Total knee replacement (total knee arthroplasty) is performed to restore function and relieve pain in patients with severely damaged knees. The surgery involves replacement of both the medial and lateral femorotibial joints and the patellofemoral joint. Although total knee replacement is an effective treatment, postoperative complications include blood clots, infection, and loosening or malalignment of the prosthetic component. Medical imaging plays a critical role in preoperative evaluation, surgical planning, and follow-up.

After completing this article, the reader should be able to:

- Discuss reasons for total knee replacement (TKR) and TKR revision surgery.
- Compare variations in common types of prosthetic components and surgical fixation techniques.
- Explain the role of medical imaging in preoperative diagnosis, TKR planning, and postoperative follow-up.
- Discuss the importance of accurate patient positioning for successful surgical outcome.
- Describe radiographic evidence of TKR complications.

Total knee replacement (TKR), also called total knee arthroplasty, is a common surgical procedure, with more than 1.5 million procedures completed annually worldwide. By the year 2030, this number is expected to increase to 3.48 million. TKR is performed to relieve pain and regain proper function of severely damaged knees by replacing all 3 knee joint compartments: the medial and lateral femorotibial joints and the patellofemoral joint. Severe damage to the knee joint is most commonly caused by arthritis but also can result from injury.

Some indications for TKR include severe knee pain or stiffness that limits a patient’s ability to carry out simple activities such as walking, knee pain while at rest, chronic swelling, knee deformity, or failure of conservative treatments such as anti-inflammatory medication, intra-articular injection, physical therapy, or less invasive surgery. The goals of TKR are to repair bony abnormalities and soft tissue imbalances.

Improvements in implant designs, materials, and patient education since the first TKR surgery in 1968 have made it a highly successful procedure. However, 18% to 30% of patients are dissatisfied after joint replacement surgery. This could be because of complications such as infection, loosening or malalignment of the prosthetic component, or unmet expectations of the surgical outcomes. Some studies indicate that preoperative arthritis severity is directly related to postoperative patient satisfaction, but other studies indicate that factors such as duration of symptoms, higher body mass index (BMI), younger age, female sex, degree of functional loss, and poor response to other therapeutic interventions are equally important, even when radiographic evidence of osteoarthritis is minimal. Pre-existing extra-articular fracture deformities of the femur or tibia also might hinder proper...
restoration of the mechanical axis, which can cause postoperative problems.\textsuperscript{11}

Conventional radiography is used preoperatively to evaluate the level of disease in the patient’s knees. Most surgeons require true anteroposterior (AP), lateral, and tangential patellar (skyline or sunrise) projections to determine the level of disease present, as well as an AP full-leg length projection to assess alignment.\textsuperscript{12} Imaging during surgery aids in accurate placement of implants and limb alignment and can include fluoroscopy or computed tomography (CT). Standard postoperative care includes serial AP, lateral, and tangential radiographs taken at follow-up visits but also might require fluoroscopy, CT, magnetic resonance (MR) imaging, nuclear medicine, and positron emission tomography (PET)-CT to evaluate complications. CT or MR images also might be used to create customized implants and cutting guides for patients with anatomy that is unusually sized or shaped.

Knee Anatomy and Biomechanics

The knee joint is one of the most complex joints in the human body.\textsuperscript{4} It is a synovial modified-hinge joint with 3 articulations, one between each of the femoral condyles (medial and lateral) and the opposing condylar surfaces of the tibia, and one between the patella and the trochlear groove of the femur (see Figure 1).\textsuperscript{4,13}

The medial and lateral condyles of the distal femur vary in size and location in the coronal plane.\textsuperscript{14} The larger medial condyle is wider in the coronal plane. The patella is located superior to the patellar surface of the femur and just lateral to the midline of the knee joint in full extension.\textsuperscript{14} It transitions through an arc-shaped path in a distal and medial direction with flexion and is fixed in position on the patellar surface of the femur when the knee is flexed 90°.\textsuperscript{15,16}

The knee joint is held together by a group of ligaments that include the posterior cruciate ligament, anterior cruciate ligament, tibial collateral ligament, and fibular collateral ligament.\textsuperscript{5,16} Articular cartilage lines surfaces of the bones where they meet.\textsuperscript{5} In addition, 2 fibrocartilage disks (the lateral and medial menisci) are located between the femur and tibia. The menisci absorb shock and provide joint stability (see Figure 2).\textsuperscript{16} A synovial membrane, which releases a lubricating synovial fluid, covers the rest of the surfaces in the knee joint.\textsuperscript{4}

The knee has the ability to move with 6 degrees of freedom throughout normal activity.\textsuperscript{3,8,16} Three degrees of freedom are translational, and 3 are rotational. Translational degrees of freedom allow 5 mm to 10 mm of movement in the anteroposterior direction, 2 mm to 5 mm of compression-distraction, and 1 mm to 2 mm in mediolateral shift. The rotational movements of the knee are flexion-extension, varus (inward)-valgus (outward) angulation, and internal-external rotation. The degree of internal-external rotation is limited by the position in which the knee is in flexion or extension (see Figure 3). The more extended the knee, the less it
is able to rotate in the internal-external direction. This wide range of motion is not yet entirely duplicated with TKR.

In part, the knee joint is susceptible to damage because it is located between the 2 longest bones in the skeleton, requiring the ligaments and capsular structures to support great loads. When the knee joint is damaged from trauma or disease, symptoms such as pain, muscle weakness, and limited function can arise.

**Indications**

Patients who undergo TKR are typically between 50 and 80 years of age and suffer from osteoarthritis; however, rheumatoid and post-traumatic arthritis also are known to cause severe symptoms. Osteoarthritis occurs when the cartilage between the bones wears down and the bones rub together; it most often is found in people older than 50 years. Systemic factors and local mechanical factors influence the degree of osteoarthritis symptoms. Systemic factors for osteoarthritis include age, sex, ethnicity, metabolic syndrome, and genetic factors; local mechanical factors include obesity, joint injury, and muscle weakness. Rheumatoid arthritis is a disease that results in cartilage loss from an inflamed synovial membrane. Post-traumatic arthritis can occur after a major injury to the knee, such as fracture to bones surrounding the joint or ligament tears, which often result in damage to the articular cartilage.

Deformity that necessitates TKR can be described as extra-articular or intra-articular. Most arthritis-related intra-articular deformities are due to bone loss. Intra-articular deformities and soft tissue damage of the knee can be repaired with standard TKR (see Figure 4). Extra-articular deformity can be classified as congenital, metabolic, traumatic, or surgical. Extra-articular deformities from fracture malunion or nonunion, or from metabolic disease of the femur or tibia, might require extra attention in surgical planning and can be described as coronal, sagittal, or rotational. The location of the extra-articular deformity, its degree, and the complexity of soft tissue imbalance are factors in the selection of implant design and surgical technique. For example, a surgical approach using a long-stemmed prosthesis in combination with an osteotomy to remove deformed bone can accomplish both the repair of the knee joint as well as the mechanical axis of the limb (see Figure 5).

