrogate effusions, fluid collections, and soft-tissue structures about the knee and can be used for dynamic evaluation of the joint. The use of US to assess the thickness of the patellar polyethylene component also has been described [43,44]. US has shown utility in the detection and evaluation of postsurgical pseudoaneurysms about the knee, a rare potential postoperative complication causing knee pain [45].

Advantages of US include its relatively low cost and high level of patient acceptance. Potential limitations include the fact that image quality and interpretation are dependent on user experience.

Nuclear Medicine

A variety of nuclear medicine imaging procedures have potential value in evaluating a TKA, and at various points in time, different studies or combination of studies have been proposed. These procedures involve the IV administration of radiopharmaceuticals. Tc-99m bone scans demonstrate areas of new bone formation and hence can identify periprosthetic fractures, osteomyelitis, or reactive bone formation related to aseptic prosthetic loosening, even when radiographs appear negative. Bone scans can also show increased TKA activity related to

normal postoperative healing for up to 2 years or longer after the initial surgery, but on serial studies this activity should gradually decrease over time. Therefore, an isolated postoperative bone scan with increased periprosthetic activity is inconclusive and not helpful unless it is a normal study, particularly in the first 2 years. Activity increasing over time is abnormal, indicating a prosthetic problem but not necessarily infection. In addition, the specificity of bone scans in differentiating osteomyelitis versus aseptic prosthetic loosening is quite limited. Bone scans may also be negative at the cement-prosthesis interface, which does not incite new bone formation [46].

At present, an indium-111 (In-111)–labeled leukocyte (white blood cell [WBC]) scan, which involves extraction, radiolabeling, and reinjection of the patient's own WBCs, followed by a Tc-99m sulfur colloid bone marrow scan, is generally considered the most robust technique for detecting periprosthetic infection. The WBC examination used alone is sensitive but nonspecific, and the sulfur colloid examination, read in conjunction with the WBC scan, contributes to improved specificity and accuracy. Increased WBC activity localizing to bone without sulfur colloid activity (incongruent activity) is consistent with osteomyelitis. Increased WBC and bone marrow activity both localizing to bone and in the same distribution (congruent activity) is interpreted as reactive marrow and not as osteomyelitis. If a WBC scan is normal in the area of concern, a bone marrow study is not indicated. There is no osteomyelitis. Furthermore, bone scans can be useful as a "road map" to target the abnormal bone, which is then assessed with the labeled leukocytes and bone marrow studies. Bone scans and WBC and bone marrow procedures are typically acquired by planar imaging. The addition of single-photon emission computed tomography (SPECT)/CT increases scan specificity and accuracy, and with subtraction techniques for the WBC and bone marrow scans, it can be helpful to assess for congruent versus incongruent activity.

Nonetheless, results from different studies of this combined WBC/sulfur colloid bone marrow technique have yielded varying results with regard to performance for detection of infection, with some authors considering it highly accurate [47-49] and others dismissing it because of limited clinical utility [50].

There is great interest in the application of fluorine-18-2-fluoro-2-deoxy-D-glucose positron emission tomography (FDG-PET)/CT for the diagnosis of periprosthetic infection, but its utility for assessment of prostheses remains to be determined. Negative predictive value (NPV) is relatively high, whereas specificity and positive predictive value (PPV) are more circumscribed. In the United States, FDG-PET is not approved for reimbursement for infection or other TKA applications. The use of gallium-67, either alone or in conjunction with a conventional bone scan, is rarely performed, having been supplanted by In-111 WBC for detection of infection in the extremities. These techniques are discussed in greater detail under Variant 5.

Discussion of Procedures by Variant

Variant 1: Follow-up of the asymptomatic patient with a total knee arthroplasty.

Radiography

Routine immediate postoperative radiographs are considered unnecessary unless the surgery is complicated or there are specific clinical indications warranting imaging evaluation [22]. It was initially thought that these films would provide information regarding complications that would warrant immediate revision surgery or would influence the rehabilitation protocol. However, several studies have indicated that the rate of complications identified in the immediate postoperative setting is low. Ververeli et al [51] studied 124 consecutive TKAs, comparing recovery room radiographs with additional predischarge radiographs. They suggested elimination of the predischarge radiographs because they found no change in postoperative management based on those films. Glaser et al [22] retrospectively reviewed radiographs from 192 consecutive primary TKAs and found no immediate postoperative radiographs that altered management or that would be needed for legal defense. Moreover, in a prospective evaluation, these authors found that 550 patients who underwent uncomplicated TKA and obtained their first postoperative radiographs at their 6-week follow-up outpatient visits would have had no need for in-hospital postoperative radiographs. Hassan et al [52] examined 624 AP and lateral radiographs obtained immediately following TKA surgery and found no cases in which results altered clinical management. They suggested that the first set of postoperative radiographs be postponed until the patient's first postoperative visit. Kosashvili et al [53] surveyed 24 arthroplasty surgeons, who reported that only 8 of an estimated 65,910 TKAs required same-day revision based on recovery room radiographs. The authors of these studies raised concerns regarding the technical limitations of immediate postoperative films because of portable technique and the patient's limited range of motion as well as the associated radiation exposure for recovery room personnel. They also noted that immediate postoperative films delay mobilization and discharge of the patient and generate additional radiation exposure and health care costs. In-hospital baseline radiographs are less likely to be

technically satisfactory than outpatient radiographs, but if they are satisfactory, then additional repeat routine radiographs at the initial follow-up visit are thought to be unnecessary [23].

Later follow-up radiographs are directed toward identifying any of the postoperative complications detailed earlier, particularly loosening. Serial radiographs are considered important for identifying subtle interval changes [54,55].

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 recommended annual or every-other-year orthopedic and radiographic examinations and more frequent follow-up if there were signs of failure or sepsis, subnormal periprosthetic bone quality, or a history of prior revision [56]. The recommendation is for follow-up every 1 to 2 years, continued for the long term (>10 years).

The routine radiographic examination for evaluation of a TKA consists of standing AP and lateral views 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 [14] compared hip-to-ankle radiographs and AP knee radiographs, both obtained standing, for assessment of alignment and measurement of the tibiofemoral angle and of tibial and femoral component alignment. They 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 weight-bearing 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 [53] 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 10^0 of internal rotation, compared with neutral AP views and with those obtained in 10^0 of external rotation.

Fluoroscopy
Knee fluoroscopy examinations are not typically ordered for evaluation of the asymptomatic patient.

Arthrography
X-ray arthrography examinations are not typically ordered for evaluation of the asymptomatic patient.

CT
CT examinations are not typically ordered for evaluation of the asymptomatic patient.

MRI
MRI examinations are not typically ordered for evaluation of the asymptomatic patient.

US
US examinations are not typically ordered for evaluation of the asymptomatic patient.

Bone scan
Tc-99m three-phase bone scan knee examinations are not typically ordered for evaluation of the asymptomatic patient.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid knee examinations are not typically ordered for evaluation of the asymptomatic patient.

FDG-PET/CT
FDG-PET/CT whole-body examinations are not typically ordered for evaluation of the asymptomatic patient.

Joint Aspiration
Joint aspiration is not typically performed for evaluation of the asymptomatic patient.

Variant 2: Status post total knee arthroplasty. Measuring component wear.

The polyethylene articular surface of a total knee prosthesis may undergo true wear and/or deformation (sometimes termed *creep*), either of which can lead to a decrease in the thickness of the polyethylene. These conditions may be clinically referred to as *wear* [57]. Several imaging modalities have been used to study the thickness of the polyethylene and thus the extent of wear.

Radiography
Radiographic evaluation of wear is based on weight-bearing AP and lateral radiographs and on axial radiographs. Linear 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 weight-bearing radiographs are recommended for detecting subclinical wear [18]. Collier et al [57] examined single-leg standing frontal radiographs of the knees for assessing polyethylene thickness. Overall, 87% of measurements (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 (accuracy roughly ±1 mm initially). However, accuracy decreased for evaluating polyethylene thickness in patients with wear requiring revision.

Fluoroscopy
Fluoroscopy has been used to align radiographs perpendicular to the joint surface in an effort to compensate for any tilt of the tibial component and thus more accurately measure thickness of the polyethylene liner and detect decreases in liner thickness indicative of wear. Correction for magnification is made using the known diameter of a portion of the tibial component. In vivo assessment has shown the repeatability (precision) of these measurements to be 0.2 mm, with a 99% confidence level [58]. Varus/valgus stress during fluoroscopic examination can help improve evaluation of polyethylene thickness [59]. The coefficient of variation for repeat examination was 3.4%.

US
US is under investigation for evaluating the thickness of polyethylene liners [44] but is not in general use for this purpose. Cadaver studies show US measurements to be accurate to 0.5 mm, with a 95% confidence interval, in comparison with caliper measurements [60], and in vivo studies have shown high correlation between radiographic and sonographic measurement [44].

Arthrography
Arthrography is not typically used for evaluation of polyethylene wear. However, the use of arthrography in the diagnosis of a displaced radiolucent polyethylene liner has been described [61].

CT
Because of metal artifact, CT has traditionally played a limited role in the evaluation of polyethylene liner wear.

MRI
The use of MRI for evaluation of polyethylene linear wear has not been described. Using metal artifact suppression techniques, however, polyethylene wear–induced periprosthetic synovitis can be visualized, described as synovial thickening with dense synovial proliferation and debris, similar in signal intensity to skeletal muscle, with variable amounts of interspersed fluid and joint distention [32]. Polyethylene fractures may also be visualized [32].

Bone Scan
Tc-99m three-phase bone scan knee examinations are not used for assessment of polyethylene liner wear.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid scan knee examinations are not used for assessment of polyethylene liner wear.

FDG-PET/CT
FDG-PET/CT whole-body examinations are not used for assessment of polyethylene liner wear.

Variant 3: Pain after total knee arthroplasty. Periprosthetic infection not excluded. Initial imaging evaluation, including image-guided intervention.

Infection is the most serious complication of joint arthroplasty and is reported in 0.8% to 1.9% of TKAs [62]. The frequency of infection is increasing as the number of primary arthroplasties is increasing [62]. Infection may be acute or delayed. Late infection has been defined as occurring at least 3 months postoperatively [63]. In 1 series, infection was responsible for 37.6% of early revisions and 21.9% of revisions performed >2 years after the initial operation [10]. *Staphylococcus aureus* and coagulase-negative *Staphylococcus* species, including *Staphylococcus epidermidis*, are the most common organisms associated with these infections [64].

