Imaging of prosthetic joints

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The changing demographics of our society and improvements in surgical techniques have meant that an increasing percentage of the population has one or more prosthetic joint. Imaging is required for the initial assessment, routine follow up and in patients with suspected complications. The radiologist should have sufficient background knowledge regarding the operative techniques employed in joint replacement surgery to be able to make an accurate assessment of radiographs of prosthetic joints. The radiologist should also be aware of the strengths and limitations

Summary

- Plain films are usually sufficient to assess the state of a prosthesis.

- Criteria for loosening depends on site and make of prosthesis.

- The wider and more extensive the periprosthetic lucency is, the higher the chance of loosening. Progressive changes are more significant.

- Scintigraphy is a sensitive but non specific technique for diagnosing loosening.

- Ultrasound and MRI are useful for assessing soft tissue collections.

- Diagnosing infection may require joint aspiration or biopsy.

Figure 1. Periprosthetic fracture. The tip of the prosthesis has breached the cortex of the femur (arrows).

Figure 2. Dislocation of the hip joint soon after surgery.
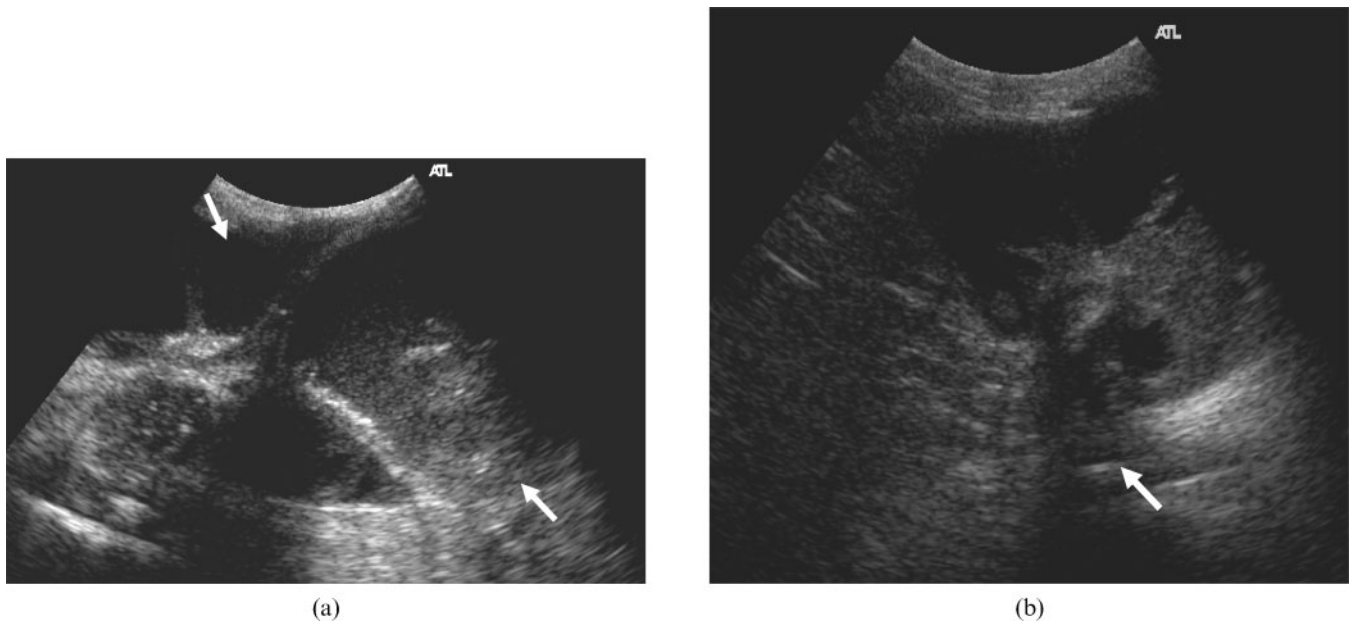
(a)

(b)