**Diagnostic Imaging**

Along with a complete medical history, physical examination, and blood tests, diagnostic imaging is used to determine whether a patient is a candidate for TKR surgery. Radiographs also are obtained...
throughout the immediate postoperative and annual follow-up visits or any time there is pain or suspicion of failure.²,¹⁹ Postoperative radiographic images are unnecessary if the surgery was uncomplicated, but routine radiographs at the first outpatient visit at 6 weeks are suggested.² Other imaging modalities such as CT, MR imaging, ultrasonography, and fluoroscopy also might be used during follow-up to assess any pain or complications.¹²

**Conventional Radiography**

Plain radiographs are valuable for diagnostic assessment of TKR because they are inexpensive, readily available, noninvasive, and offer a low radiation dose to patients of 0.001 mSv per view.⁸,¹⁸ Some studies indicate that the severity of osteoarthritis on preoperative radiographs is a predictor for the patient’s perceived improvement of health-related quality of life after TKR.⁴ Patients are more likely to be satisfied with TKR results when they present with radiographic evidence of severe osteoarthritis.⁸ Surgeons use radiographs to reveal bony abnormalities, joint space narrowing, prosthesis fit on the bone, and alignment of the knees.¹⁴,¹⁶,¹⁹ Radiographs of the knee replacement are standard for follow-up, and the postoperative examination might be considered incomplete and insufficient without them.⁴,²² Serial radiographs following TKR might allow the surgeon to predict implant failure.

**Figure 4.** A. Knee with severe osteoarthritis. B. A total knee replacement. The arthritic cartilage and underlying bone has been removed and resurfaced with metal implants on the femur and tibia. A plastic spacer has been placed between the implants. For clarity, the patella is not shown. Reproduced with permission from OrthoInfo. Copyright American Academy of Orthopaedic Surgeons. http://orthoinfo.aaos.org.

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**Figure 5.** Anteroposterior (AP) views of a left knee before and after total knee replacement (TKR) revision surgery using a long-stemmed prosthesis. A. AP view of left knee before revision demonstrating lateral subluxation of the tibia and fibula relative to the femur. The density within the distal femur is an antibiotic spacer, and the rectangular fragment along the lateral aspect of the proximal fibula a fracture fragment. B. AP view of the same left knee after revision surgery demonstrating adequate anatomic alignment. Images courtesy of April Apple, R.T.(R), FASRT, Duke Health Systems, Department of Radiology, Durham, NC.
much sooner than when the patient presents with symptoms.22

With more than 600,000 TKR surgeries performed annually in the United States, image quality has a tremendous effect on patient care for this population.4,19 Accurate positioning is essential for proper evaluation of healing and functionality of the knee replacement.19 Errors in alignment measurements and pathological changes can occur unless the technologist precisely reproduces positioning at each examination.5,28 When possible, weight-bearing images should be obtained because they can offer information about the laxity of ligaments, joint space loss, and postoperative polyethylene wear (see Figure 6).22,23 In addition, problems such as gradual loosening might be measured precisely with serial radiographs of consistent quality.19

Preoperative images typically include the weight-bearing AP, true lateral, skyline of the patellae, and the AP full-leg length views.24 Some physicians include the posteroanterior (PA) weight-bearing (tunnel) view and a variety of stress views, depending upon the specific condition.24

The American Knee Society reports that AP and lateral radiographs should be used to evaluate alignment after TKR.12 The skyline view of the patellofemoral joint also might be requested.22 Both the short AP and hip-knee-ankle AP radiographs can be used to evaluate coronal alignment of the prosthetic components.22 A full-leg length radiograph with the patient bearing weight should be included following TKR for better determination of limb alignment, position of components, and quality of the prosthesis/bone interface.12,25 When this image is unavailable, AP short films of the complete femur (from hip to knee) and tibia (from knee to ankle) that include both proximal and distal joints to the long bones can be used to evaluate component position in relation to the mechanical axis.22 The short images can be stitched together to offer a full-leg length view of the limb, but this method does not offer the same level of accuracy for alignment interpretation.23

Traditionally, alignment measurements on radiographs have been made with a ruler and protractor. However, with digital imaging and patient archiving and communication systems (PACS) software, it is

![Figure 6. A. The AP nonweight-bearing knee shows small marginal osteophytes and mild narrowing of the medial compartment. B. The weight-bearing projection shows nearly complete joint space loss. Images courtesy of Gary Mlady, MD, chief medical director, musculoskeletal radiology, University of New Mexico Health Sciences Center, Albuquerque, NM.](image)
possible to measure alignment digitally.\textsuperscript{11} The degree of varus or valgus deformity of the limb is evaluated by comparing where the knee lies along a line drawn from the ankle to the femoral head on the AP full-leg length image. Normal alignment is present when the knee is located along this line. If the knee is located medial to this line, a valgus deformity is present, whereas a varus deformity exists if the knee is lateral to this line.\textsuperscript{11}

Alignment of the replacement components in the sagittal plane is evaluated with a lateral radiograph. The position of the femoral component is determined by the angle between the midshaft of the femur and the neutral line of the femoral component and is called the \textit{flexion/extension angle}.\textsuperscript{12} The angle used to measure the position of the tibial component is called the tibial slope. It is measured between a line drawn through the midshaft of the tibia and one tangential to the tibial component.\textsuperscript{12} Ideally, there is no overhang of the components beyond the condylar surfaces, which could lead to postoperative pain.\textsuperscript{12}

The position of the joint line often is different after TKR, which can cause limited range of motion and patellar pain.\textsuperscript{15} The joint line can be measured on either the AP or lateral radiograph with a variety of reference points used by surgeons. When the AP view is used, the femoral epicondyles often are used as a reference. On the lateral view, surgeons might choose to use the tip of the fibular head or the lower pole of the patella to the proximal tibial surface.\textsuperscript{15} For revision TKR, the postoperative joint line should be compared to the preoperative anatomic joint line, not the one measured after primary arthroplasty has occurred. When original preoperative images are not available, the joint-line position of the opposite knee can be used as a reference if it has not undergone arthroplasty.\textsuperscript{16}

Innovations in automated measurement methods using digital radiography have improved evaluation of failing knee replacements. These innovations include edge detection and active shape modeling.\textsuperscript{12} With edge detection, the knee joint space is measured based on boundaries set according to changes in brightness.\textsuperscript{12} Active shape modeling constructs a knee shape based on selected landmarks from the radiographic images; then the model is compared to serial images to analyze changes in shape.\textsuperscript{12}