Both radiographs and joint aspiration are appropriate procedures for the initial evaluation of periprosthetic infection, although the preliminary assessment is based on clinical examination and blood test results.

Clinical

Low-grade or chronic TKA infections may be difficult to diagnose preoperatively. Duff et al [15] noted that diagnosis of infection was not obvious in 53% of knees before revision arthroplasty. Pain is the most common presenting symptom of infection; however, pain is a nonspecific finding [65]. In acute infection, findings such as pain, swelling, warmth, erythema, and fever are common, whereas chronic infections may be manifested by pain alone [62]. Night pain or pain at rest is characteristic of infection, whereas pain on weight bearing 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 [15].

On June 18, 2010, the American Academy of Orthopedic Surgeons (AAOS) published a guideline and evidence report on the diagnosis of periprosthetic joint infections of the hip and knee, which recommended different testing strategies depending on whether there was a higher or lower probability of periprosthetic infection. According to the AAOS guideline, high probability of infection is suspected in a patient with one or more symptoms *and* with one or more risk factors (eg, prior knee infection, superficial surgical site infection, operative time >2.5 hours, and immunosuppression) *or* a physical finding *or* early implant loosening/osteolysis as detected by radiographs [66].

Laboratory

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 value of the test [67]. 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), although a normal CRP level did not exclude infection [68]. CRP has sensitivity of 73% to 91% and specificity of 81% to 86% for the diagnosis of prosthetic knee infection when a cutoff of 13.5 mg/L or more is used [62].

Although CRP can be elevated after surgery, under normal circumstances it generally returns to baseline values within 2 months after surgery [62]. A large multicenter study found CRP and joint aspiration to be the most useful tools to diagnose infection [69]. In an attempt to construct an algorithm for evaluating TKA infection, Savarino et al [70] found that abnormal results for at least two of three 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%). The AAOS guideline recommends the use of ESR and CRP testing for patients being assessed for periprosthetic joint infection, noting that when both ESR and CRP are negative, infection is unlikely [66]. Positive results for either ESR or CRP warrant further evaluation [66]. More recently, interleukin-6 has also shown promise for diagnosing infection with higher predictive values than most other serologic markers [71] and has shown excellent sensitivity for detecting infection after TKA when combined with CRP [72]. Serologic tests can be hard to interpret when underlying inflammatory arthropathy is present [73].

More recently, the use of an α-defensin laboratory test (Synovasure; Zimmer Biomet, Warsaw, Indiana) has been described for the diagnosis of periprosthetic joint infection. α-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 [74-76]. In a study by Deirmengian et al [75] of 149 synovial fluid aspirates, synovial fluid α-defensin tests alone demonstrated sensitivity of 97% and specificity of 96% for the diagnosis of periprosthetic joint infection, and the combination of synovial fluid α-defensin and CRP tests demonstrated sensitivity of 97% and specificity of 100% for the diagnosis of periprosthetic joint infection.

Radiography

Although radiographs are considered an integral part of the workup of suspected periprosthetic infection, they are neither sensitive nor specific for diagnosing infection [73,77]. The radiographic appearance of an infected TKA can vary from "normal" to subtle periprosthetic lucency to advanced bone destruction. It is often not possible to distinguish infection from loosening or particle disease on the basis of radiographs [18]. Duff et al [15] found radiographs not to be of help because loosening, periostitis, focal osteolysis, and radiolucent lines were seen in both infected and uninfected knees.

If standard radiographs are inconclusive, then oblique or fluoroscopically positioned films may be useful. Fluoroscopically positioned radiographs provide optimal visualization of the prosthesis-bone interface and are

especially helpful in imaging uncemented prostheses [13]. Serial radiographs are important in identifying subtle signs of loosening. However, minor differences in positioning can greatly alter the appearance of the periprosthetic lucencies.

Aspiration

Knee joint aspiration has been found to be extremely useful in diagnosing joint infection after TKA [63,65,78]. 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 evaluated with Gram stain, total and differential cell counts, and aerobic and anaerobic cultures [13,62], although Gram stain has a relatively poor sensitivity and specificity [79]. 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 [80,81]. Toms et al [82] recommended 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. The absence of fluid (ie, "dry tap") at the time of aspiration does not indicate the absence of infection [83].

Duff et al [15] 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 et al [68] 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 et al [63] 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 et al [84] noted that false-negative aspirations may occur in patients who have had preaspiration antibiotic treatment. At least 2 weeks off antibiotics is recommended before the 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 [13]. Therefore, weekly repeat aspirations are recommended 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 et al [69], 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 et al [85] 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 [85]. The AAOS recommends joint aspiration of patients being assessed for periprosthetic knee infections who have abnormal ESR and/or CRP results [66]. The opinion of that group was that repeat knee aspiration should be performed when there is a discrepancy between the probability of periprosthetic joint infection and the initial aspiration culture result [66].

Fluoroscopy

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 [13]. However, this finding by itself is nonspecific for distinguishing between infection and mechanical loosening.

Arthrography

Arthrography is not typically ordered for the workup of suspected TKA infection. Arthrography (with subtraction technique) has been found to have poorer PPVs and NPVs than radiography for detecting loosening [86].

CT

At present, 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 [17,87]. CT with IV contrast could help demonstrate periprosthetic fluid collections and fistulae. Advances in metal artifact reduction may expand the potential role of CT.

MRI

At present, MRI has a limited role in the workup of periprosthetic infection. However, advances in metal artifact reduction may expand the potential role of MR. Using metal reduction techniques, Potter and Foo found that infected synovium has hyperintense laminar appearance, distinct from the appearance of particle disease [20,32]. They noted that in selected cases, MRI may be helpful in detecting extracapsular spread of infection and abscess

formation. IV contrast may be helpful in this regard [32]. On the basis of their findings, Plodkowski et al [37] examined 28 patients with proven infected TKAs and 28 controls with noninfected TKAs and found sensitivity of 86% to 92% and specificity of 85% to 87%, with almost perfect interobserver agreement, when using the appearance of lamellated hyperintense synovitis to classify infected versus noninfected TKAs. MRI with metal artifact reduction techniques has also been shown to detect osteolysis that is not visible on radiographs [40,88].

US
At present, US has a limited role in the workup of periprosthetic infection, but it can be readily used to assess soft tissues and fluid collections about the knee joint in patients with TKA and can be used to guide aspiration of fluid collections about the joint.

Bone Scan
Tc-99m bone scintigraphy is more sensitive than radiographs in the detection of osteomyelitis [89]. However, periprosthetic uptake on bone scan is nonspecific [90] and can be seen because of normal remodeling after prosthesis surgery (for up to 1-2 years or longer) [91], infection, aseptic prosthesis loosening [92], and/or periprosthetic fracture. Normal bone scans have a high NPV and indicate that infection, loosening, or fracture is unlikely.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid scan knee examinations are not the initial tests in the workup of periprosthetic infection.

FDG-PET/CT
FDG-PET/CT whole-body examinations are not the initial tests in the workup of periprosthetic infection.

Variant 4: Pain after total knee arthroplasty. Joint aspiration cultures positive for infection. Additional imaging following radiographs.

According to the AAOS, 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 [66,93]. In that setting, no further imaging is recommended for the diagnostic workup of the infection.

MRI and CT
In certain circumstances, cross-sectional imaging such as MRI or CT might be considered to evaluate the extent of periprosthetic bone marrow (MRI) or soft-tissue (MRI, CT) changes, with the caveat that metal artifact could obscure or distort findings. In the absence of contraindications, IV contrast, particularly in the case of CT, could help distinguish fluid collections from soft-tissue edema.

Fluoroscopy
Knee fluoroscopy is not typically ordered if the joint aspirate culture is positive.

Arthrography
Knee joint arthrography is not typically ordered if the joint aspirate culture is positive.

US
US might also be used to evaluate soft tissues but would require sufficient operator expertise, would not be able to demonstrate bony changes such as osteolysis, fracture or cortical thinning, and would be less conducive to comparing studies from different time points.

Bone Scan
Nuclear medicine studies would not be relevant in this setting unless there was interest in identifying additional sites of infection, in which case a three-phase bone scan and combined WBC leukocyte/sulfur colloid bone marrow scan would be the preferred studies.

Nuclear Medicine
Nuclear medicine studies would not be relevant in this setting unless there was interest in identifying additional sites of infection, in which case a three-phase bone scan and combined WBC leukocyte/sulfur colloid bone marrow scan would be the preferred studies.

FDG-PET/CT
FDG-PET/CT whole-body examinations are not used if the joint aspirate culture is positive, but they can be useful if there is concern for multifocal infection.

Variant 5: Pain after total knee arthroplasty. Joint aspiration culture(s) negative or inconclusive. Suspect infection. Additional imaging following radiographs, including image-guided intervention.

Berbari et al [64] studied 897 cases of periprosthetic joint infection and found that 60 (7%) were associated with negative cultures. Thirty-two of these patients (53%) had received antibiotics in the preceding 3 months.

According to the AAOS guidelines, if the joint aspiration is negative or inconclusive, then repeat aspiration should be attempted. If the repeat aspiration is also negative, then additional assessment of joint fluid and/or frozen section can be performed at surgery. If surgery is not planned, then the AAOS guidelines indicate that various nuclear imaging tests are options for patients in whom the diagnosis of periprosthetic joint infection has not been established [66].

As noted earlier, a variety of nuclear medicine imaging techniques have potential value in evaluating a TKA, and at various points in time, different studies or combinations of studies have been proposed. These studies all involve IV administration of some form of radioactive tracer, with imaging occurring several hours to a day later. In general, these studies are typically more sensitive than radiographs for detection of periprosthetic infection and also have a high NPV for periprosthetic infection. Sensitivities and specificities vary and it is often difficult to compare studies directly because of differences in technique.

Aspiration

According to the AAOS guidelines, if the original joint aspiration is negative or inconclusive, then repeat aspiration should be attempted [66].

Bone Scan

A three-phase bone scan (or bone scintigraphy) involves the IV injection of Tc-99m methylene diphosphonate, followed by gamma camera imaging at three distinct time points: (1) a flow or angiographic phase (immediate dynamic imaging of 2-5 seconds for 60 seconds after methylene diphosphonate administration with imaging centered over the knees to detect asymmetric increased blood flow), (2) a tissue or blood-pool phase (static view immediately after the angiogram and in the same projection to identify increased extracellular fluid in the setting of soft-tissue inflammation), and (3) a delayed or skeletal phase (obtained 2-4 hours after radiopharmaceutical injection to demonstrate increased tracer activity at sites of active new bone formation). The sensitivity of a bone scan is dependent on blood flow and the rate of new bone formation, which are increased in acute osteomyelitis.

