Knee

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11.1 Introduction

Prosthetic knee surgery is one of the most common and successful procedures in orthopedic surgery. Newer prosthetic designs, standardization of surgical technique, and a correct post-operative rehabilitation have improved overtime the outcomes and reduced the rate of revision surgery. The imaging plays an essential role in the preoperative planning and follow-up of the prosthetic knee. This chapter describes the most common implants and surgical techniques used in knee replacement procedures as well as the imaging techniques widely used pre- and postoperatively.

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11.2 Type of Prosthesis and Implantation Technique

11.2.1 Total Knee Replacement

Primary total knee replacement (TKR) is a widely performed and successful procedure, improving the quality of life in more than 90 % of patients [1]. The goals of TKR are to obtain a correct knee alignment and a functional pain-free joint by using a stable implant with a correct soft tissue balance.

Modern designs include metal femoral and tibial components, a polyethylene liner, and a polyethylene patellar component, when necessary. Currently, TKRs can be (1) cruciate retaining or posterior stabilized; (2) with mobile-bearing or fixed-bearing tibial tray; and (3) cemented or cementless (press fit).

In cruciate-retaining TKRs, the posterior cruciate ligament is maintained and a more conforming tibial polyethylene component is used to provide anterior and posterior stability. Conversely in posterior-stabilized TKRs, the posterior cruciate ligament is substituted with a cam and post mechanism.

In mobile-bearing designs, the polyethylene insert articulates with a metallic femoral component and a metallic tibial tray (in order to reduce contact stresses and polyethylene wear), while in fixed-bearing TKRs, no motion is allowed between the tibial tray and the insert. Alternatively, between nonmobile-bearing

C. V. Albanese and C. Faletti (eds.), *Imaging of Prosthetic Joints*,
DOI: 10.1007/978-88-470-5483-7_11, © Springer-Verlag Italia 2014

designs, all-polyethylene tibia components are available on the market.

In addition, TKRs can be implanted either with a cement fixation or with a press-fit (cementless) technique. In a cemented TKR, components are fixed by using polymethylmethacrylate, which allows the implant to fit the irregularities of the bone with a strong primary fixation. In cementless implants, components have a roughened porous surface to allow bone ingrowth.

In some difficult cases, modular TKRs with continuum of constraint may be necessary. The indications range from higher degrees of ligamentous incompetency to severe restriction of the range of motion with substantial flexion contracture to post-traumatic arthritis and to post-osteotomy deformity of either the distal part of the femur or the proximal part of the tibia. Modularity allows intraoperative customization by using stems, wedges, and augments. Frequently, these difficult primary or revision TKRs require the use of posterior-stabilized constrained implants.

The most common surgical approach is the anterior approach to the knee with a medial parapatellar arthrotomy. Capsular incision is performed along the medial border of quadriceps tendon leaving 2–3 mm of tendon attached to the muscle. The capsular incision is extended distally to the medial border of tibial tubercle proximally to the pes anserinus insertion. Afterward, the medial joint capsule is elevated from the medial tibial flare at least to the midline of the tibia subperiosteally, externally rotating the leg for better exposure. Minimally invasive approaches (i.e., subvastus, midvastus) have been described to minimize surgical damage to the extensor mechanism of the knee [2]. The posterior half of infrapatellar fat pad and the lateral meniscus are removed to achieve a good lateral exposure. With the knee in full extension, the patella is laterally dislocated, possibly without eversion. The anterior cruciate ligament is then sectioned. In posterior-stabilized implants, also the posterior cruciate ligament is excised with the knee flexed at 90°, allowing for anterior dislocation of the tibia and a complete exposure of tibial plateau. Once the exposure of the tibial plateau is complete, meniscal remnants and osteophytes are removed. The surgical procedure includes a proximal tibial cut and 4 essential femoral cuts (distal, anterior, posterior, and oblique) for both cemented and cementless implants. An additional sixth cut for the removal of the intercondylar notch is performed in PCL sacrifice TKRs. The tibial and distal femoral osteotomy are independent of each other; therefore, there is no fixed order to perform the bone cuts. The authors usually begin with the tibial cut; nevertheless in tighter knees or in presence of important posterior osteophytes, it is preferable to start with distal femoral osteotomy to gain space, allowing a better view of tibial plateau. According to the prosthesis design chosen, trial components are placed first and stability, range of motion and patellar tracking are checked out. Afterward, the definitive prosthesis components are positioned.