Anteroposterior Weight-bearing Projection

The AP weight-bearing projection requires the patient to stand with his or her back to a vertical grid device with the feet and patellae facing straight ahead.\textsuperscript{16,19} The feet should be placed wide enough for the patient to balance with his or her weight equally distributed, and the knees should be fully extended.\textsuperscript{16} The technologist might need to rotate the affected knee, either internally or externally, if the patella naturally shifts during weight bearing.\textsuperscript{16} The goal is to place the femoral condyles equidistant from the cassette.\textsuperscript{15} The central ray should be perpendicular to the knee and centered 0.5 inch beneath the patellae apices.\textsuperscript{16} When a patient is unable to fully extend the knee, the central ray should be placed perpendicular to the anterior lower leg surface, then decreased by about 5°. This will place the central ray parallel to the tibial plateau.\textsuperscript{15}

On the preoperative AP projection, the medial and lateral femoral epicondyles should be in profile with the intercondylar eminence centered within the intercondylar fossa (see Figure 7).\textsuperscript{15} When the patient’s leg is over-rotated internally, the lateral femoral condyle will appear larger than the medial femoral condyle and the head of the fibula will not be superimposed by the tibia.\textsuperscript{15} Alternatively, when the patient’s leg is under-rotated, the medial femoral condyle will appear larger than the lateral femoral condyle and the fibular head and neck will be superimposed by the tibia.\textsuperscript{19}

With accurate positioning, the AP weight-bearing projection of the postoperative knee replacement will demonstrate the femoral component with symmetrical alignment of the medial and lateral femoral condyles with the patella in the middle, the tibial tray between the femur and tibia, and the tibial component and head of the fibula just behind the tibia (see Figure 8).\textsuperscript{19} If poor positioning is used, the knee will appear at an oblique angle such that the condyles are rotated and the joint space is obscured.\textsuperscript{19} In addition, the tilt of the base-plate component on AP radiographs can be measured to evaluate the consistency of patient positioning.\textsuperscript{17}

Joint space narrowing is evaluated by measuring the medial and lateral compartments of the femoro-tibial joint.\textsuperscript{19} Measurements between the distal femoral condylar surface and the posterior condylar margin of the tibia are obtained for both compartments.
A lateral compartment that is narrower than the medial compartment indicates a valgus deformity. The opposite is true for a varus deformity in which the medial compartment is narrower than the lateral compartment. If the patella appears to be laterally displaced on the radiograph, the technologist should make sure the knee is not rotated because this can mimic patellar subluxation.

When the AP view is used to evaluate the position of the joint line, it is found by drawing a tangential straight line between the most distal points of the femoral condyles when the knee is in extension. Ideally, the distance between the joint line and a tangential line connecting the epicondyles (transepicondylar axis) is preserved after TKR. To ensure accurate measurements, the radiographic magnification factor must be determined. This factor can be found by placing a ruler with radiopaque markers at a known distance on the skin of the patient’s distal thigh. Then the distance measured between the radiopaque marks along the ruler on the radiograph is divided by the known distance. Surgeons can use the magnification factor to select an appropriately sized prosthesis and to determine the proper location of surgical cuts for the prosthesis.

Weight-bearing Lateral Projection

A weight-bearing lateral projection should be used whenever possible; however, a recumbent lateral position can be obtained with the patient lying on the affected side, with the affected knee bent 15° to 30° and the unaffected leg placed across and above the affected joint. The radiographer can place a positioning sponge under the heel

Figure 7. Preoperative AP weight-bearing projection. Image courtesy of April Apple, R.T.(R), FASRT, Duke Health Systems, Department of Radiology, Durham, NC.

Figure 8. A. Knee replacement prosthesis positioned for a true AP projection. B. Radiograph of a true AP projection obtained with the patient standing shows the medial and lateral femoral condyles symmetrically aligned. C. Prosthetic improperly aligned for a true AP projection. D. Radiograph showing a standing AP projection of the knees that is not a true AP view. Images courtesy of MGH REMS Media Services.
on the affected side to obtain a more accurate lateral position. It might be necessary to have the patient roll posteriorly if the knee is tilted toward the table.\textsuperscript{19}

Adequate alignment of the preoperative knee will demonstrate superimposition of the distal articulating surfaces of the femoral condyles and an open femorotibial joint space (see \textbf{Figure 9}).\textsuperscript{15} Postoperatively, the lateral projection primarily is used to evaluate the bone/cement interface for loosening of components.\textsuperscript{19} When a weight-bearing lateral projection is achieved, the patella appears in profile on the radiograph, the femoral condyles overlap, and the femoral pegs from the implant are superimposed. Also, the bone/cement interface can be visualized (see \textbf{Figure 10}).\textsuperscript{19} If one femoral condyle appears to be anterior to the other, the patient’s patella should be rolled perpendicularly to the cassette and another radiograph obtained after repositioning.\textsuperscript{15}

The central ray should be angled 5° to 7° cephalad to prevent overlap of the medial condyle in the femorotibial joint space.\textsuperscript{15} The degree of angulation depends on the width of the patient’s pelvis and the length of the femur.\textsuperscript{14} The narrower a patient’s pelvis and the longer the femur, the less angulation is required to demonstrate an open femorotibial joint space. If the radiographer uses too great a central ray angle, the distal surface of the medial condyle will be projected proximal to the distal surface of the lateral condyle.\textsuperscript{15}

When the recumbent lateral position is used to evaluate the position of the joint line, the line is measured as...
the height from the superior aspect of the tibial tubercle to the parallel surface of the tibial plateau or prosthetic component. In some cases, alternate landmarks must be used because of joint deformity; the head of the fibula can be used in place of the tibial tuberosity and the distal end of the femoral condyles in place of the tibial plateau.

A mediolateral view of the lateral recumbent projection is obtained with the patient lying on the affected side. The patient can be instructed to bring the affected knee forward and straighten the unaffected leg. An alternative is to instruct the patient to bring the unaffected knee in front of the affected knee and then support the unaffected knee with a block. To relax the muscles and demonstrate maximum joint cavity volume, the affected knee should be flexed 20° to 30°. The central ray should be directed to the knee joint 1 in distal to the medial epicondyle and angled 5° to 7° cephalad. Proper positioning demonstrates the distal end of the femur, patella, and knee joint, and the proximal ends of the tibia and fibula.

Tangential Patellofemoral Projections

There are many ways to obtain the tangential—also known as skyline or sunrise—view for evaluation of the patellofemoral joint. It is the physician’s preference as to which view is included in the knee imaging protocol, and it can be altered depending on the patient’s clinical presentation. According to some physicians, this projection should be taken before and after TKR. The most common technique is the Merchant patella view, especially for visualization of patellar subluxation. This view requires the patient to lie supine with knees at the end of the table and flexed at 45°. This angle is used because the patella does not always centralize in the intercondylar sulcus until the knee is bent to 45° (see Figure 11). An adjustable support device is used to maintain position and hold the cassette.