It is usually stated that bone scintigraphy is useful for excluding osteomyelitis and hence is useful as a screening study [13,89,94]. Bone scans are also sensitive but not specific in detecting osteomyelitis and cannot differentiate infection from aseptic loosening. A three-phase versus single-phase (a delayed-only skeletal acquisition) bone scan does not improve the accuracy of the test [95]. The accuracy of bone scans, either single-phase or three-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 [96].

Bone scans are more sensitive than radiographs in the detection of orthopedic prosthesis infection [89]. The classic finding for an infected TKA is increased uptake on all 3 phases in the same location (a positive three-phase bone scan) [13]. However, increased uptake is a nonspecific finding and may persist on 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 [89]. In fact, Duff et al [15] reported persistent bone scan activity in the absence of infection 2 years after surgery. However, this activity is not likely to be three-phase positive. Bone scans can potentially be negative with loosening at the cement-prosthetic interface that does not incite new bone formation [46].

Although Love et al [95] report that the use of three-phase bone scintigraphy does not improve the accuracy of the test, Smith et al [90] 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 three-phase bone scan [90]. 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 [95].

When the equipment or expertise is not available for WBC imaging, three-phase bone scans may be valuable, even though their accuracy is lower than that of the WBC or FDG-PET/CT scan [94].

WBC Scan

Leukocyte scanning using In-111 was introduced in the 1980s [97]. WBCs may be radiolabeled in vitro with In-111 oxine or Tc-99m exametazime (Tc-99m-hexamethylpropyleneamineoxime [HMPAO]) [49]. Labeling leukocytes in vitro requires that the patient's venous blood sample be drawn and the WBCs isolated and radiolabeled [98]. The radiolabeled WBCs are then reinjected into the patient [98], with imaging performed 18 to 24 hours after injection of the In-111-radiolabeled WBCs [94]. Comparison of activity on the WBC image with activity on a bone scan (usually a three-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 three-phase bone scan [98]. 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 [98].

Bernard et al [69] reported a multicenter trial of various methods for diagnosing hip and knee infections. Scans using tagged WBCs or radiolabeled immunoglobulin demonstrated sensitivity of 74% and specificity of 76% for diagnosing infection [69]. A literature review indicates sensitivities of 40% to 96% and specificities of 76% to 100% for WBC scans of joint prostheses [49,68,69,98-102]. Therefore, these studies were (as noted earlier) not recommended as routine for differentiating mechanical failure from occult infection in painful loose total knee prostheses.

Filippi et al [103] 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 decreased sensitivity with low-grade infection [46] and a limited neutrophilic component.

Bone Scan

Scher et al [98] used a sequential combination of bone and In-111-labeled leukocyte scans in patients with loose or painful knee prostheses and found sensitivity of 88%, specificity of 78%, PPV of 75%, and NPV of 90% for diagnosis of infection. They recommended against using labeled leukocyte scans in the routine assessment of TKA infection because of the expense and complexity of the examination and because of its limited performance. They noted a small 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 where an experienced musculoskeletal pathologist is not available to interpret an intraoperative frozen section.

Nuclear Medicine

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 [50,95]. The addition of Tc-99m-labeled sulfur colloid bone marrow scanning has been investigated to reduce this confusion. Palestro et al [48] 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 [50], however, 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 sensitivity of 66%, specificity of 100%, PPV of 100%, NPV of 88%, and an accuracy of 91%. 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, however, the performance of the labeled leukocyte marrow scan protocol was nonetheless thought to be of limited clinical utility [50].

In contrast, Love et al [47] found the combination of In-111-labeled leukocyte/Tc-99m-labeled sulfur colloid marrow scanning to be the gold standard for diagnosing periprosthetic infection [47]. These authors found the combination of labeled WBC and marrow scanning to be 100% sensitive and 100% specific for diagnosing infection in TKAs [47]. Semiquantitative assessment of WBC scans using a combination of early and delayed imaging as a substitute for bone marrow imaging produced >90% sensitivity and specificity in one series [49]. Love et al [104] examined 150 failed joint prostheses with histopathologic correlation and found that leukocyte/marrow imaging yielded sensitivity of 96%, specificity of 87%, and 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.

FDG-PET/CT

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 metabolic activity. Zhuang et al [105] reported that elevated glycolytic activity causes inflammatory cells such as neutrophils and activated macrophages to be FDG avid at sites of inflammation and infection.

An FDG-PET scan takes less time (a few hours) to complete than the combined bone, radiolabeled WBC, and marrow studies [105]. Additionally, FDG-PET requires a single radiopharmaceutical injection and no handling of blood products [94]. One disadvantage of PET imaging is greater equipment maintenance [94]. Some periprosthetic uptake may occur because of marrow activity, and adding marrow scanning can increase specificity [47]. 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, 511 keV; Tc-99m, 140 keV). In the United States, FDG-PET is not approved for reimbursement for imaging of inflammation and infection.

Zhuang et al [105] 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 [106] found a PPV of 28% (15 of 54) for infection in 54 patients with painful joint arthroplasty (24 knee, 48 hip) using FDG-PET. Van Acker et al [107] 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 [47]. Manthey et al [108] reported that by analyzing intensity and periprosthetic uptake patterns on FDG-PET, accurate differentiation among aseptic loosening, synovitis, and infection is possible. Kwee et al [109], 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 [110], 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 [111] performed a meta-analysis of the diagnostic performance of different radiotracers in peripheral osteomyelitis and prosthetic joint infections, yielding results for FDG-PET sensitivity of 94%, specificity of 87%, PPV of 87%, NPV of 94%, and overall accuracy of 92%. Although metal artifacts have very little impact on nuclear medicine examinations (except as photopenic defects) and create negligible scatter [105,112,113], FDG-PET would be expected to introduce CT-based metal artifact into the CT imaging portion of the fused FDG-PET study and potentially metallic high-density artifact on the FDG-PET attenuation-corrected images.

FDG uptake is not specific for infection. Synovitis and aseptic loosening (in hip prostheses) may cause increased FDG uptake [47]. Sterner et al [114] examined 14 patients with painful TKAs to detect early aseptic loosening. Overall accuracy was 71% (sensitivity, 100%; specificity, 56%). In addition, Stumpe et al [115] 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 [116]. Noting the lack of specificity for detection of periprosthetic infection on conventional FDG-PET, Aksoy et al [106] explored the use of FDG-labeled leukocyte PET/CT for imaging patients with painful joint prostheses and found sensitivity of 93%, specificity of 97%, PPV of 93%, and NPV of 97%. However, this examination is not in general use.

Other Radionuclide Studies

Antigranulocyte scintigraphy and Tc-99m-labeled interleukin-8 scintigraphy are additional nuclear medicine studies that have been explored for assessment of infection. These agents are not currently available, even on an investigational basis, in the United States [117,118].

CT

At present, 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 [17,87]. CT with IV contrast could help demonstrate periprosthetic fluid collections and fistulae. Advances in metal artifact reduction may expand the potential role of CT.

MRI
At present, MRI has a limited role in the workup of periprosthetic infection. However, using metal reduction techniques, Potter and Foo found that infected synovium has hyperintense laminar appearance, distinct from the appearance of particle disease [20,32]. They noted that in selected cases MRI may be helpful in detecting extracapsular spread of infection and abscess formation. IV contrast may be helpful in this regard [32]. On the basis of their findings, Plodkowski et al [37] examined 28 patients with proven infected TKAs and 28 controls with noninfected TKAs and found sensitivity 86% to 92% and specificity of 85% to 87%, with almost perfect interobserver agreement, when using the appearance of lamellated hyperintense synovitis to classify infected versus noninfected TKAs.

Fluoroscopy
Fluoroscopy is not typically ordered in this setting.

Arthrography
Arthrography is not typically ordered in this setting.

US
At present, US has a limited role in the workup of periprosthetic infection, but it can be readily used to assess soft tissues and fluid collections about the knee joint in patients with TKA and can be used to guide aspiration of fluid collections about the joint.

Variant 6: Pain after total knee arthroplasty. Negative studies for infection. Suspect aseptic loosening. Additional imaging following radiographs.

If a patient has undergone a full workup and infection has been substantially excluded, then loosening should be considered as a potential cause of knee pain and periprosthetic lucency. In multiple studies, aseptic loosening has been found to be a common cause of TKA failure [10,119-121]. Starkey et al [10] found aseptic loosening to be the major cause of late (>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, and sometimes poor bone stock [18]. Loosening is closely related to other forms of mechanical failure such as osteolysis, instability, polyethylene liner wear, and periprosthetic fracture.

Fluoroscopy
Fluoroscopy may be useful to see lucent lines in profile that could be obscured on standard AP radiographs [17,122,123] and can also be useful for demonstrating loosening under real-time manipulation.

Arthrography
Arthrography (with subtraction technique) has been found to have poorer PPV and NPV than radiography for detecting loosening [86].

Bone Scan
Bone scintigraphy may be helpful in diagnosing loosening, especially when obtained many years after surgery [92]. This delay in maximum utility is due to the observation that positive bone scans are noted in 20% of asymptomatic knees a year after surgery and in 12.5% of individuals 2 years postoperatively [91]. Serial bone scans are more helpful than a single examination [124]. 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 [90]. 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 [46].

Smith et al [90] evaluated 80 bone scans in patients with symptomatic TKAs, 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. However, the test was not specific in that it was unable to distinguish between aseptic loosening and infection [90]. If infection is excluded by other studies, loosening of the tibial component may be detected using quantitative analysis of bone scintigraphy, with sensitivity of 90% and specificity of 100% [125].

FDG-PET/CT
Sterner et al [114] examined 14 patients with painful TKAs using FDG-PET to detect early aseptic loosening. Overall accuracy was 71% (sensitivity, 100%; specificity, 56%). Delank et al [110], 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 [110].

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid scan knee scans are not typically obtained for evaluation of aseptic knee prosthetic loosening.

MRI
To date, MRI has not been validated for use in the detection of implant loosening. Using metal artifact reduction techniques, Fritz et al [32] 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. The use of IV contrast in this context has not been described.

CT
CT, particularly when metal artifact reduction techniques are used, can be used to show the extent and width of lucent zones that may be less apparent on radiographs [17]. IV contrast is not required for CT assessment of aseptic loosening.

US
US has no significant role in assessing for aseptic prosthesis loosening.