11.2.2 Unicompartmental Knee Arthroplasty

Unicompartmental knee arthroplasty (UKA) is a surgical option which allows to manage degenerative changes involving either the medial or the lateral compartment of the knee. Both metal backed and all-polyethylene tibial components are available on the market, according to the implant selected.

A minimally invasive technique is used to implant UKAs [3]. A 6–10-cm medial parapatellar skin incision is performed, and a subvastus approach to the joint is commonly used. Some authors advocate an antero-lateral approach for the lateral compartment, but a slightly more extensile medial parapatellar approach may be used as well. The patella is then dislocated, and all osteophytes are removed. The tibial cut is performed first perpendicular to the tibial shaft. After tibial preparation, either a dependent or an independent femoral cut is carried out according to the surgeon's preferred technique and prosthetic design. Trial components are positioned and range of motion together with limb alignment is controlled. Final components are then cemented and implanted.

11.2.2.1 Patellofemoral Arthroplasty

Patellofemoral arthroplasty (PFA) has recently risen in popularity for the treatment of isolated patellofemoral osteoarthritis in young patients. Many implants with different features are currently available. Those implants may be mainly divided in three categories: (1) in-lay implants in which trochlear component surface is at the same level of the surrounding articular surface; (2) on-lay implants characterized by a trochlear component surface prominent compared to the surrounding articular surface; (3) minimally invasive implants which allow a minimal cartilage/bone resection and component implantation with in-lay technique.

A midline skin incision is carried out to allow for future total knee arthroplasty, in case of subsequent degeneration to the tibiofemoral compartments. Quadriceps tendon, midvastus and subvastus approaches may be used. The patellar cut is performed first in order to allow for easier patellar dislocation during femoral preparation. All the osteophytes are removed, and the patellar cut is made to reestablish the original thickness with implant in place. Afterward, the trochlea is prepared removing synovium, osteophytes, and fat from anterior femur immediately adjacent to the most proximal extent of the trochlea, and the femoral cut is performed. Trial components are positioned, and patellar tracking, possible tilt, and stability are checked throughout the complete range of motion of the knee. Finally, definitive components are implanted.

11.3 Preoperative Imaging

Preoperative imaging assessment of the patient is mandatory for the planning of the surgical procedure. The aim of the radiologic preoperative evaluation is to determine: malalignment, localization, and the severity of the degenerative process, underlying bone stock, the surgical technique in terms of both approach and implant selection. Preoperative imaging is also used in order to template the prosthesis, to choose the appropriate type and size of the prosthesis, to determine component position and orientation, and to prevent limb length discrepancies.

11.3.1 Conventional Radiography

Conventional radiography remains the cornerstone of musculoskeletal imaging in the planning of knee prostheses. Preoperative radiographic assessment includes bilateral weight-bearing antero-posterior (AP) views in full extension as well as tunnel views at 30° of flexion or Rosenberg views at 45° of flexion. Lateral and axial (Merchant or Skyline) views and a weight-bearing hip-to-ankle AP view are also required for a complete evaluation of the extensor mechanism and the lower limb axis, respectively.

The AP view assesses the joint space and allows the evaluation of the medial and lateral compartments; furthermore, it provides a gross assessment of femoro-tibial alignment. Rosenberg and tunnel views demonstrate the posterior aspect of the intercondylar notch, the inner posterior aspects of the medial and lateral femoral condyles, and the tibial spines and plateaus, improving joint space narrowing visualization [4, 5]. Lateral radiographs are ideal to assess the tibial slope, posterior osteophytes, and bone loss. On lateral view, patellar height can be evaluated as well using the Insall-Salvati, Blackburne-Peel, or Caton-Deschamps indices [6]. Axial views provide an excellent evaluation of patellofemoral alignment, trochlear dysplasia, and patellofemoral articular surface. Weight-bearing hip-to-ankle AP radiographs show bone deformities and the mechanical axis of the lower limb, from the center of the femoral head to the center of the talus [7]. In a neutral mechanical axis, the line passes through the center of the knee joint. The angle of the tibiofemoral axis or anatomic axis is measured drawing a line through the center of tibial and femoral shafts, and it ranges from 5 to 7° of valgus. The tibial implant is typically placed perpendicular to the anatomic mechanical axis. This entails a slight change from the anatomic 2–3° of varus alignment in the native tibiofemoral joint.