If the patient has thick posterior calf muscles, the central ray should be increased 5° to 10°, or the angle of the support device should be reduced. The height of the support device should be adjusted so that the femurs are parallel with the table, not angled with the distal femur higher or lower than the proximal femur. The cassette is then placed on the shins, and the x-ray beam is aligned perpendicular to the cassette and parallel to the joint so that the beam enters at the level of the patellofemoral joint centered between the right and left patellae. The knees should be rotated internally until the femoral epicondyles are parallel with the tabletop. The patient’s legs should be held in position with Velcro straps placed around the calves. The patient should be instructed to relax the quadriceps femoris as much as possible to ensure the muscles are not pulling the subluxed patellae back into alignment. Pillows or foam wedges can be placed under the patient’s head and back to encourage relaxation.

The degree of subluxation is determined by measuring the angle of congruence. This angle is found by first determining a reference line, which passes vertically through the middle of the sulcus. Then a line is drawn to connect the apex of the medial side of the patella to the lowest point on the sulcus. The angle between these lines is given a negative value when it falls lateral to the reference line and a positive value when it is located medial to the reference line. When the knee is flexed 45°, the normal range for the angle of congruence is between -6° and 11° degrees from the reference line. Because rotating the patient’s leg during positioning also results in the radiographic appearance of a displaced patella, the radiographer should consider whether positioning error or subluxation is the cause of the displaced appearance. If the patella is entirely displaced from the groove, it is dislocated.

The tilt of the patella also can be evaluated with the Merchant patella view and can be described as neutral, medial, or lateral. An alternative method for the tangential projection of the patella, which might offer better visualization of patellar tilt, is the Laurin angle (see Figure 12). By using only 30° of knee flexion, tracking abnormalities might be more apparent because the femoral muscles are not engaged to pull the patella back into alignment. The angle of patellar tilt is determined by drawing a line across the lateral patellar facet and another line between the anterior surface of the femoral condyles. When the patella is in the normal position, this angle appears to be open laterally, but when it is tilted, the lines might be nearly parallel or create an angle that is opened medially instead.
Full-leg Length (Hip-Knee-Ankle) AP Projection

The AP full-leg length projection primarily is used to evaluate the status of the mechanical axis. The mechanical axis is defined as the line drawn from the femoral head to the center of the ankle. The joint line of the knee should be perpendicular to the mechanical axis for proper alignment.22

Positioning for the AP full-leg length radiograph requires the lower limb to be in neutral rotation.22 If the patient is accurately positioned, half of the lesser trochanter will be apparent on the femoral side and half of the fibular head will overlap the tibial metaphysis on the tibial side of the joint (see Figure 13).22 The femur is most likely externally rotated if the entire lesser trochanter is visible.

If the fibular head is not overlapping the tibial metaphysis, the tibia is most likely internally rotated.22

Weight-bearing Posteroanterior Projection

A PA weight-bearing (tunnel) projection of the knees might be included in the preoperative assessment because it offers a better view of joint space narrowing and diseased articular cartilage (see Figure 14).16 This information is then used to recommend unicompartmental or TKR treatment.30

This positioning method requires the patient to stand facing the vertical grid device. The knees are flexed to 45° until they touch the surface of the grid device. The cassette is then centered approximately 0.5 inches below the patellae apices. The patient may hold on to the edges of the grid device for balance. The horizontal central ray should be angled 10° caudad so that it exits about 0.5 in below the patellae apices and is centered to the cassette.16

A variation of the PA weight-bearing projection, called the fixed-flexion view, has been described as using a fluoroscopy unit to capture the images. This projection requires the patient to stand close to the vertical table, externally rotate the feet, and bend his or her knees until the anterior surface of the knees and thighs are flush with the table.30 The x-ray beam is angled 10° caudad to pass through the tibiofibular joint space. This projection has been recommended for surgical planning because it offers more precise measurement of joint space width, which helps determine whether moderate or severe joint space narrowing is present.30
Posteroanterior Oblique Condylar Projection

The PA oblique condylar projection generally is performed to obtain better visualization of the posterior condylar region because abnormalities on either the medial or lateral side of this region can be obscured by overlap of the other condyle on the lateral projection. Since osteolysis often occurs in the posterior aspect of the femoral condyles, visualization of this region may be required in symptomatic knees after TKR.

Lateral and medial rotation views are obtained with the patient placed prone on the radiographic table. Then the hip is lifted on the affected side and supported with a sponge. The knee and toes are rotated laterally or medially 45° while the knee maintains a bend of approximately 10°. The perpendicular central ray should be centered 0.5 in below the patellar apex. Proper positioning demonstrates the medial femoral and tibial condyles when the lateral rotation is used, and the lateral femoral and tibial condyles when the medial rotation is used.

Miura et al described a variation of the posterior condylar projection and reported that it is useful for routine imaging of the femoral component after TKR and for planning of revision surgery. They described placing the patient in a seated position with the knee flexed 90° and rotated 45° to 50° for bilateral oblique views. A horizontal x-ray beam was used.

Computed Tomography

Following plain radiographs, the American College of Radiology Appropriateness Criteria states that CT with or without contrast is appropriate when there has been a positive joint aspiration for infection, or when pain is present and joint aspiration cultures are negative or inconclusive. CT without contrast is appropriate when pain continues after TKR and a radiograph has demonstrated loosening, or if an occult fracture or malposition are suspected (see Figure 15). CT is valuable for assessing rotation and provides detailed information about the size and extent of periprosthetic infections. The level of radiation exposure is about 5.7 mSv for evaluation of the knee.

Although more costly than radiography, preoperative CT or MR scans can be used to determine proper mechanical alignment of the joint for complicated cases. Custom-made instrumentation and cutting guides can be made based on the data from these.
imaging studies.

CT imaging is especially useful for TKR revision because metal components are already in place and can obscure MR images. Computer software uses the CT data to design virtual 3-D models of the patient’s anatomy and to decide the best size and positioning of the new implant. Virtual surgical plans, which surgeons are able to alter, can be made based on the CT data.

Because it can be challenging to pinpoint the location and cause of knee pain, the combination of CT and single-photon emission computerized tomography (SPECT), which measures bone metabolism and joint homeostasis, can be beneficial following TKR. SPECT is a useful tool for treatment planning when results from other imaging modalities have been nonspecific.