Variant 7: Pain after total knee arthroplasty. Negative studies for infection. Suspect granulomas/osteolysis. Additional imaging following radiographs.

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 from polyethylene, cement, and metal can all be causes of cell-mediated inflammatory response and osteolysis [126], but typically polyethylene is the most common cause. Areas of osteolysis contain granulation tissue with phagocytosed particulate debris [18]. The incidence of osteolysis is higher for cementless, compared with cemented, TKAs [127]. 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 [127,128].

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 surgery [129]. Imaging can also help evaluate available bone stock in preparation for revision surgery. MRI and CT have both been shown to be more sensitive for detection of osteolysis than radiographs [129].

Fluoroscopy
Fluoroscopy can be useful in optimally positioning the joint for detection of radiographic osteolysis [122,123].

Arthrography
Arthrography is not typically used in this setting.

CT
CT can be used to detect osteolysis and to determine the total volume of osteolytic lesions, particularly when metal reduction techniques are used [130]. CT is recommended by Math et al [17] 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 [87] found that only 17% of 48 lesions visible by CT were detected on radiographs. They recommended multidetector CT in cases where osteolysis is expected, such as when there is aseptic loosening and gross polyethylene wear. IV contrast is not required for CT assessment of osteolysis.

MRI
MRI with metal artifact reduction techniques can detect osteolysis that is not visible on radiographs, even around the femoral component [88]. An MRI investigation of 11 TKAs 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 [40]. MRI can also show synovial changes due to particle disease before osteolytic lesions become apparent [20]. IV contrast is not required for MRI assessment of osteolysis.

US
US is not typically used for the assessment of osteolysis. In experienced hands, US can be used to evaluate synovitis and soft tissues about the joint and to guide joint aspiration [131].

Bone Scan
The three-phase bone scan is moderately sensitive (76%) in identifying the failed joint prosthesis but with specificity of only 51% and an accuracy of 50% to 70% [132]. A positive three-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.

The bone scan, however, can be useful as a screening test, with a high NPV with one caveat. A false-negative or normal bone scan may potentially occur if there is loosening at the cement-prosthetic interface without inciting new bone formation [46]. Math et al [17] 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 value of a contralateral asymptomatic TKA as a comparative control. On the other hand, 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 [133]. In any event, with a positive three-phase bone scan, WBC and marrow imaging are needed to delineate between infection and aseptic loosening, the latter of which can be related to particle disease.

Nuclear Medicine
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 [134]. A negative WBC scan negates an acute neutrophilic infection but may be falsely negative in chronic infection [99]. Love et al [104] reported WBC/marrow sensitivity, specificity, and accuracy as 96%, 87%, and 91%, respectively, for 150 total hip and knee replacements. Joseph et al [50] reported preoperative WBC/marrow imaging in 58 total hip and knee replacements with sensitivity, specificity, and accuracy of 46%, 100%, and 88%, respectively. Palestro et al [48,135] described greater than 90% accuracy and 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 [46]. 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 three-phase bone scan because a negative WBC/marrow study does not include aseptic loosening [46].

FDG-PET/CT
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 inflammation and infection because of activated lymphocytes, neutrophils, and macrophages.

Jansen et al [46] reported that postoperative remodeling can be seen as nonspecific periprosthetic uptake in the first 6 months after arthroplasty. A negative FDG study has a high NPV for loosening related to particle disease, which incites a granulomatous response. As with bone scans, a false-negative scan may be seen if loosening occurs at the cement-prosthetic interface [46]. Increased FDG activity is sensitive but cannot differentiate between

TKA infection and loosening [132]. 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 [136]. Although FDG is reportedly limited in evaluating patients with chronic knee pain post-TKA [46,134], with further advancements FDG may potentially be a promising tool in identifying prosthetic osteolysis [136]. Its exact role in the failed joint prosthesis, however, has yet to be determined.

Variant 8: Pain after total knee arthroplasty. Clinical concern for instability.

Instability, one of the most common causes of early TKA failure, refers to abnormal and excessive displacement of the articular surfaces of the prosthesis [18]. Instability usually occurs because of surgical error and poor prosthesis selection and often results in revision surgery an average of 4 years after primary arthroplasty [18]. Severe instability can result in dislocation. In a 2014 review of 781 cases of prosthesis failure, Sharkey et al [10] found that instability represented the third most common cause of prosthesis failure overall, accounting for 7.5% of all cases. Assessment of instability is based on radiographs and CT, with radiographs providing the advantage of obtaining weight-bearing and stress views.

As noted earlier, instability refers abnormal and excessive displacement of articular surfaces of a prosthesis, and is evaluated on images 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) [137], and is evaluated on full length standing radiographs of the lower extremity [18]. In fact, the concepts of instability, malalignment, and loosening in TKA are closely interrelated [138]. When malalignment of the joint is created at the time of surgery, then 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—and can be affected by—joint instability, it is not the only factor accounting for stability or the lack thereof [139].

Radiography
Weight-bearing AP radiographs of the knee allow for assessment of coronal plane alignment of the knee in routine follow-up of TKA. Full-length (hip-to-ankle) weight-bearing radiographs are used to accurately assess the weight-bearing mechanical axis in patients with suspected lower limb malalignment [14]. AP radiographs during unilateral weight bearing help to evaluate for the presence of wear. Lateral radiographs with the knee in full extension (to assess for posterior subluxation and recurvatum and for tibial slope in a posterior cruciate–retaining prosthesis) and maximum flexion are obtained [18]. Varus and valgus stress views help in evaluation of collateral ligament integrity and help determine whether deformities are reducible. Anterior and posterior drawer dynamic radiographs are used to assess for flexion-extension gap discrepancies.

Fluoroscopy
Fluoroscopy facilitates dynamic assessment of the knee under stress.

Arthrography
Arthrography is not typically used for assessment of instability.

CT
CT allows the assessment of rotational positioning of the prosthesis components, which can affect patellofemoral tracking and varus/valgus ligamentous stability in flexion [140]. Imaging of rotational instability of a TKA is discussed in greater detail under Variant 11. IV contrast is not required for CT assessment of instability.

MRI
When effective metal suppression can be used, MRI can allow direct visualization of ligaments and tendons about the knee [32]. Use of MRI for imaging of rotational instability of a TKA is discussed in greater detail under Variant 11. IV contrast is not required for MRI assessment of instability.

US
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 a TKA.

Bone Scan
Tc-99m three-phase bone scan studies are not typically used for assessment of instability.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid studies are not typically used for assessment of instability.

FDG-PET/CT
FDG-PET/CT studies are not typically used for assessment of instability.

Variant 9: Pain after total knee arthroplasty. Suspect periprosthetic fracture.

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 [141,142]. Supracondylar fractures occur in 0.3% to 2.5% of TKAs, usually within 2 to 4 years after surgery, and often occur in the setting of low-energy trauma [142]. 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, with 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.

Radiography
Radiographs are the initial examination for assessment of suspected periprosthetic fractures. Images should include the entire prosthesis as well as some surrounding bone.

Fluoroscopy
Fluoroscopy is not typically used for assessment of periprosthetic fractures.

Arthrography
Arthrography is not typically used for assessment of periprosthetic fractures.

CT and MRI
Radiographically occult fractures may be detected on CT [17] or on MRI [20] when metal artifact reduction techniques are used. IV contrast is not required for CT or MRI assessment of periprosthetic fracture.

Bone Scan
Radionuclide three-phase bone scans can demonstrate increased activity at a site of periprosthetic fracture and can show fractures that are radiographically occult [143,144]. In older osteopenic individuals with low rates of bone remodeling, it may take 48 to 72 hours for 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.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid studies are not typically used for assessment of periprosthetic fractures.

FDG-PET/CT
FDG-PET/CT studies are not typically used for assessment of periprosthetic fractures.

US
US is not typically used for assessment of periprosthetic fractures.

Variant 10: Status post total knee arthroplasty. Suspect complications related to the patella or the patellar liner (subluxation, dislocation, fracture, component loosening or wear, impingement, and osteonecrosis).

Patellar complications after TKA include subluxation, dislocation, fracture [145], component loosening or wear, impingement, and osteonecrosis [146,147]. In one series of 1272 consecutive radiographic examinations, patellar complications were found in 3.6% of cases [148]. According to Meding et al [147], patellar fractures occur in up to 5.2% of patients, usually within the first few postoperative years [146]. Most are not associated with prior injury, and many are asymptomatic, highlighting the importance of radiography for their identification [146]. Transverse fractures are thought to be associated with patellar maltracking, whereas vertical fractures often occur through a fixation hole [146].

Patellar component loosening or failure is uncommon but requires revision when it occurs. Failure of the patellar component was more common with older metal-polyethylene components [149-151]. Failure of the patellar

resurfacing component can result in metal-on-metal contact and can go on to global joint failure [18]. When the patella has not been resurfaced, patellar remodeling can occur and may result in anterior knee pain or fracture [152].

Patellofemoral instability can occur from imbalance in the extensor mechanism characterized by excessive tightness of the lateral retinaculum, component malrotation, or valgus alignment of the extensor retinaculum. The incidence of patellofemoral instability after TKA is 1% to 12% [153], likely most often due to internal malrotation of the femoral and/or tibial components [154].

Radiography
Radiographs are usually satisfactory for assessment of patellar complications [17] and are helpful in guiding treatment [155]. Axial radiographs demonstrate the degree of patellar tilt or subluxation [18]. Baldini et al [156] recommended a weight-bearing axial radiograph to better assess patellofemoral kinematics.

Arthrography
Arthrography is not typically used for assessment of patellar complications.

Fluoroscopy
Fluoroscopy is not typically used for assessment of patellar complications.

CT and MRI
When metal artifact reduction techniques are used, patellar complications may be detectable on CT [17] or on MRI [20,32]. IV contrast is not required for CT or MRI assessment of patellar complications.

US
US is not typically used for assessment of patellar complications.

Bone Scan
Tc-99m three-phase bone scans are not typically used for assessment of patellar complications.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid studies are not typically used for assessment of patellar complications.

FDG-PET/CT
FDG-PET/CT studies are not typically used for assessment of patellar complications.

Variant 11: Pain after total knee arthroplasty. Measuring component rotation.

Malposition of femoral and tibial components may affect patellar alignment [154]. Excessive combined internal rotation of tibial and femoral components has been shown to be associated with patellar complications [154]. Moreover, Berger and Rubash [157] found that the amount of excessive combined internal rotation is directly proportional to the severity of patellofemoral complications.