The femoral component is usually places with some degrees of valgus orientation. The authors prefer a 5° valgus femoral component positioning in varus knees and 3° of valgus in valgus knees. The prosthetic femoral component is placed in slight external rotation relative to the native femur (3 to 5°). Joint line orientation is also obtained using weight-bearing hip-to-ankle AP view of both limbs.

Conventional AP and lateral X-rays are widely used for templating. Templating is a preoperative process used by surgeons to plan the intraoperative steps, choose the appropriate type and size of the prosthesis, determine component position and orientation, and prevent limb length discrepancies [8]. Templating techniques are similar using either acetate overlays with properly magnified radiographs or a digital templating system. Digital templating has the advantage to accurately record the preoperative plan and sizing information, which assists the operating staff and implant inventory manager in having the necessary implant available.

11.3.2 Computed Tomography

Computed tomography (CT) provides detailed information in the assessment of osseous structures. CT is not routinely performed but is useful in assessing the extent of cystic disease in osteoarthritis or bone loss in primary/revision surgery. In addition, a CT could be obtained to assess severe axial or rotational deformities of the lower limb [9, 10].

11.3.2.1 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is not used as a routine technique for the preoperative planning in knee arthroplasty; however, it can be useful for the diagnosis and the severity assessment of osteonecrosis or soft tissue conditions.

Recently, a new technology using preoperative MRI data to manufacture custom cutting jigs specific to patient's bony anatomy has been developed. A hip-to-ankle MRI is obtained and sent to the manufacturer. Using a specific software, the preoperative planning is then sent to the surgeon for approval. Then, patient-specific cutting jigs are created in order to perfectly fit the tibial and femoral anatomy (osteophytes included) of the patient. The jigs allow for theoretically quicker and more precise tibial and femoral cuts, without the use of intra or extramedullary cutting guides [11–13]. This technology, originally designed for TKRs, is now available also for UKAs.

11.4 Imaging in the Follow-up

Post-operative imaging is mandatory to evaluate the correct positioning of the prosthetic components and to rule out complications that might occur over time. In addition to conventional radiographs, metal artifact reduction techniques allow the use of CT and MRI in the post-operative evaluation of prosthetic knees [14, 15].

The frequency of the post-operative imaging in the follow-up is dictated by surgeon's and institution's preference. Typically, immediate post-operative AP and lateral and Merchant views are obtained to evaluate gross malpositioning of the components, femoral notching, or up-/down-size of the components. Subsequently, at 3, 6, and 12 months weight-bearing AP, lateral, long leg and axial (Merchant or Skyline) views are obtained to rule out secondary displacement of the components. Normally on the AP film, the tibial tray should be perpendicular to the long axis of the tibia and should cover at least the 85 % of the tibial surface. Mechanical axis should be neutral and femoro-tibial angle should be anatomic (5 to 8° of valgus) on the long leg radiographs.

On the lateral view, the femoral component should be 90° to the femoral shaft, the condylar component should mirror the size of the native femoral condyles, and the anterior aspect should sit flush against and be parallel to the anterior cortex of the distal femur. A too large condylar component might be the reason of a limited range of motion, whereas an undersized condylar component may lead to instability and notching of the anterior femoral cortex. Lateral view also allows for tibial slope evaluation. Excessive tibial slope can lead to anterior tibial subluxation, posterior polyethylene wear, and lack of extension. Lastly, on the lateral view, patellar height can be measured.

The patellar component should be centered in the trochlea of the femoral component without significant tilt. The thickness of the patellar polyethylene component should not exceed the total thickness of the native patella in order to avoid risk of increased wear and reduced range of motion.

11.4.1 Complications

11.4.1.1 Periprosthetic Fractures

Periprosthetic fractures may occur either during surgery or in the post-operative period with TKRs. The overall incidence is low, with supracondylar femoral fractures ranging between 0.3 and 3 %. Periprosthetic fractures of the proximal tibia are even rarer [1, 16]. However, particular attention should be paid intra-operatively in patients with poor bone quality (i.e., because of the age, rheumatoid arthritis). Fractures may also occur after the positioning of lateral and medial UKAs. Risk factors for post-operative fracture include osteopenia, femoral notching, poor flexion, focal osteolysis as well as component loosening. Conventionally radiographs are the first step in diagnosing periprosthetic fractures. Often a CT is required to rule out loosening of the components or better delineate the fracture's pattern.