Magnetic Resonance Imaging

MR imaging offers better soft tissue contrast than does radiography or CT (see Figure 16). In addition, MR imaging does not require the use of contrast agents or expose the patient to radiation. It also is better than radiography or CT for detecting osteolytic lesions. One challenge in using MR imaging is that it is a nonweight-bearing study and the patient’s range of motion is limited. Another
challenge when using MR imaging postoperatively is that the metal implants cause signal loss and distortion on the images because the metal interferes with the main magnetic field. This interference results in strong and varying local gradients.33–35 Metal artifact defects are enhanced with gradient-echo imaging techniques, so these techniques should be avoided.34 Several conventional strategies can minimize implant artifacts.33,34 One method is to position the patient with the long axis of the hardware parallel to the direction of the magnetic field.33,34 Fast spin-echo proton density-weighted or T1-weighted sequences are the least sensitive to metal artifacts.34 Inversion recovery and using the maximum bandwidth receiver setting also can reduce artifacts.33,34

Protocols with new pulse sequences and technique adjustments have been developed to allow for better visualization of ligaments, tendons, nerves, and the implant-bone interface.23 One of these new techniques is called slice encoding for metal artifact correction, which employs a 3-D spin-echo acquisition to prevent signal loss and a view-angle tilting gradient to avoid distortion within the plane.34 Another technique, called multi-acquisition variable-resonance image combination selects limited spectral bandwidths to excite, thereby reducing distortion on a standard 3-D readout.33

**Fluoroscopy**

A weight-bearing fluoroscopy technique can better visualize motion of the patellofemoral joint and tibiofemoral kinematics for postoperative evaluation of TKR.9 Fluoroscopy enables the clinician to visualize how the prosthesis tracks and the degree to which the patella stays within the femoral groove through a series of weight-bearing images while the knee is progressively flexed. Breaking the degree of flexion into small increments helps identify the position that produces pain, which aids in determining the cause of continued pain after TKR. This method also might be used to monitor structural and functional changes. Researchers have used this technique to compare the outcomes of a variety of prostheses.9

The utility of fluoroscopic guidance during TKR has been debated because it increases expense and radiation exposure and can increase surgical time.36 However, it is less expensive and offers a lower radiation dose to patients than CT. Fluoroscopy can help surgeons achieve limb alignment when placing the prosthesis, which is essential for the longevity of the knee replacement.36 Surgeons can use fluoroscopy to identify bony landmarks along the mechanical axis to improve precision for locating surgical resection sites. The goal is to place the prosthesis components so they receive equal load.36

**Nuclear Imaging**

Bone scanning is used to detect abnormality in the metabolic activity of bone, which can be caused by arthritis or infection.37 The patient is injected with a technetium Tc 99m phosphorus radiopharmaceutical. In places where bone turnover is great, the uptake of the radiopharmaceutical might be seen on radiographic images.37 The 3 phases of these studies are vascular, blood pool, and delayed. The vascular phase includes serial imaging at 2- to 5-second intervals while the isotope travels through the vascular system and displays areas of increased or decreased blood flow. The blood-pool phase involves static images that can detect areas of excess blood, which can indicate an inflammatory response.37 The delayed phase requires taking static images of the bone to identify areas of increased or decreased radiopharmaceutical uptake.37 An alternative study used to identify infection around metallic implants uses indium In 111-labeled white blood cells instead of the technetium Tc 99m. Bone scanning might be used as a preliminary test before MR imaging or CT studies are ordered.37

Radionuclide arthrography can be used to differentiate septic vs aseptic loosening.38 Radionuclide arthrography studies involve injecting technetium Tc 99m calcium phosphate colloid into the joint space under fluoroscopic guidance. At 30 minutes and at 4 hours postinjection, anterior, posterior, medial, and lateral images are taken. Leakage of the radiopharmaceutical around the prosthesis indicates loosening (see Figure 17).39

Regardless of the imaging modality, technologists must communicate clearly with the patient to obtain high-quality diagnostic images.19 Technologists also must communicate with one another and the physician to ensure they provide images that offer the most diagnostic information for each patient.19
Total Knee Replacement Surgery

**Total Knee Replacement Components**

During TKR surgery, the articulating surfaces of the bones are replaced with a prosthesis. Although improvements continue to be made in implant design, manufacturers are not able to create standard implant components that replicate the natural human knee precisely. For example, the femoral component is typically created with equally sized and symmetrically positioned medial and lateral condyles even though the medial condyle is larger and more distal than the lateral in the natural knee. Therefore, the postoperative motion of the treated joint is different from the motion the patient had prior to disease or injury. Surgeons strive to restore function to the joint and provide implant longevity.

Many types of knee prostheses are available and include a variety of sizes, component materials, and methods for fixation. The goal is to match the patient’s anatomy as best as possible and restore joint function. All prosthesis types contain femoral, tibia, and patellar components, but one major difference is whether the implant requires the removal of the posterior cruciate ligament (PCL) to be placed. The PCL is retained when it is healthy enough to stabilize the knee. Radiographs can aid in determining the best type of prosthesis for the patient.

The shape of the polyethylene insert can be visualized on the lateral radiograph because it is more radiolucent than the bone and soft tissue of the knee. With PCL-retaining prostheses, the tibial polyethylene insert is typically more flattened in the AP direction than in the dish-shaped insert of the PCL-sacrificing type. The posterior-stabilized prosthesis has a “cam-post” mechanism, which is an internal post in the tibial component that fits into a special bar (cam) in the femoral component. The cam-post mechanism is designed to mimic the function of the PCL by limiting the anterior motion of the femur over the tibia in flexion. For placement of this type of prosthesis, bone must be removed from the intercondylar notch.

Another design difference is whether the prosthesis has fixed or mobile bearings. Mobile-bearing prostheses often have metal markers inside the polyethylene insert that are used to assess rotation of the femorotibial articulation. Other parts that might be visualized radiographically include metallic pins, pegs, studs, and control arms or stops that limit the mobility of the insert. With complex cases or revision TKR, long stems might be used. The long stems can be placed in the femur, tibia, or both, and are usually placed using a press-fit technique rather than with cement because of the risk of extrusion. The press-fit technique uses implants built with rough surfaces.

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The bone grows into the rough area and secures the implant. Polyethylene tibial inserts can be specially designed to limit varus-valgus malalignment and contain a metallic pin within the post.22

Common materials for knee prostheses are cobalt-chromium for the femoral component and polyethylene for the tibial component.25 However, the use of other materials has been investigated because polyethylene wear can lead to a process of osteoclastic resorption and reduced osteoblastic function, which can cause osteolysis. An improvement over cobalt chromium in biocompatibility with polyethylene is oxidized zirconium.25 Biophosphonate drugs and zoledronic acid inhibit osteoclastic bone resorption and have been reported to increase the longevity of knee prostheses and decrease the need for revision surgery.6

Components should match the patient’s anatomy as closely as possible.22 Customized implants can be made to fit patients with unusual geometry, extreme size variations, juvenile rheumatoid arthritis, or patients whose previous implants have failed.14 Customized components are made using MR imaging and CT scan data that has been transformed into a usable format for the implant manufacturer’s engineering software through a process called segmentation. Segmentation is accomplished by creating points along the outer joint surface of each scan slice over the entire joint region to create a point cloud.14 Next, the point cloud is imported into a computer-assisted design program used to create a model of the joint.14 Implant manufacturers then create an implant to fit the patient’s model.14 Prior to the use of CT or MR imaging, implant manufacturers used radiographs that contained embedded measurement devices to create the custom components.14 Customized knee instrumentation such as cutting guides, which improve precision of the initial femoral and tibial bone cuts, are designed from CT and MR imaging data.