Radiography
Although axial radiographs may be used to determine axial rotation of the femoral component [158], CT is most commonly used for this purpose.

Arthrography
Arthrography is not typically used for assessment of rotational alignment of a TKA.

Fluoroscopy
Fluoroscopy is not typically used for assessment of rotational alignment of a TKA.

CT
As noted, CT is the modality most commonly used for measuring axial malrotation of a knee prosthesis [24]. Jazrawi et al [24] 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 [17,24,154]. Femoral component rotation may be assessed in relation to the transepicondylar axis [154,157], the Whiteside line [159], or the posterior femoral condyles [154,159]. Berger et al constructed the transepicondylar axis from the lateral epicondyle to the trough in the medial epicondyle [154,157]. 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) [158].

According to Berger and Rubash [157] 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. IV contrast is not required for CT assessment of rotational alignment. Three-dimensional CT studies may also be used for assessing component rotation [160].

MRI
When adequate metal reduction techniques are used, MRI can also be used to assess TKA component rotation [161]. Anatomic landmarks and axes required for measurement of rotational alignment parameters can be identified [42,162]. In a study of 50 patients with painful TKAs and 16 controls, Murakami et al [162] 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. IV contrast is not required for MR assessment of rotational alignment.

US
US is not used for the assessment of rotational alignment of a TKA.

Bone Scan
Tc-99m three-phase bone scans are not used for the assessment of rotational alignment of a TKA.

Nuclear Medicine
In-111 WBC and Tc-99m sulfur colloid studies are not used for the assessment of rotational alignment of a TKA.

FDG-PET/CT
FDG-PET/CT studies are not used for the assessment of rotational alignment of a TKA.

Variant 12: 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).

The incidence of quadriceps or patellar tendon tears after TKA is low, at 0.17% to 2.5% [163]. Sharkey et al [10] 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 in Lombardi et al [120] series. Additional periprosthetic soft-tissue causes of postoperative knee pain are also uncommon and include impingement of nerves or other soft tissues.

Radiography
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 [18,164].

MRI
MRI that uses robust metal reduction techniques can be used for evaluation of quadriceps or patellar tendinopathy in patients with TKA [165] and for evaluation of arthrofibrosis [32]. MRI can also demonstrate suprapatellar arthrofibrosis that can be associated with post-TKA patellar clunk syndrome [42]. In addition, MRI can be used for the workup of periarticular soft-tissue masses, including neoplastic masses and inflammatory pseudotumors [166].

US
US can be used for evaluation of quadriceps or patellar tendinopathy [148], postsurgical arthrofibrosis [167], and periarticular soft-tissue masses in patients with TKA.

Fluoroscopy
Fluoroscopy is not typically used for assessment of periprosthetic soft-tissue abnormalities.

Arthrography
Arthrography is not typically used for assessment of periprosthetic soft-tissue abnormalities.

CT
CT is not typically used for assessment of periprosthetic soft-tissue abnormalities.

Bone Scan
Tc-99m three-phase bone scans are not typically used for assessment of periprosthetic soft-tissue abnormalities.

Nuclear Medicine

In-111 WBC and Tc-99m sulfur colloid studies are not used for the assessment of periprosthetic soft-tissue abnormalities.

FDG-PET/CT

FDG-PET/CT studies are not used for the assessment of periprosthetic soft-tissue abnormalities.

Other 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.

Summary of Recommendations

- For follow-up of the asymptomatic patient with a TKA, knee radiographs should be obtained.
- For measuring component wear after TKA, radiographs are usually appropriate.
- In assessment of patients with pain after TKA, including potential periprosthetic infection, initial imaging should consist of a knee radiograph, if not previously obtained, followed by aspiration of the knee joint.
- In assessment of patients with pain after TKA, when joint aspiration cultures are positive for infection, the AAOS guidelines indicate that no additional imaging is required and patients will typically proceed to surgery.
- In assessment of patients with pain after TKA, when joint aspiration cultures are negative or inconclusive for infection but when infection is nonetheless suspected and radiographs have been obtained, reaspiration of the knee is usually appropriate and is recommended by AAOS guidelines.
- In assessment of patients with pain after TKA, when aspiration and other studies are negative for infection and aseptic loosening is suspected, if radiographs have already been obtained, then CT without IV contrast is usually appropriate.
- In assessment of patients with pain after TKA, when aspiration and other studies are negative for infection and granuloma/osteolysis is suspected, if radiographs have already been obtained, then CT of the knee without IV contrast is usually appropriate.
- In assessment of patients with pain after TKA, when conventional instability (not rotational instability) is suspected and the possibility of infection has been excluded, then knee radiographs are usually appropriate. Fluoroscopy is usually appropriate as a potential supplement to radiographs to directly visualize motion of an unstable prosthesis.
- In assessment of patients with pain after TKA, when periprosthetic fracture is suspected, knee radiographs and knee CT without IV contrast are both usually appropriate. Radiographs would typically be obtained as the first imaging study.
- In assessment of patients with pain after TKA, when complications related to the patella or patellar liner are suspected, knee radiographs are usually appropriate.
- In assessment of patients with pain after TKA, when component malrotation is suspected, CT without IV contrast is usually appropriate and is currently the preferred modality.
- In assessment of patients with pain after TKA, when a soft-tissue abnormality other than infection is suspected (eg, quadriceps or patellar tendon tears, postoperative arthrofibrosis, or impingement of nerves or other soft tissues), MRI (metal artifact reduction techniques should be employed) without IV contrast and US are 2 alternative imaging modalities, either one of which is considered usually appropriate.

Summary of Evidence

Of the 168 references cited in the *ACR Appropriateness Criteria® Imaging After Total Knee Arthroplasty* document, 26 are categorized as therapeutic references including 7 good-quality studies. Additionally, 140 references are categorized as diagnostic references including 16 good-quality studies, and 51 quality studies that may have design limitations. There are 92 references that may not be useful as primary evidence. There are 2 references that are meta-analysis studies.

The 168 references cited in the *ACR Appropriateness Criteria® Imaging After Total Knee Arthroplasty* document were published from 1986-2016.

While there are references that report on studies with design limitations, 23 good quality studies provide good evidence.

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, both because of 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 to 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 [168].

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".		

Supporting Documents

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

References

1. Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR. Total knee arthroplasty volume, utilization, and outcomes among Medicare beneficiaries, 1991-2010. *JAMA*. 2012;308(12):1227-1236.
2. Daigle ME, Weinstein AM, Katz JN, Losina E. The cost-effectiveness of total joint arthroplasty: a systematic review of published literature. *Best Pract Res Clin Rheumatol.* 2012;26(5):649-658.
3. Agency for Healthcare Research and Quality (AHRQ). Healthcare Cost and Utilization Project (HCUP). http://www.ahrq.gov/research/data/hcup/index.html. Accessed March 1, 2017.
4. Mulcahy H, Chew FS. Current concepts in knee replacement: features and imaging assessment. *AJR Am J Roentgenol.* 2013;201(6):W828-842.
5. Weinstein AM, Rome BN, Reichmann WM, et al. Estimating the burden of total knee replacement in the United States. *J Bone Joint Surg Am.* 2013;95(5):385-392.
6. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am.* 2007;89(4):780-785.
7. Losina E, Thornhill TS, Rome BN, Wright J, Katz JN. The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic. *J Bone Joint Surg Am.* 2012;94(3):201-207.
8. Seil R, Pape D. Causes of failure and etiology of painful primary total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(9):1418-1432.

9. Kurtz S, Mowat F, Ong K, Chan N, Lau E, Halpern M. Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002. *J Bone Joint Surg Am.* 2005;87(7):1487-1497.
10. Sharkey PF, Lichstein PM, Shen C, Tokarski AT, Parvizi J. Why are total knee arthroplasties failing today--has anything changed after 10 years? *J Arthroplasty.* 2014;29(9):1774-1778.
11. Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM. Insall Award paper. Why are total knee arthroplasties failing today? *Clin Orthop Relat Res.* 2002(404):7-13.
12. Dennis DA. Evaluation of painful total knee arthroplasty. *J Arthroplasty.* 2004;19(4 Suppl 1):35-40.
13. Mandalia V, Eyres K, Schranz P, Toms AD. Evaluation of patients with a painful total knee replacement. *J Bone Joint Surg Br.* 2008;90(3):265-271.
14. Skytta ET, Lohman M, Tallroth K, Remes V. Comparison of standard anteroposterior knee and hip-to-ankle radiographs in determining the lower limb and implant alignment after total knee arthroplasty. *Scand J Surg.* 2009;98(4):250-253.
15. Duff GP, Lachiewicz PF, Kelley SS. Aspiration of the knee joint before revision arthroplasty. *Clin Orthop Relat Res.* 1996(331):132-139.
16. Malchau H, Potter HG. How are wear-related problems diagnosed and what forms of surveillance are necessary? *J Am Acad Orthop Surg.* 2008;16 Suppl 1:S14-19.
17. Math KR, Zaidi SF, Petchprapa C, Harwin SF. Imaging of total knee arthroplasty. *Semin Musculoskelet Radiol.* 2006;10(1):47-63.
18. Mulcahy H, Chew FS. Current concepts in knee replacement: complications. *AJR Am J Roentgenol.* 2014;202(1):W76-86.
19. Nadaud MC, Fehring TK, Fehring K. Underestimation of osteolysis in posterior stabilized total knee arthroplasty. *J Arthroplasty.* 2004;19(1):110-115.
20. Potter HG, Foo LF. Magnetic resonance imaging of joint arthroplasty. *Orthop Clin North Am.* 2006;37(3):361-373, vi-vii.
21. Zotti MG, Campbell DG, Woodman R. Detection of periprosthetic osteolysis around total knee arthroplasties an in vitro study. *J Arthroplasty.* 2012;27(2):317-322.
22. Glaser D, Lotke P. Cost-effectiveness of immediate postoperative radiographs after uncomplicated total knee arthroplasty: a retrospective and prospective study of 750 patients. *J Arthroplasty.* 2000;15(4):475-478.
23. Niskanen RO. Early repetitive radiography is unnecessary after an uncomplicated cemented hip or knee arthroplasty for osteoarthritis. *Acta Orthop Belg.* 2005;71(6):692-695.
24. Jazrawi LM, Birdzell L, Kummer FJ, Di Cesare PE. The accuracy of computed tomography for determining femoral and tibial total knee arthroplasty component rotation. *J Arthroplasty.* 2000;15(6):761-766.
25. Bamberg F, Dierks A, Nikolaou K, Reiser MF, Becker CR, Johnson TR. Metal artifact reduction by dual energy computed tomography using monoenergetic extrapolation. *Eur Radiol.* 2011;21(7):1424-1429.
26. Coupal TM, Mallinson PI, Gershony SL, et al. Getting the Most From Your Dual-Energy Scanner: Recognizing, Reducing, and Eliminating Artifacts. *AJR Am J Roentgenol.* 2016;206(1):119-128.
27. Gupta A, Subhas N, Primak AN, Nittka M, Liu K. Metal artifact reduction: standard and advanced magnetic resonance and computed tomography techniques. *Radiol Clin North Am.* 2015;53(3):531-547.
28. Kataoka ML, Hochman MG, Rodriguez EK, Lin PJ, Kubo S, Raptopolous VD. A review of factors that affect artifact from metallic hardware on multi-row detector computed tomography. *Curr Probl Diagn Radiol.* 2010;39(4):125-136.
29. Pessis E, Campagna R, Sverzut JM, et al. Virtual monochromatic spectral imaging with fast kilovoltage switching: reduction of metal artifacts at CT. *Radiographics.* 2013;33(2):573-583.
30. Subhas N, Primak AN, Obuchowski NA, et al. Iterative metal artifact reduction: evaluation and optimization of technique. *Skeletal Radiol.* 2014;43(12):1729-1735.
31. Zhou C, Zhao YE, Luo S, et al. Monoenergetic imaging of dual-energy CT reduces artifacts from implanted metal orthopedic devices in patients with factures. *Acad Radiol.* 2011;18(10):1252-1257.
32. Fritz J, Lurie B, Potter HG. MR Imaging of Knee Arthroplasty Implants. *Radiographics.* 2015;35(5):1483-1501.
33. Hayter CL, Koff MF, Shah P, Koch KM, Miller TT, Potter HG. MRI after arthroplasty: comparison of MAVRIC and conventional fast spin-echo techniques. *AJR Am J Roentgenol.* 2011;197(3):W405-411.