Figure 3. Ultrasound of an infected hip. (a) There is a large multilocular collection with an echogenic component (arrows). (b) The collection lies just deep to the scar but is seen to extend down to the neck of the femoral component which appears as a well defined echogenic line (arrow).
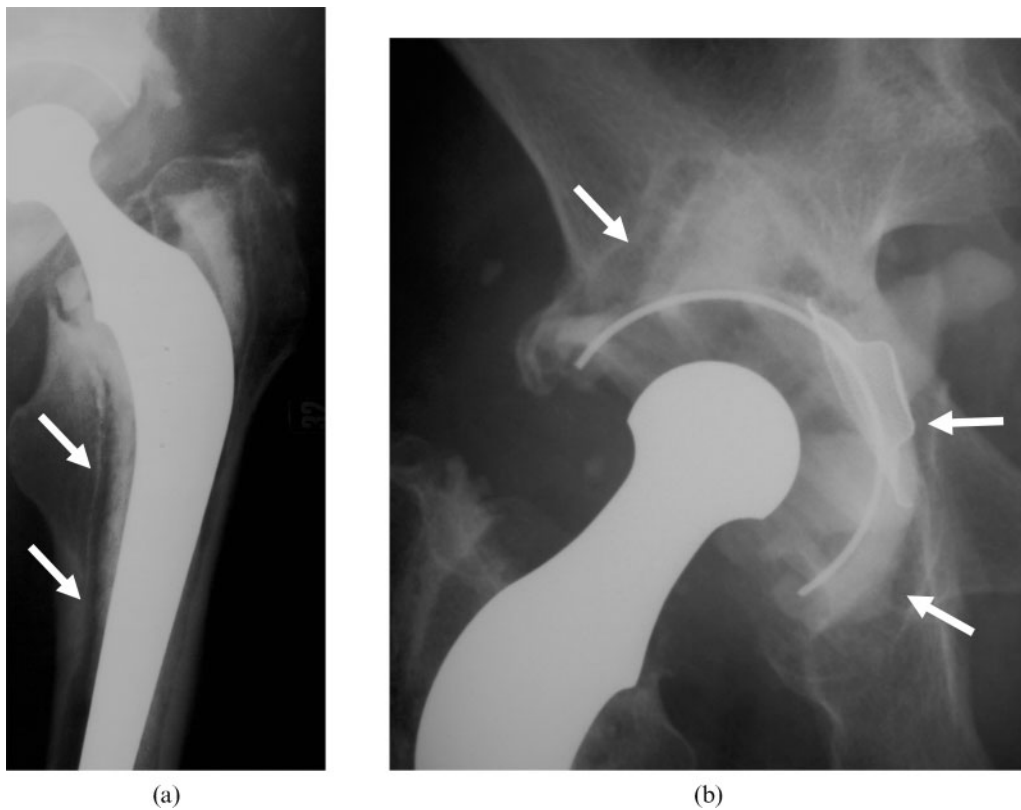

(a)

(b)

Figure 4. Loose cemented prostheses. Wide extensive lucency at the bone/cement interface is seen at (a) a femoral and (b) an acetabular component (arrows).

of the various techniques available to investigate complications. As joint replacement has become more prevalent, a myriad of prostheses have become available. The radiological criteria for diagnosing failure of a prosthesis may depend on the type of prosthesis and technique used.