Surgical Procedure

During TKR surgery, a long incision is made down the center of the knee so the surgeon can move the patella and obtain access to the damaged cartilage lining the femur and tibia.39 The damaged cartilage and a thin layer of bone are removed from the articulating surfaces and replaced with metal implants. Polyethylene lining separates the metallic surfaces so that movements are smooth.6,39 Seven separate cuts through the bones of the knee joint are made during TKR. These cuts are located along the distal, anterior, and posterior margins of the femur; the anterior and posterior chamber; across the tibia; and at the patella. The precision of each cut affects the accuracy of prosthesis placement and overall success in obtaining limb alignment.20

In the majority of cases, the PCL is removed along with the anterior cruciate ligament.14 A variety of cements, screws, and “bone ingrowth” techniques (treatment of the metallic implant surface to encourage bone to grow into it) can be used to adhere the implant to the bone.4,39 The decision to use cement or cementless fixation is dependent upon the prosthesis selected and the surgeon’s preference. Most often, cement is used because it offers greater longevity.22 Radiographically, these prostheses appear to have a rough or beaded surface. When cement is used, the prosthesis should appear interlinked with the bone for a depth of at least 2 mm around the entire prosthesis. Occasionally, only the tibial component is implanted with cement, while the femoral component is not.22 Multiple studies have indicated that patients report more residual pain when cement is not used.41

When an osteotomy is being performed simultaneously with TKR, the surgeon must consider the extent of the osteotomy site when deciding to use cement.11 Extrusion of cement at the osteotomy site can result in nonunion and failure of the TKR.11 There is some debate regarding the survival rates for cemented vs cementless fixation, but more studies need to be conducted to evaluate implant survival after 15 years.11

Alignment guides are used during TKR surgery to create a mechanical axis within 3° of neutral in the coronal plane.17 Knee replacements with accurate alignment can last more than 20 years.19 If coronal alignment falls outside a certain range (+/− 3° degrees from neutral), early implant failure could result.17

In addition, rotational alignment can be a challenge.42 The components rotate along the polyethylene interface through flexion and extension. The tibial component is more involved with rotation over the polyethylene bearing of the joint during early to midflexion, whereas the femoral component rotates more dominantly along the polyethylene bearing in greater degrees of flexion. Mobile polyethylene bearings allow...
Postoperative Care and Patient Outcome

For pain management immediately following TKR, narcotic pain medications are prescribed. After that, over-the-counter medications such as naproxen, ibuprofen, or acetaminophen may be used. Icing and elevating the limb are effective to treat swelling. Depending on the patient’s level of fitness and activity demands, it can take from 3 weeks to 6 months to return to full work duties. Measurable progress can continue for up to 12 months. Rehabilitation programs are designed to restore a patient’s mobility and independence. Physical therapy might include a gradual walking program, strength training, or exercises in a pool. Patients must take special care throughout the rest of their life because of the TKR.

The patient’s clinical outcome can be evaluated in several ways. The functional outcome strategy relies on measurements including revision rates or joint function scores to determine whether TKR was successful. Revision rates are not necessarily indicative of satisfaction. A different strategy is to consider the subjective satisfaction of patients. One test for TKR outcome is the Oxford Knee Score, which is a questionnaire that includes 12 items related to pain assessment and function. Some studies suggested that patient dissatisfaction following TKR was related to psychological problems and that depression affected postsurgical outcomes. Some uncertainty has been reported as to whether pain following arthroplasty or depression prior to surgery leads to dissatisfaction. In general, the longer patients suffered from osteoarthritis symptoms or knee pain, the more pleased they were with TKR outcomes. Patients with reduced range of motion after surgery or those with milder symptoms prior to surgery were more likely to be unhappy with TKR. Patient satisfaction scores have been reported to be independent of the amount of time that has passed since the TKR operation.

Revision surgery might be necessary to relieve pain or treat postoperative complications from the initial TKR. When TKR revision is required, it occurs within 2 years after surgery in 55% of cases or within 5 years in 63% of cases. Common problems that necessitate early revision include instability, polyethylene wear, aseptic loosening, and patellofemoral problems.

Complications

Between 14% and 44% of TKR patients have reported long-term persistent pain during follow-ups. Postoperative complications include blood clots, joint infection, implant problems, continued pain, and neurovascular injury. Pain could be related to overstressing the patellofemoral joint, which occurs when the implant takes up more room in the joint space than the presurgical amount of space between the patella and the femoral condyles. Malrotation of the component or advanced degenerative disease of the patella also can cause pain. The most common complication of TKR is the development of blood clots in the leg veins. Patients should be educated about prevention including elevating the legs, completing circulation exercises, wearing support stockings, and taking prescribed blood thinning medications. Complications that lead to the failure of knee replacements can be described as intra-articular or extra-articular. Some intra-articular problems are infection, instability, poor alignment, aseptic loosening, fracture of the prosthesis, polyethylene wear, osteolysis, and soft-tissue impingement. Extra-articular complications include bursitis, stress fracture, or periprosthetic fracture.

Implant Malalignment

Malalignment can result in reduced function and greater rates of revision surgery. If TKR revision is required within 2 years of the initial surgery, it is often because of malposition. Up to 10% of TKR surgeries have been reported to have mechanical malalignment, which can lead to aseptic loosening and failure. Patellar alignment can be affected if the femoral or tibial components are poorly positioned. CT most commonly is used to visualize axial rotation of the femoral component. Research has shown that the degree of internal rotation of the components is directly related to the severity of complications.
On the AP radiograph, the femoral component should appear flush with the borders of the femoral condyles; however, it is better that it be on the lateral side of the joint if there is overhang. The lateral view should demonstrate the anterior ridge of the femoral component in line with the anterior femoral cortex and the implant’s posterior condyles with the patient’s posterior condyles. If a femoral component is too small, femoral notching (tilting of the component into the cortical bone) might be apparent on the postoperative lateral radiograph. Similarly, the margins of the tibial components should be aligned evenly with the patient’s cortices.

The lateral view can be used to assess the height of the patella. An abnormally low patella might result if the patellar tendon is shortened during surgery. The skyline view can be used to measure the thickness of the patella and the medial-to-lateral position in the femoral groove. Thickness affects patella tracking, and proper placement of the patellar component is essential to avoid subluxation.

**Loosening**

Multiple diagnostic imaging tests are used, along with serum laboratory testing, to determine the reason for implant component loosening and the degree to which the components are loose. Imaging might include plain radiography, CT, scintigraphy, and radionuclide arthrography. On plain radiographs, loosening is demonstrated by a:

- Prosthetic fracture.
- Cement fracture.
- Significant migration of components.
- Lucent zone that shows progressive widening on serial images.
- Lucrency at the interface of metal and bone or metal and cement.
- Lucent zone greater than 2 mm wide in which the cement adheres to the bone.