34. Koch KM, Brau AC, Chen W, et al. Imaging near metal with a MAVRIC-SEMAC hybrid. *Magn Reson Med.* 2011;65(1):71-82.
35. Koch KM, Lorbiecki JE, Hinks RS, King KF. A multispectral three-dimensional acquisition technique for imaging near metal implants. *Magn Reson Med.* 2009;61(2):381-390.
36. Lu W, Pauly KB, Gold GE, Pauly JM, Hargreaves BA. SEMAC: Slice Encoding for Metal Artifact Correction in MRI. *Magn Reson Med.* 2009;62(1):66-76.
37. Plodkowski AJ, Hayter CL, Miller TT, Nguyen JT, Potter HG. Lamellated hyperintense synovitis: potential MR imaging sign of an infected knee arthroplasty. *Radiology.* 2013;266(1):256-260.
38. Potter HG, Nestor BJ, Sofka CM, Ho ST, Peters LE, Salvati EA. Magnetic resonance imaging after total hip arthroplasty: evaluation of periprosthetic soft tissue. *J Bone Joint Surg Am.* 2004;86-A(9):1947-1954.
39. Sutter R, Hodek R, Fucentese SF, Nittka M, Pfirrmann CW. Total knee arthroplasty MRI featuring slice-encoding for metal artifact correction: reduction of artifacts for STIR and proton density-weighted sequences. *AJR Am J Roentgenol.* 2013;201(6):1315-1324.
40. Vessely MB, Frick MA, Oakes D, Wenger DE, Berry DJ. Magnetic resonance imaging with metal suppression for evaluation of periprosthetic osteolysis after total knee arthroplasty. *J Arthroplasty.* 2006;21(6):826-831.
41. Li AE, Sneag DB, Greditzer HGt, Johnson CC, Miller TT, Potter HG. Total Knee Arthroplasty: Diagnostic Accuracy of Patterns of Synovitis at MR Imaging. *Radiology.* 2016;281(2):499-506.
42. Heyse TJ, Chong le R, Davis J, Boettner F, Haas SB, Potter HG. MRI analysis of the component-bone interface after TKA. *Knee.* 2012;19(4):290-294.
43. Guillin R, Laporte JL, Sabouret P, Cardinal E. Polyethylene wear in knee arthroplasty: a new sonographic sign. *J Ultrasound Med.* 2008;27(2):275-279.
44. Sofka CM, Adler RS, Laskin R. Sonography of polyethylene liners used in total knee arthroplasty. *AJR Am J Roentgenol.* 2003;180(5):1437-1441.
45. Boutchichi A, Ciornohac J, Daubresse F. Pseudoaneurysm after total knee arthroplasty: a rare complication with different possible clinical presentations. *Acta Orthop Belg.* 2013;79(1):16-19.
46. Jansen JA, Smit F, Pereira Arias-Bouda LM. The role of nuclear medicine techniques indifferentiation between septic and aseptic loosening of total hip and knee arthroplasty. *Tijdschr Nucl Geneesk.* 2012;34(4):988-994.
47. Love C, Marwin SE, Tomas MB, et al. Diagnosing infection in the failed joint replacement: a comparison of coincidence detection 18F-FDG and 111In-labeled leukocyte/99mTc-sulfur colloid marrow imaging. *J Nucl Med.* 2004;45(11):1864-1871.
48. Palestro CJ, Swyer AJ, Kim CK, Goldsmith SJ. Infected knee prosthesis: diagnosis with In-111 leukocyte, Tc-99m sulfur colloid, and Tc-99m MDP imaging. *Radiology.* 1991;179(3):645-648.
49. Pelosi E, Baiocco C, Pennone M, et al. 99mTc-HMPAO-leukocyte scintigraphy in patients with symptomatic total hip or knee arthroplasty: improved diagnostic accuracy by means of semiquantitative evaluation. *J Nucl Med.* 2004;45(3):438-444.
50. Joseph TN, Mujtaba M, Chen AL, et al. Efficacy of combined technetium-99m sulfur colloid/indium-111 leukocyte scans to detect infected total hip and knee arthroplasties. *J Arthroplasty.* 2001;16(6):753-758.
51. Ververeli PA, Masonis JL, Booth RE, Hozack WJ, Rothman RH. Radiographic cost reduction strategy in total joint arthroplasty. A prospective analysis. *J Arthroplasty.* 1996;11(3):277-280.
52. Hassan S, Wall A, Ayyaswamy B, Rogers S, Mills SP, Charalambous CP. Is there a need for early post-operative x-rays in primary total knee replacements? Experience of a centre in the UK. *Ann R Coll Surg Engl.* 2012;94(3):199-200.
53. Kosashvili Y, Alvi M, Mayne IP, Safir O, Gross A, Backstein D. Immediate recovery room radiographs after primary total knee arthroplasty-why do we keep doing them? *Int Orthop.* 2010;34(8):1167-1173.
54. Brown EC, 3rd, Clarke HD, Scuderi GR. The painful total knee arthroplasty: diagnosis and management. *Orthopedics.* 2006;29(2):129-136; quiz 137-128.
55. Clarke HD, Math KR, Scuderi GR. Polyethylene post failure in posterior stabilized total knee arthroplasty. *J Arthroplasty.* 2004;19(5):652-657.
56. Teeny SM, York SC, Mesko JW, Rea RE. Long-term follow-up care recommendations after total hip and knee arthroplasty: results of the American Association of Hip and Knee Surgeons' member survey. *J Arthroplasty.* 2003;18(8):954-962.

57. Collier MB, Jewett BA, Engh CA, Jr. Clinical assessment of tibial polyethylene thickness: comparison of radiographic measurements with as-implanted and as-retrieved thicknesses. *J Arthroplasty.* 2003;18(7):860-866.
58. Hide IG, Grainger AJ, Wallace IW, Hui A, Campbell RS. A radiological technique for the assessment of wear in prosthetic knee replacements. *Skeletal Radiol.* 2000;29(10):583-586.
59. Sanzen L, Sahlstrom A, Gentz CF, Johnell IR. Radiographic wear assessment in a total knee prosthesis. 5- to 9-year follow-up study of 158 knees. *J Arthroplasty.* 1996;11(6):738-742.
60. Yashar AA, Adler RS, Grady-Benson JC, Matthews LS, Freiberg AA. An ultrasound method to evaluate polyethylene component wear in total knee replacement arthroplasty. *Am J Orthop (Belle Mead NJ).* 1996;25(10):702-704.
61. Bradshaw DA, Lam B, Hoffman R, Zicat B. Case report: Total knee arthroplasty polyethylene liner disengagement identified by arthrography. *Knee.* 2014;21(6):1288-1290.
62. Del Pozo JL, Patel R. Clinical practice. Infection associated with prosthetic joints. *N Engl J Med.* 2009;361(8):787-794.
63. Bach CM, Sturmer R, Nogler M, Wimmer C, Biedermann R, Krismer M. Total knee arthroplasty infection: significance of delayed aspiration. *J Arthroplasty.* 2002;17(5):615-618.
64. Berbari EF, Marculescu C, Sia I, et al. Culture-negative prosthetic joint infection. *Clin Infect Dis.* 2007;45(9):1113-1119.
65. Leone JM, Hanssen AD. Management of infection at the site of a total knee arthroplasty. *J Bone Joint Surg Am.* 2005;87(10):2335-2348.
66. American Academy of Orthpaedic Surgeons. The Diagnosis of Periprosthetic Joint Infections of the Hip and Knee. Guidelines and Evidence Report. 2010; http://www.aaos.org/research/guidelines/PJIguideline.pdf. Accessed March 1, 2017.
67. Magnuson JE, Brown ML, Hauser MF, Berquist TH, Fitzgerald RH, Jr., Klee GG. In-111-labeled leukocyte scintigraphy in suspected orthopedic prosthesis infection: comparison with other imaging modalities. *Radiology.* 1988;168(1):235-239.
68. Virolainen P, Lahteenmaki H, Hiltunen A, Sipola E, Meurman O, Nelimarkka O. The reliability of diagnosis of infection during revision arthroplasties. *Scand J Surg.* 2002;91(2):178-181.
69. Bernard L, Lubbeke A, Stern R, et al. Value of preoperative investigations in diagnosing prosthetic joint infection: retrospective cohort study and literature review. *Scand J Infect Dis.* 2004;36(6-7):410-416.
70. Savarino L, Tigani D, Baldini N, Bochicchio V, Giunti A. Pre-operative diagnosis of infection in total knee arthroplasty: an algorithm. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(6):667-675.
71. Di Cesare PE, Chang E, Preston CF, Liu CJ. Serum interleukin-6 as a marker of periprosthetic infection following total hip and knee arthroplasty. *J Bone Joint Surg Am.* 2005;87(9):1921-1927.
72. Bottner F, Wegner A, Winkelmann W, Becker K, Erren M, Gotze C. Interleukin-6, procalcitonin and TNF-alpha: markers of peri-prosthetic infection following total joint replacement. *J Bone Joint Surg Br.* 2007;89(1):94-99.
73. Bauer TW, Parvizi J, Kobayashi N, Krebs V. Diagnosis of periprosthetic infection. *J Bone Joint Surg Am.* 2006;88(4):869-882.
74. Deirmengian C, Kardos K, Kilmartin P, Cameron A, Schiller K, Parvizi J. Diagnosing periprosthetic joint infection: has the era of the biomarker arrived? *Clin Orthop Relat Res.* 2014;472(11):3254-3262.
75. Deirmengian C, Kardos K, Kilmartin P, Cameron A, Schiller K, Parvizi J. Combined measurement of synovial fluid alpha-Defensin and C-reactive protein levels: highly accurate for diagnosing periprosthetic joint infection. *J Bone Joint Surg Am.* 2014;96(17):1439-1445.
76. Deirmengian C, Kardos K, Kilmartin P, Gulati S, Citrano P, Booth RE, Jr. The Alpha-defensin Test for Periprosthetic Joint Infection Responds to a Wide Spectrum of Organisms. *Clin Orthop Relat Res.* 2015;473(7):2229-2235.
77. Miller TT. Imaging of knee arthroplasty. *Eur J Radiol.* 2005;54(2):164-177.
78. Squire MW, Della Valle CJ, Parvizi J. Preoperative diagnosis of periprosthetic joint infection: role of aspiration. *AJR Am J Roentgenol.* 2011;196(4):875-879.
79. Chimento GF, Finger S, Barrack RL. Gram stain detection of infection during revision arthroplasty. *J Bone Joint Surg Br.* 1996;78(5):838-839.
80. Mason JB, Fehring TK, Odum SM, Griffin WL, Nussman DS. The value of white blood cell counts before revision total knee arthroplasty. *J Arthroplasty.* 2003;18(8):1038-1043.