11.4.1.2 Joint Instability

Ligamentous imbalance and the following varus-valgus instability accounts for the 1–2 % of primary instability in knee replacement surgery [5]. That is well evaluated by an asymmetric widening of the prosthetic joint space seen on the X-rays films, with or without mechanical malalignment on the long leg X-rays.

11.4.1.3 Prosthesis Wear

Many factors contribute to liner wear of the prosthesis, including weight and activity level of the patient, polyethylene thickness, alignment of the condylar component, relationship between the polyethylene spacer and the metal surface of the femoral and tibial components, and physical properties of the polyethylene. The wear involves shedding of metal or polyethylene, resulting in hypertrophic synovium, histiocytic response, and ultimately osteolysis. The thickness of the polyethylene liner should be at least 8 mm. Polyethylene wear is evaluated on standing AP and lateral views with the X-ray beam parallel to the tibial base plate. The distance from the femoral condyles to the tibial base plate is measured on serial radiographs. Interval narrowing of the joint space is suggestive of polyethylene wear. Eventually, wear can progress to metal-to-metal contact, erosion of the tibial metal back, and metal synovitis. Ultrasonography may be also used to evaluate accurately the polyethylene thickness. Osteolysis is occasionally noted on radiographs, although it is not visible until far along in the process. CT is more sensitive in the detection and quantification of osteolysis and synovitis and allows the assessment of components rotation at the same time [5]. MRI with metal suppression is useful to detect synovitis and occult osteolytic lesions offering more accurate extent and localization of osteolysis prior to revision surgery [17].

11.4.1.4 Prosthesis Loosening

Loosening can be seen in both the femoral and the tibial components, although it is more frequent in uncemented tibial components along the medial side, resulting in varus angulation (Figs. 11.1 and 11.2). A loose femoral component tends to shift into flexion. Development of thin radiolucent lines at the bone–cement or bone–prosthesis interface of less than 2 mm within the first 6 months in a cemented implant or during the first 1–2 years in noncemented implants without evidence of progression is

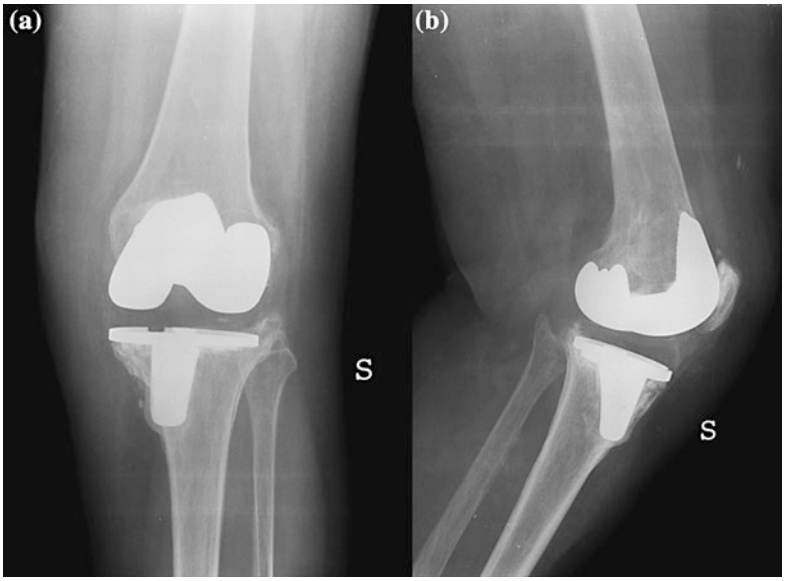

Fig. 11.1 AP and lateral views of an aseptic loosening of the tibial tray in total knee arthroplasty

Fig. 11.2 AP view of an aseptic loosening of the tibial tray in unicompartmental knee arthroplasty

considered normal [5, 18]. Widening of greater than 2 mm at the bone–cement, metal–cement, prosthesis–bone interval, increases in the width of an existing radiolucency, cement fracture, and changes in component position suggest loosening. A bone scan may also be used to diagnose loosening. Arthrography may confirm the diagnosis showing the presence of contrast between the bone–cement and the bone–metal interface.