A variety of scoring systems have been created to distinguish the location of radioluencies around the components. Radioluencies are either physiological, resulting from normal healing processes, or pathological, caused by disease. Physiological radioluencies generally are less than 2 mm thick, have well-defined margins, and are adjacent to a parallel radiodense line (see Figure 18). Pathologic radioluencies are greater than 2 mm thick and are not well defined.

Lateral radiographs with the joint in flexion and extension also can be used to evaluate movement of the components. Loosening appears as a radiolucent wedge defect between the femur and the base of the component on the lateral extension view and as a crescent-shaped luency between the femoral component and anterior femoral cortex on the lateral flexion view.

Radionuclide arthrography is effective for detecting loosening but is not widely used. This procedure requires the injection of contrast under fluoroscopic guidance into the joint space. Radiographic images are taken after 30 minutes and again after 4 hours to evaluate tracer leakage around the prosthesis or any overall changes in the images. One concern with using this technique is the possibility of introducing infection into the joint space.

**Polyethylene Wear**

The thickness of polyethylene tibial inserts can be measured on radiographs to determine wear. For this measurement, a weight-bearing AP projection is used to evaluate the space between the femoral component and the metal tibial tray. When serial images of this projection are compared, the rate of polyethylene loss can be estimated. The rate of loss is directly proportional to the likelihood for revision surgery: The faster the rate of loss, the more likely revision is needed. A polyethylene loss rate of 0.15 mm per year or higher has been associated with higher probability of revision surgery. If wear is too severe, the polyethylene liner could fracture or separate from the metal plate of the tibial component. High levels of patient activity, along with implant longevity, increase the implant’s susceptibility to wear.

Thickness of the medial compartment of the polyethylene is measured along a vertical line drawn between 2 transverse lines: one made at the distal margin of the femoral component and one at the widest section on the upper surface of the baseplate. The degree of tilt caused by polyethylene wear can be assessed by measuring the thickness of the baseplate. The vertical thickness of the baseplate on the radiograph is compared to the known thickness of the
component, as reported by the manufacturer, to determine wear.\textsuperscript{27}

Osteolysis, the resorption of bone matrix by osteoclasts, can result from implant particles that break off with wear.\textsuperscript{2,45} CT can be used to evaluate osteolysis and provide a volume measurement for osteolytic lesions, and CT arthrography can be used to localize large fragments of polyethylene that have broken off.\textsuperscript{2} MR imaging also might offer detailed information about periprosthetic osteolytic lesions, especially around the distal femur.\textsuperscript{34} Fluoroscopy can be used to better assess lucencies around the polyethylene liner while the joint is manipulated.\textsuperscript{2,12}

**Infection**

Although relatively rare (occurring in 1%-2% of primary knee arthroplasties and in 3%-5% of revision knee arthroplasties), infections can develop in the wound site or around the prosthesis and might take years to appear.\textsuperscript{46,47} Periprosthetic infection is the most common reason for early revision of TKR.\textsuperscript{2,48} The time frame for prosthetic joint infections to appear is early (0-3 months), delayed (3-12 months), or late (>12 months) after surgery.\textsuperscript{47} Most early and delayed infections are iatrogenic in nature, caused by infectious organisms present at the time of surgery. In late-forming infections, bacteria spreads to the knee replacement in a variety of ways, including through the bloodstream during dental procedures, from urinary tract infections, or from skin infections.\textsuperscript{4,47} These joint infections can produce a biofilm that is resistant to host immune responses and antibiotics.\textsuperscript{46} Treatment for infection ranges from antibiotic treatment to surgical intervention, including:\textsuperscript{46}

- Irrigation and debridement of the infected areas.
- Exchange of the polyethylene liner.
- Placement of an antibiotic-impregnated cement in the joint.
- Resection arthroplasty.
- Amputation (rare).

Many strategies for prevention are emerging because prevention is the best approach to minimizing infection.\textsuperscript{4,48}

Some patient-related and iatrogenic risk factors for infection are listed in the Box. Signs of infection include pain around the implant location and presence of a fistula.\textsuperscript{47} Radiography can be used to detect

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**Figure 18.** A. Radiograph showing an example of presumed mechanical loosening. B. The periosteal reaction indicates the possibility of septic loosening. Images courtesy of Gary Mlady, MD, chief medical director, musculoskeletal radiology, University of New Mexico Health Sciences Center, Albuquerque, NM.
infection but has a low sensitivity and low specificity. Some radiographic signs include enlarging lucencies, endosteal scalloping, periosteal new bone formation, foci of radiolysis, and radiolucency around the prosthetic components. Occasionally, a radiograph of the oblique posterior condylar projection is used to evaluate osteolysis because the prosthesis obscures the radiolucencies around the condyles on standard projections. However, radiolucencies, osteolysis, and migration can be indicative of either infection or aseptic loosening.

Aspiration biopsy of the joint space fluid is the most reliable test for infection of the joint and might require ultrasonography for accurate needle placement. MR imaging, CT, and nuclear medicine scans also might be used for complex cases, but the information gained often is nonspecific. Several types of radionuclide bone scans are available to aid in diagnosing a prosthetic joint infection. With gallium citrate Ga 67 imaging, areas of inflammation, bone marrow, and elevated rates of bone mineral turnover have increased uptake of the radiopharmaceutical. The location and amount of gallium citrate Ga 67 uptake, relative to the intensity of the isotope administered, might indicate infection.

A combination of 2 types of scintigraphy can be used to detect infection. Labeled leukocyte scintigraphy involves injecting the patient with his or her own white blood cells (leukocytes) that are labeled with indium In 111 oxine or technetium TC 99m exametazime. An imaging examination is performed 24 hours after the injection, and the results are compared to a bone scintigraphy scan. Infection is suspected with increased activity on the labeled leukocyte study compared with the bone scan. This dual study has a sensitivity of 93%. It is not routinely recommended because it is costly and complex.

Fluorodeoxyglucose positron emission tomography (FDG-PET) scans can identify inflammatory cells such as leukocytes and macrophages, which indicate infection. This is possible because inflammatory cells cause an intracellular accumulation of deoxyglucose. Although FDG-PET has been reported to have 91% sensitivity and 72% specificity for total knee replacements, it is cost-prohibitive and not widely available.

**Patellar Clunk Syndrome**

Another adverse condition that could result from TKR is called patellar clunk syndrome, which occurs when focal scarring produces a growth of soft tissue around the superior portion of the patella. The soft tissue gets caught in the intercondylar notch when the knee flexes, then is displaced when it extends, creating a “clunk” sound. Patients might complain of a locking sensation or difficulty extending the knee.