81. Trampuz A, Hanssen AD, Osmon DR, Mandrekar J, Steckelberg JM, Patel R. Synovial fluid leukocyte count and differential for the diagnosis of prosthetic knee infection. *Am J Med.* 2004;117(8):556-562.
82. Toms AD, Davidson D, Masri BA, Duncan CP. The management of peri-prosthetic infection in total joint arthroplasty. *J Bone Joint Surg Br.* 2006;88(2):149-155.
83. Ali F, Wilkinson JM, Cooper JR, et al. Accuracy of joint aspiration for the preoperative diagnosis of infection in total hip arthroplasty. *J Arthroplasty.* 2006;21(2):221-226.
84. Barrack RL, Jennings RW, Wolfe MW, Bertot AJ. The Coventry Award. The value of preoperative aspiration before total knee revision. *Clin Orthop Relat Res.* 1997(345):8-16.
85. Della Valle CJ, Sporer SM, Jacobs JJ, Berger RA, Rosenberg AG, Paprosky WG. Preoperative testing for sepsis before revision total knee arthroplasty. *J Arthroplasty.* 2007;22(6 Suppl 2):90-93.
86. Marx A, Saxler G, Landgraeber S, Loer F, Holland-Letz T, von Knoch M. Comparison of subtraction arthrography, radionuclide arthrography and conventional plain radiography to assess loosening of total knee arthroplasty. *Biomed Tech (Berl).* 2005;50(5):143-147.
87. Reish TG, Clarke HD, Scuderi GR, Math KR, Scott WN. Use of multi-detector computed tomography for the detection of periprosthetic osteolysis in total knee arthroplasty. *J Knee Surg.* 2006;19(4):259-264.
88. Mosher TJ, Davis CM, 3rd. Magnetic resonance imaging to evaluate osteolysis around total knee arthroplasty. *J Arthroplasty.* 2006;21(3):460-463.
89. Gemmel F, Van den Wyngaert H, Love C, Welling MM, Gemmel P, Palestro CJ. Prosthetic joint infections: radionuclide state-of-the-art imaging. *Eur J Nucl Med Mol Imaging.* 2012;39(5):892-909.
90. Smith SL, Wastie ML, Forster I. Radionuclide bone scintigraphy in the detection of significant complications after total knee joint replacement. *Clin Radiol.* 2001;56(3):221-224.
91. Duus BR, Boeckstyns M, Stadeager C. The natural course of radionuclide bone scanning in the evaluation of total knee replacement--a 2 year prospective study. *Clin Radiol.* 1990;41(5):341-343.
92. Kantor SG, Schneider R, Insall JN, Becker MW. Radionuclide imaging of asymptomatic versus symptomatic total knee arthroplasties. *Clin Orthop Relat Res.* 1990(260):118-123.
93. Garvin KL, Konigsberg BS. Infection following total knee arthroplasty: prevention and management. *J Bone Joint Surg Am.* 2011;93(12):1167-1175.
94. Reinartz P. FDG-PET in patients with painful hip and knee arthroplasty: technical breakthrough or just more of the same. *Q J Nucl Med Mol Imaging.* 2009;53(1):41-50.
95. Love C, Marwin SE, Palestro CJ. Nuclear medicine and the infected joint replacement. *Semin Nucl Med.* 2009;39(1):66-78.
96. Palestro CJ. Nuclear medicine and the failed joint replacement: Past, present, and future. *World J Radiol.* 2014;6(7):446-458.
97. Pring DJ, Henderson RG, Rivett AG, Krausz T, Coombs RR, Lavender JP. Autologous granulocyte scanning of painful prosthetic joints. *J Bone Joint Surg Br.* 1986;68(4):647-652.
98. Scher DM, Pak K, Lonner JH, Finkel JE, Zuckerman JD, Di Cesare PE. The predictive value of indium-111 leukocyte scans in the diagnosis of infected total hip, knee, or resection arthroplasties. *J Arthroplasty.* 2000;15(3):295-300.
99. Glithero PR, Grigoris P, Harding LK, Hesslewood SR, McMinn DJ. White cell scans and infected joint replacements. Failure to detect chronic infection. *J Bone Joint Surg Br.* 1993;75(3):371-374.
100. Rand JA, Brown ML. The value of indium 111 leukocyte scanning in the evaluation of painful or infected total knee arthroplasties. *Clin Orthop Relat Res.* 1990(259):179-182.
101. Rosas MH, Leclercq S, Pegoix M, et al. Contribution of laboratory tests, scintigraphy, and histology to the diagnosis of lower limb joint replacement infection. *Rev Rhum Engl Ed.* 1998;65(7-9):477-482.
102. Teller RE, Christie MJ, Martin W, Nance EP, Haas DW. Sequential indium-labeled leukocyte and bone scans to diagnose prosthetic joint infection. *Clin Orthop Relat Res.* 2000(373):241-247.
103. Filippi L, Schillaci O. Usefulness of hybrid SPECT/CT in 99mTc-HMPAO-labeled leukocyte scintigraphy for bone and joint infections. *J Nucl Med.* 2006;47(12):1908-1913.
104. Love C, Tronco G, Yu A, Marwin S, Nichols K, Palestro C. Diagnosing lower extremity (LE) prosthetic joint infection: Bone, gallium & labeled leukocyte imaging. *Journal of Nuclear Medicine.* 2008;49(supplement 1):133P.
105. Zhuang H, Duarte PS, Pourdehnad M, et al. The promising role of 18F-FDG PET in detecting infected lower limb prosthesis implants. *J Nucl Med.* 2001;42(1):44-48.
106. Aksoy SY, Asa S, Ozhan M, et al. FDG and FDG-labelled leucocyte PET/CT in the imaging of prosthetic joint infection. *Eur J Nucl Med Mol Imaging.* 2014;41(3):556-564.