11.4.1.5 Metal Synovitis

Metal-induced chronic synovitis results from metal wear debris caused by abrasion of metal components that occurs after failure of the interposed polyethylene-bearing surfaces. A line of linear opacity outlining a distended knee capsule or an articular surface on radiographs (metal line sign) is secondary to the deposit of metal debris in the joint causes and is diagnostic of metal synovitis.

11.4.1.6 Patellar and Extensor Mechanism Complications

The majority of patellar complications are commonly ruled out using both lateral and axial radiographs. Instability/dislocation and loosening of patellar components as well as stress patellar fractures are the most common complications reported. Patellar instability is related to imbalance of soft tissue (tight lateral retinaculum) and malposition and malalignment of components (Fig. 11.3). Tilt and subluxation of the patella are usually recognized on the axial views, although any underlying rotatory malalignment of components is best assessed on CT. The thin polyethylene liner may wear or displace from the metal backing into the Hoffa fat pad.

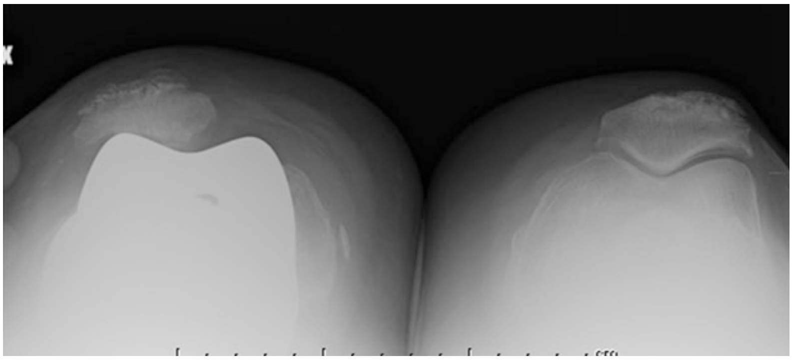

Fig. 11.3 Merchant view of patellar maltracking with lateral tilt in total knee arthroplasty

Fig. 11.4 AP view of septic loosening of a total knee replacement

Patellar fractures have been reported to be up to 21 % of cases and are commonly seen in older patients [19]. Over-resection of the patella may predispose to fractures. Radiographs can easily detect fatigue fractures, which occur frequently at the peg-plate junction of metal-backed prosthesis. Occult fractures may be ruled out by MRI study. Quadriceps tendon tear and ruptures have also been described, resulting in abnormal position of the patella observed on radiographs. Ultrasonography and MRI confirms these complications. Fibrosis and scarring of the Hoffa pad may result in a low-lying patella (patella baja) [5].

11.4.1.7 Infection

The prevalence of infections in knee arthroplasty ranges from 0.5 to 2 % [5]. Infection is typically seen within the first 2 years of surgery, although sometimes may occur later. The diagnosis of low-grade and chronic infection may be particularly difficult, and the evidence of infection is often not obvious prior revision surgery. Microorganisms, introduced at the time of surgery (usually skin bacteria) or through hematogenous spread or direct contamination from compromised adjacent tissues, adhere to the prosthesis, residing in a biofilm that limits the effects of antimicrobial agents.

Conventional radiography does not show a high sensitivity since the appearance of infection can be variable, besides radiographs are normal in most patients. Radiologic distinction between septic and aseptic loosening can be challenging (Fig. 11.4). Periosteal reaction, periprosthetic widening, osteolysis, presence of bone destruction as well as irregular periprosthetic lucency or lucency that extends completely around the prosthesis are all signs which suggest septic loosening. Soft tissue swelling is also indicative for infection.