Radiographic evidence of this syndrome might include patella infera (an abnormally low-lying patella) or displacement of the implant’s patellar components. MR imaging is more valuable for evaluating the soft tissue proximal to the patella because it provides a multiplanar view and better soft tissue contrast. Treatment for patella clunk syndrome is the removal of the damaged cartilage with arthroscopic debridement.

**Surgical Navigation During Total Knee Replacement**

Computer-assisted navigation in TKR surgery has been studied in recent years with the goal of increasing safety and reducing the invasive nature of procedures through preoperative planning, perioperative...
intervention, and improved positioning of implants.\textsuperscript{1} Three-dimensional navigation using a portable CT scanner can help visualize true mechanical alignment, which can be challenging to see during surgery.\textsuperscript{1} Surgical navigation can improve the precision and reduce the incision size of tibial and femoral cuts for placement of the prosthetic joint.\textsuperscript{7,17,48} It also might be a useful tool for perioperative intervention.\textsuperscript{1}

To date, this technique has proven to be most beneficial in patients with extra-articular knee deformity greater than 10°.\textsuperscript{7,17} However, a great deal of training for the surgeon and operating room staff is necessary to optimize the benefits of using this equipment.\textsuperscript{1} Consequently, there are mixed reviews regarding whether the added expense of materials, training, and operating room time are worth the improved implant placement accuracy achieved using computer-assisted navigation.\textsuperscript{7,17,49}

**Conclusion**

TKR surgery frequently is used to treat severely damaged knees by replacing all 3 articulations of the knee joint: the medial and lateral femorotibial joints and the patellofemoral joint. Plain radiography remains the standard for preoperative and postoperative follow-up imaging. Surgeons rely on competent technologists to properly position patients and adjust radiographic technique to aid in TKR treatment assessment. New software programs allow surgeons to more accurately measure limb alignment on digital radiographs.

Postoperative complications that can arise include blood clots, infection, loosening or malalignment of the implant, and wear of the polyethylene liner. Additional diagnostic studies that might be required to evaluate complications include CT, PET-CT, MR, scintigraphy, and fluoroscopy. CT and MR imaging also are used to create customized implants and surgical cutting guides when the patient has a severe deformity or unusual anatomy. Radiologic technologists specializing in these modalities should be familiar with preoperative and postoperative imaging for TKR patients.

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**References**


Total Knee Replacement and Imaging

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Read the preceding Directed Reading and choose the answer that is most correct based on the article.

1. Indications for total knee replacement (TKR) surgery include:
   1. severe knee pain.
   2. chronic swelling.
   3. knee deformity.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

2. Only preoperative arthritis severity is directly related to postoperative patient satisfaction.
   a. true
   b. false

3. Standard serial imaging for postoperative assessment includes all of the following projections except:
   a. posterior condylar oblique.
   b. lateral.
   c. tangential.
   d. anteroposterior.

4. Most arthritis-related intra-articular deformities are due to:
   a. congenital defect.
   b. trauma.
   c. metabolic disorder.
   d. bone loss.

5. TKR surgical considerations include:
   1. degree of extra-articular deformity.
   2. complexity of soft tissue imbalance.
   3. location of extra-articular deformity.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

continued on next page
6. Preoperative images typically include the weight-bearing anteroposterior (AP) views along with which of the following views?
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

7. The tibial slope is used to measure the position of the ______ component.
   a. femoral
   b. tibial
   c. fibular
   d. patellar

8. When the patient cannot fully extend the knee on the AP weight-bearing radiograph, the central ray should be placed perpendicular to the anterior lower leg surface and decreased by:
   a. 5°.
   b. 10°.
   c. 15°.
   d. 20°.

9. The degree of cephalic angulation of the central ray depends on ______ for the true lateral projection.
   a. width of the pelvis
   b. length of the femur
   c. length of the tibia
   d. 1, 2, and 3

10. The ______ view is most often used to evaluate subluxation of the patella.
    a. AP
    b. posterior condylar
    c. Merchant
    d. Laurin

11. When the knee is flexed 45° for the Merchant view, the normal range for the angle of congruence is between ______ and ______.
    a. -4°; 9°
    b. -5°; 10°
    c. -6°; 11°
    d. -7°; 12°

12. The mechanical axis is defined as a line drawn between the femoral ______ to the center of the ______.
    a. head; knee
    b. head; ankle
    c. neck; knee
    d. neck; ankle

13. To best visualize articular cartilage on the posteroanterior (PA) weight-bearing (tunnel) projection, the knees should be flexed:
    a. 15°.
    b. 30°.
    c. 45°.
    d. 60°.

14. The PA oblique condylar projection is especially useful when ______ is suspected.
    a. osteolysis
    b. malrotation
    c. fracture
    d. wear
15. The American College of Radiology Appropriateness Criteria states that computed tomography is appropriate when:
   1. a joint aspiration is positive for infection.
   2. pain is present and joint aspiration cultures are negative or inconclusive.
   3. an occult fracture or malposition are suspected.

   a. 1 and 2  
   b. 1 and 3  
   c. 2 and 3  
   d. 1, 2, and 3

16. The following are strategies to minimize distortion from metal implants on magnetic resonance imaging except:
   a. patient-positioning.  
   b. inversion recovery.  
   c. fast spin-echo sequencing.  
   d. low bandwidth.

17. Fluoroscopy enables the clinician to visualize how the prosthesis tracks and the degree to which the patella stays within the femoral groove through a series of ______ images while the knee is progressively ______.
   a. weight-bearing; extended  
   b. weight-bearing; flexed  
   c. nonweight-bearing; extended  
   d. nonweight-bearing; flexed

18. In TKR, manufacturers typically make the medial and lateral femoral condyles ______ sized and ______ positioned.
   a. equally; symmetrically  
   b. equally; asymmetrically  
   c. unequally; symmetrically  
   d. unequally; asymmetrically

19. The most common complication of TKR surgery is:
   a. infection.  
   b. blood clots.  
   c. physical instability.  
   d. periprosthetic fracture.

20. Femoral notching might be apparent on the ______ postoperative projection.
   a. AP  
   b. lateral  
   c. tangential patella  
   d. PA tunnel

21. When evaluating loosening, physiologic radiolucencies are generally less than ______ mm thick.
   a. 2  
   b. 4  
   c. 6  
   d. 8

22. A polyethylene loss rate of ______ mm or greater has been associated with higher probability of revision surgery.
   a. 0.5  
   b. 0.10  
   c. 0.15  
   d. 0.20

23. The most common reason for early TKR revision is:
   a. malalignment.  
   b. periprosthetic infection.  
   c. cement fracture.  
   d. aseptic loosening.
24. Radiographic signs of joint infection include:
   1. endosteal scalloping.
   2. foci of radiolysis.
   3. periosteal new bone formation.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

25. Computer-assisted surgical navigation can improve surgical precision but requires larger tibial and femoral cuts.

   a. true
   b. false