107. Van Acker F, Nuyts J, Maes A, et al. FDG-PET, 99mtc-HMPAO white blood cell SPET and bone scintigraphy in the evaluation of painful total knee arthroplasties. *Eur J Nucl Med.* 2001;28(10):1496-1504.
108. Manthey N, Reinhard P, Moog F, Knesewitsch P, Hahn K, Tatsch K. The use of [18 F]fluorodeoxyglucose positron emission tomography to differentiate between synovitis, loosening and infection of hip and knee prostheses. *Nucl Med Commun.* 2002;23(7):645-653.
109. Kwee TC, Kwee RM, Alavi A. FDG-PET for diagnosing prosthetic joint infection: systematic review and metaanalysis. *Eur J Nucl Med Mol Imaging.* 2008;35(11):2122-2132.
110. Delank KS, Schmidt M, Michael JW, Dietlein M, Schicha H, Eysel P. The implications of 18F-FDG PET for the diagnosis of endoprosthetic loosening and infection in hip and knee arthroplasty: results from a prospective, blinded study. *BMC Musculoskelet Disord.* 2006;7:20.
111. Prandini N, Lazzeri E, Rossi B, Erba P, Parisella MG, Signore A. Nuclear medicine imaging of bone infections. *Nucl Med Commun.* 2006;27(8):633-644.
112. Chacko TK, Zhuang H, Nakhoda KZ, Moussavian B, Alavi A. Applications of fluorodeoxyglucose positron emission tomography in the diagnosis of infection. *Nucl Med Commun.* 2003;24(6):615-624.
113. Schober O, Heindel W. *PET-CT Hybrid Imaging.* 1st ed. Stuttgart/New York: Thieme; 2008.
114. Sterner T, Pink R, Freudenberg L, et al. The role of [18F]fluoride positron emission tomography in the early detection of aseptic loosening of total knee arthroplasty. *Int J Surg.* 2007;5(2):99-104.
115. Stumpe KD, Romero J, Ziegler O, et al. The value of FDG-PET in patients with painful total knee arthroplasty. *Eur J Nucl Med Mol Imaging.* 2006;33(10):1218-1225.
116. Zhuang H, Chacko TK, Hickeson M, et al. Persistent non-specific FDG uptake on PET imaging following hip arthroplasty. *Eur J Nucl Med Mol Imaging.* 2002;29(10):1328-1333.
117. Bleeker-Rovers CP, Rennen HJ, Boerman OC, et al. 99mTc-labeled interleukin 8 for the scintigraphic detection of infection and inflammation: first clinical evaluation. *J Nucl Med.* 2007;48(3):337-343.
118. Gratz S, Behr TM, Reize P, Pfestroff A, Kampen WU, Hoffken H. (99m)Tc-Fab' fragments (sulesomab) for imaging septically loosened total knee arthroplasty. *J Int Med Res.* 2009;37(1):54-67.
119. Dalury DF, Pomeroy DL, Gorab RS, Adams MJ. Why are total knee arthroplasties being revised? *J Arthroplasty.* 2013;28(8 Suppl):120-121.
120. Lombardi AV, Jr., Berend KR, Adams JB. Why knee replacements fail in 2013: patient, surgeon, or implant? *Bone Joint J.* 2014;96-B(11 Supple A):101-104.
121. Thiele K, Perka C, Matziolis G, Mayr HO, Sostheim M, Hube R. Current failure mechanisms after knee arthroplasty have changed: polyethylene wear is less common in revision surgery. *J Bone Joint Surg Am.* 2015;97(9):715-720.
122. Fehring TK, McAvoy G. Fluoroscopic evaluation of the painful total knee arthroplasty. *Clin Orthop Relat Res.* 1996(331):226-233.
123. Mintz AD, Pilkington CA, Howie DW. A comparison of plain and fluoroscopically guided radiographs in the assessment of arthroplasty of the knee. *J Bone Joint Surg Am.* 1989;71(9):1343-1347.
124. Hofmann AA, Wyatt RW, Daniels AU, Armstrong L, Alazraki N, Taylor A, Jr. Bone scans after total knee arthroplasty in asymptomatic patients. Cemented versus cementless. *Clin Orthop Relat Res.* 1990(251):183-188.
125. Klett R, Steiner D, Laurich S, Bauer R, Kordelle J. Evaluation of aseptic loosening of knee prostheses by quantitative bone scintigraphy. *Nuklearmedizin.* 2008;47(4):163-166.
126. Archibeck MJ, Jacobs JJ, Roebuck KA, Glant TT. The basic science of periprosthetic osteolysis. *Instr Course Lect.* 2001;50:185-195.
127. Gupta SK, Chu A, Ranawat AS, Slamin J, Ranawat CS. Osteolysis after total knee arthroplasty. *J Arthroplasty.* 2007;22(6):787-799.
128. Gonzalez MH, Mekhail AO. The failed total knee arthroplasty: evaluation and etiology. *J Am Acad Orthop Surg.* 2004;12(6):436-446.
129. Sneag DB, Bogner EA, Potter HG. Magnetic resonance imaging evaluation of the painful total knee arthroplasty. *Semin Musculoskelet Radiol.* 2015;19(1):40-48.
130. Buckwalter KA, Parr JA, Choplin RH, Capello WN. Multichannel CT Imaging of Orthopedic Hardware and Implants. *Semin Musculoskelet Radiol.* 2006;10(1):86-97.
131. Sofka CM, Potter HG, Adler RS, Pavlov H. Musculoskeletal imaging update: current applications of advanced imaging techniques to evaluate the early and long-term complications of patients with orthopedic implants. *HSS J.* 2006;2(1):73-77.

132. Love C, Tomas MB, Marwin SE, Pugliese PV, Palestro CJ. Role of nuclear medicine in diagnosis of the infected joint replacement. *Radiographics.* 2001;21(5):1229-1238.
133. Rosenthall L, Lepanto L, Raymond F. Radiophosphate uptake in asymptomatic knee arthroplasty. *J Nucl Med.* 1987;28(10):1546-1549.
134. Segura AB, Munoz A, Brulles YR, et al. What is the role of bone scintigraphy in the diagnosis of infected joint prostheses? *Nucl Med Commun.* 2004;25(5):527-532.
135. Palestro CJ, Kim CK, Swyer AJ, Capozzi JD, Solomon RW, Goldsmith SJ. Total-hip arthroplasty: periprosthetic indium-111-labeled leukocyte activity and complementary technetium-99m-sulfur colloid imaging in suspected infection. *J Nucl Med.* 1990;31(12):1950-1955.
136. Kandahari AM, Yang X, Laroche KA, Dighe AS, Pan D, Cui Q. A review of UHMWPE wear-induced osteolysis: the role for early detection of the immune response. *Bone Res.* 2016;4:16014.
137. Benjamin J. Component alignment in total knee arthroplasty. *Instr Course Lect.* 2006;55:405-412.
138. Moreland JR. Mechanisms of failure in total knee arthroplasty. *Clin Orthop Relat Res.* 1988(226):49-64.
139. Parratte S, Pagnano MW. Instability after total knee arthroplasty. *J Bone Joint Surg Am.* 2008;90(1):184-194.
140. Yercan HS, Ait Si Selmi T, Sugun TS, Neyret P. Tibiofemoral instability in primary total knee replacement: A review Part 2: diagnosis, patient evaluation, and treatment. *Knee.* 2005;12(5):336-340.
141. Dennis D, Komistek R, Scuderi G, et al. In vivo three-dimensional determination of kinematics for subjects with a normal knee or a unicompartmental or total knee replacement. *J Bone Joint Surg Am.* 2001;83-A Suppl 2 Pt 2:104-115.
142. Yoo JD, Kim NK. Periprosthetic fractures following total knee arthroplasty. *Knee Surg Relat Res.* 2015;27(1):1-9.
143. Cross MB, Nam D, van der Meulen MC, Bostrom MP. A rare case of a bisphosphonate-induced peri-prosthetic femoral fracture. *J Bone Joint Surg Br.* 2012;94(7):994-997.
144. Nam D, Abdel MP, Cross MB, et al. The management of extensor mechanism complications in total knee arthroplasty. AAOS exhibit selection. *J Bone Joint Surg Am.* 2014;96(6):e47.
145. Keating EM, Haas G, Meding JB. Patella fracture after post total knee replacements. *Clin Orthop Relat Res.* 2003(416):93-97.
146. Chun KA, Ohashi K, Bennett DL, El-Khoury GY. Patellar fractures after total knee replacement. *AJR Am J Roentgenol.* 2005;185(3):655-660.
147. Meding JB, Fish MD, Berend ME, Ritter MA, Keating EM. Predicting patellar failure after total knee arthroplasty. *Clin Orthop Relat Res.* 2008;466(11):2769-2774.
148. Melloni P, Valls R, Veintemillas M. Imaging patellar complications after knee arthroplasty. *Eur J Radiol.* 2008;65(3):478-482.
149. Bayley JC, Scott RD, Ewald FC, Holmes GB, Jr. Failure of the metal-backed patellar component after total knee replacement. *J Bone Joint Surg Am.* 1988;70(5):668-674.
150. Kelly MA. Patellofemoral complications following total knee arthroplasty. *Instr Course Lect.* 2001;50:403-407.
151. Piraino D, Richmond B, Freed H, Belhobek G, Schils J, Stulberg B. Total knee replacement: radiologic findings in failure of porous-coated metal-backed patellar component. *AJR Am J Roentgenol.* 1990;155(3):555-558.
152. Meneghini RM. Should the patella be resurfaced in primary total knee arthroplasty? An evidence-based analysis. *J Arthroplasty.* 2008;23(7 Suppl):11-14.
153. Eisenhuth SA, Saleh KJ, Cui Q, Clark CR, Brown TE. Patellofemoral instability after total knee arthroplasty. *Clin Orthop Relat Res.* 2006;446:149-160.
154. Berger RA, Crossett LS, Jacobs JJ, Rubash HE. Malrotation causing patellofemoral complications after total knee arthroplasty. *Clin Orthop Relat Res.* 1998(356):144-153.
155. Parvizi J, Kim KI, Oliashirazi A, Ong A, Sharkey PF. Periprosthetic patellar fractures. *Clin Orthop Relat Res.* 2006;446:161-166.
156. Baldini A, Anderson JA, Zampetti P, Pavlov H, Sculco TP. A new patellofemoral scoring system for total knee arthroplasty. *Clin Orthop Relat Res.* 2006;452:150-154.
157. Berger RA, Rubash HE. Rotational instability and malrotation after total knee arthroplasty. *Orthop Clin North Am.* 2001;32(4):639-647, ix.
158. Kanekasu K, Kondo M, Kadoya Y. Axial radiography of the distal femur to assess rotational alignment in total knee arthroplasty. *Clin Orthop Relat Res.* 2005(434):193-197.

159. Whiteside LA, Arima J. The anteroposterior axis for femoral rotational alignment in valgus total knee arthroplasty. *Clin Orthop Relat Res.* 1995(321):168-172.
160. Roper GE, Bloemke AD, Roberts CC, Spangehl MJ, Clarke HD. Analysis of tibial component rotation following total knee arthroplasty using 3D high definition computed tomography. *J Arthroplasty.* 2013;28(8 Suppl):106-111.
161. Griffin FM, Math K, Scuderi GR, Insall JN, Poilvache PL. Anatomy of the epicondyles of the distal femur: MRI analysis of normal knees. *J Arthroplasty.* 2000;15(3):354-359.
162. Murakami AM, Hash TW, Hepinstall MS, Lyman S, Nestor BJ, Potter HG. MRI evaluation of rotational alignment and synovitis in patients with pain after total knee replacement. *J Bone Joint Surg Br.* 2012;94(9):1209-1215.
163. Schoderbek RJ, Jr., Brown TE, Mulhall KJ, et al. Extensor mechanism disruption after total knee arthroplasty. *Clin Orthop Relat Res.* 2006;446:176-185.
164. Allen AM, Ward WG, Pope TL, Jr. Imaging of the total knee arthroplasty. *Radiol Clin North Am.* 1995;33(2):289-303.
165. Sofka CM, Potter HG, Figgie M, Laskin R. Magnetic resonance imaging of total knee arthroplasty. *Clin Orthop Relat Res.* 2003(406):129-135.
166. Kenan S, Kahn L, Haramati N. A rare case of pseudotumor formation associated with methyl methacrylate hypersensitivity in a patient following cemented total knee arthroplasty. *Skeletal Radiol.* 2016;45(8):1115-1122.
167. Boldt JG, Munzinger UK, Zanetti M, Hodler J. Arthrofibrosis associated with total knee arthroplasty: gray-scale and power Doppler sonographic findings. *AJR Am J Roentgenol.* 2004;182(2):337-340.
168. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: http://www.acr.org/~/media/ACR/Documents/AppCriteria/RadiationDoseAssessmentIntro.pdf. Accessed March 1, 2017.