Ultrasound is useful to detect joint effusions, soft tissue fluid collections, and in some cases, synovial hypertrophy and inflammation (aided by the use of color and power Doppler). The more advantageous use of ultrasound, however, is to guide intervention such as joint aspiration. Joint aspiration is a useful confirmatory test showing sensitivity and a specificity ranging from 67 to 82 % and from 91 to 95 %, respectively [20, 21]. In spite of the past limitation due to metal artifacts, nowadays, CT and MRI are useful tools to assess the extent of soft tissue

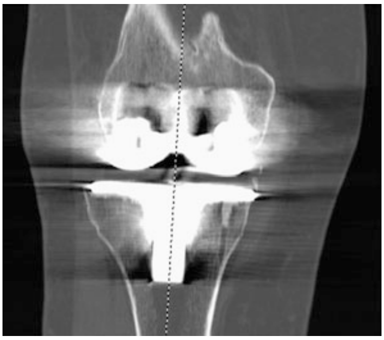

Fig. 11.5 CT scan in a correctly positioned total knee arthroplasty

infection in close proximity to the arthroplasty (Fig. 11.5).

Nuclear medicine studies are extremely useful in the evaluation prosthetic complications. Bone scan, performed with technetium-99 m (Tc-99 m)-labeled diphosphonates, is highly sensitive for detecting complications of lower extremity prosthetic joint surgery (Fig. 11.6). Both infection and aseptic loosening may show increased uptake on delayed images, but the test is not specific mostly in the early post-operative period [22]. Furthermore, even in the absence of complications, persistent periprosthetic activity has been shown to be increased for up to 2 years because of continued post-operative reparative osteoblastic activity, and performing the bone scan as a three-phase study does not improve the accuracy of the test. As a matter of fact, the blood pool images may also show increased activity in both loosening and infection. Despite the overall accuracy of bone scintigraphy in evaluation of the painful prosthetic joint is about 50–70 %, this study has a high negative predictive value and a negative bone scan excludes both loosening and infection. Therefore, it may be use as an initial screening test in conjunction with other diagnostic tests [22].

Sequential bone/gallium imaging is often performed along with a bone scan and the studies are interpreted together, but it is nonspecific and offers only a slight improvement over bone scintigraphy alone and is of limited value in differentiating prosthetic joint infection from other causes of prosthetic failure.

Labeled leukocyte [white blood cell (WBC)] imaging has been proposed as the radionuclide procedure of choice for diagnosing prosthetic infection (Fig. 11.7). Bone scan combined with Indium-111-labeled WBC has a low sensitivity and specificity, but both are increased when a Tc-99 m sulfur colloid marrow scan is done in addition offering the accuracy up to 95 % [5]. The principle of combined WBC/marrow imaging is based on the fact that WBC and marrow images both reflect radiotracer accumulation in the reticuloendothelial cells, or fixed macrophages, of the marrow. Normal individuals and in those with underlying marrow abnormalities show either a similar or spatially congruent distribution of marrow activity on WBC and marrow images. Osteomyelitis, including prosthetic joint infection, which stimulates uptake of leukocytes but suppresses uptake of sulfur colloid, results in spatially incongruent images.

^{18}F-fluorodeoxyglucose positron emission tomography (FDG-PET) has been reported to be effective for diagnosing prosthetic joint infection, since studies have shown sensitivity and specificity of 100 and 86 %, respectively, in limited numbers [5]. FDG is transported into cells via glucose transporters, but unlike glucose, it is not metabolized and remains trapped within the cell. Normal bone marrow has only a low glucose metabolism under physiologic conditions, whereas the infection shows an increased FDG uptake due to increased expression of glucose transporters in inflammatory cells and increased affinity of these glucose transporters for deoxyglucose. Degenerative bone changes usually show only faintly increased FDG uptake compared with infection. In spite of the fact FDG-PET has generated considerable interest because of its advantages, studies have concluded that PET offers no benefit over standard three-phase bone scans so far [22].

The emergence of hybrid modality imaging using integrated single photon emission computed tomography (SPECT) and PET with CT

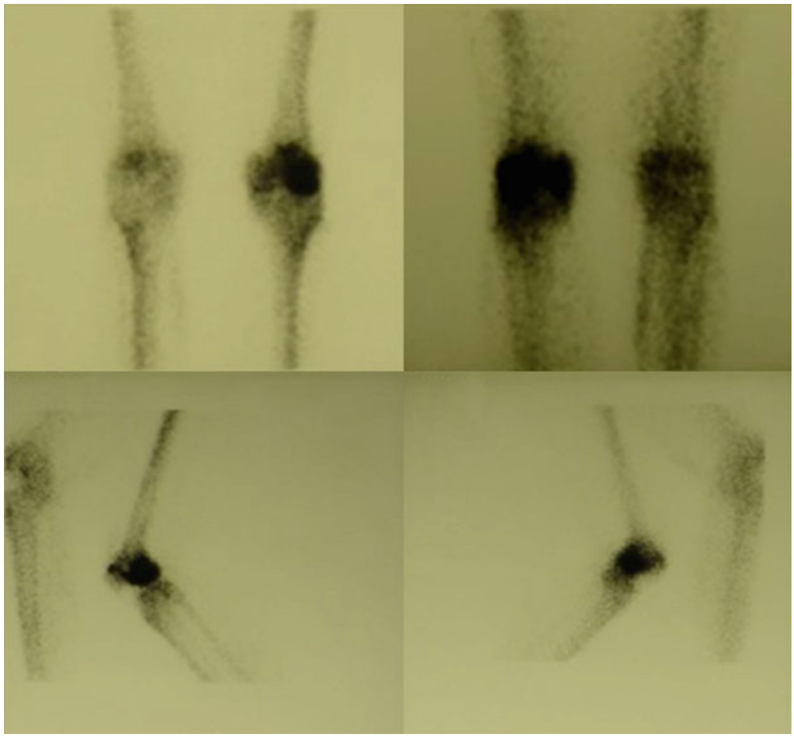

Fig. 11.6 Three-phase bone scan positive for infected TKR

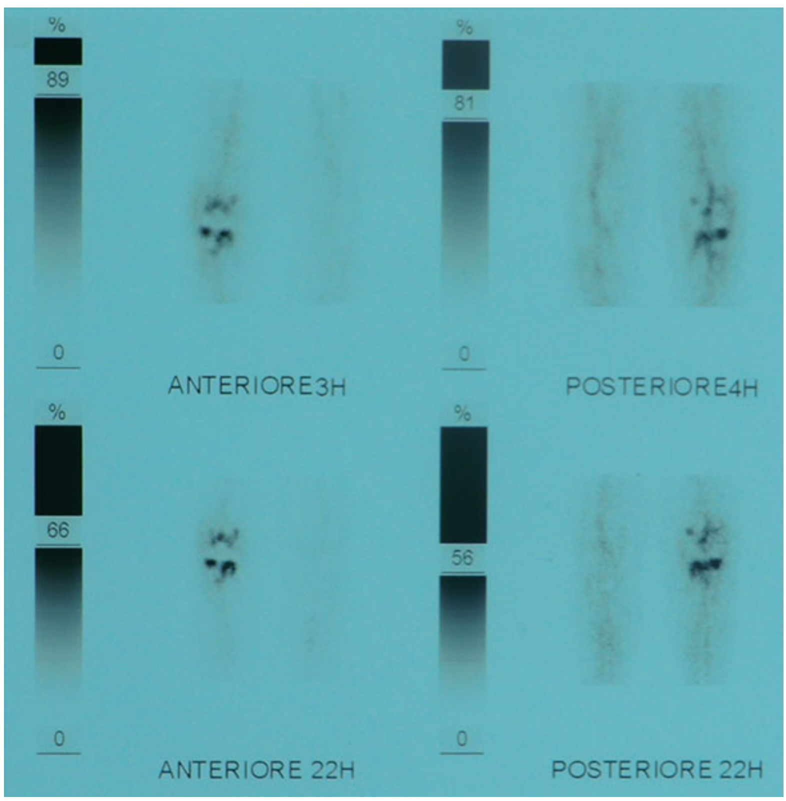

Fig. 11.7 Bone scan with Indium-111-labeled WBC. Positivity for infection in TKR

(SPECT/CT and PET/CT) may also have a contributing role for more accurate assessment of joint replacement complications, especially combined with new radiotracers [22].

11.5 Conclusions

The role of the imaging is essential in achieving the best assessment of the prosthetic knee in both preoperative and post-operative stages. Conventional radiology is still the cornerstone of both the preoperative diagnosis and planning and post-operative follow-up. In addition to radiographs, a wide number of diagnostic techniques such ultrasonography, CT, MRI, and nuclear medicine studies are available nowadays to investigate post-operative complications. However, in some cases of painful TKRs, the diagnosis is uncertain despite precise and complete imaging studies. Further studies and new technologies are necessary for a more anatomic reconstruction and to diagnose earlier complications such infections, upgrading the overall outcome of knee replacements.

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