Plain films are the mainstay for assessing joint replacements, and most management decisions can be made without resort to more complex imaging. Ultrasound, MRI scintigraphy, arthrography, aspirations and biopsies all have a part to play in the investigation of complications.
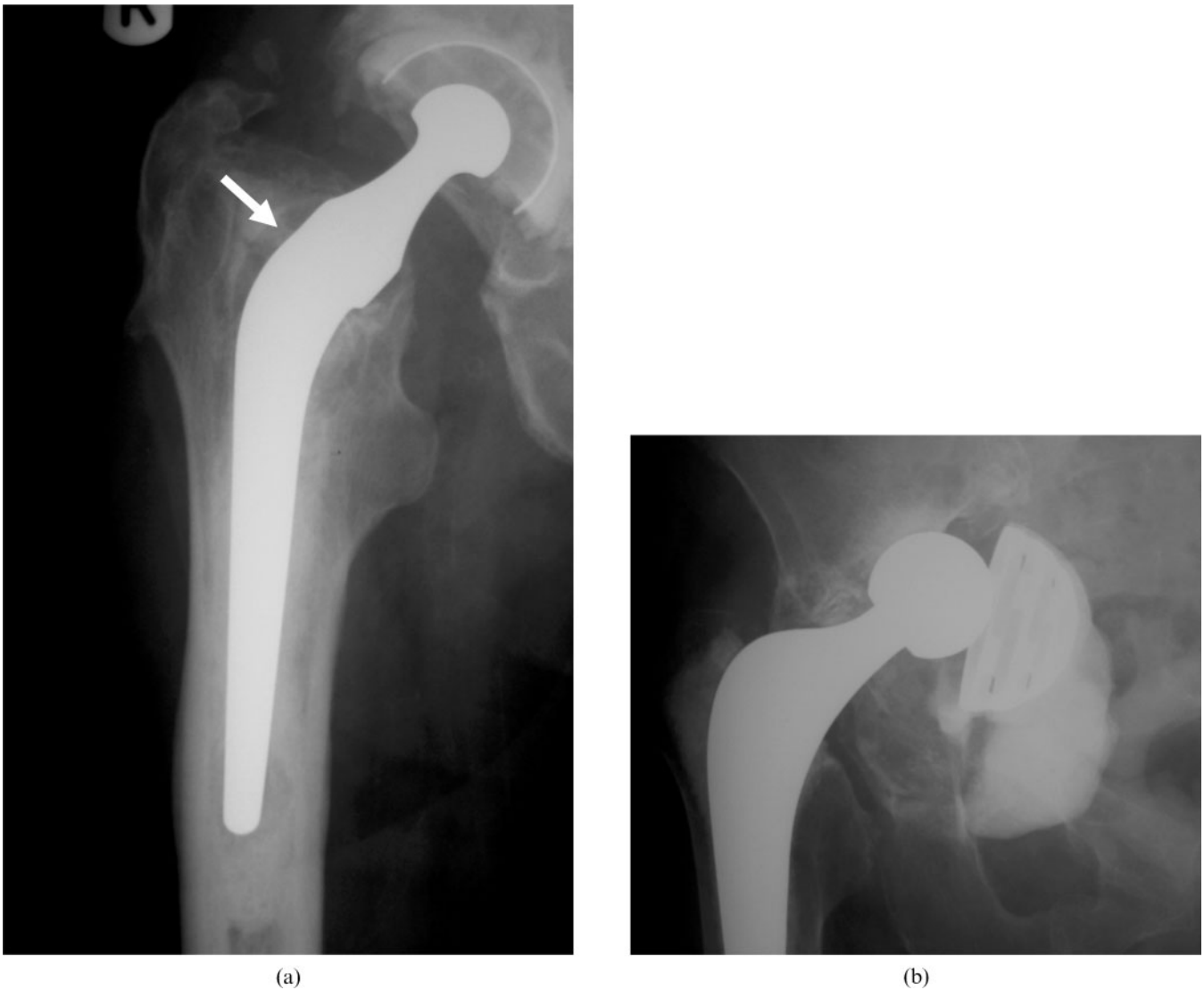
Figure 5. Migration of the prosthesis. (a) Femoral component showing subsidence with wide lucency at the prosthesis cement interface proximally and laterally (arrow). (b) Acetabular migration. The cup and cement has migrated medially into the pelvis.

The hip

Approximately 38 000 hips are replaced each year in England and Wales. It is estimated that 60 different hip prostheses are currently available to National Health Service surgeons in the UK. However, the basic principle has changed little from the original Charnley design.

Total hip replacements consist of an acetabular and femoral component. The components may be cemented or uncemented. Uncemented components may have a proximal porous coating to encourage bone in-growth. The radiographic signs of loosening differ between the cemented and uncemented varieties. Surface femoral replacements are increasingly being used in the younger age group to preserve bone stock. Femoral hemiarthroplasty is used in displaced intracapsular fractures in hips without major osteoarthritis when it is considered that the native acetabulum will survive longer than the patient. Assessment of a revision arthroplasty is more challenging and heavily relies on examining serial radiographs.

Early post-operative complications

In the immediate post operative period a plain film is routinely performed. The position of the femoral prosthesis should be noted. An excessively varus stem may predispose to loosening. Periprosthetic fracture may be seen particularly in revision prostheses and patients with poor bone stock (Figure 1). Dislocation is a common early complication with an incidence of approximately 3% (Figure 2).

Early post-operative haematoma and infection are quite common. Ultrasound is an excellent technique for identifying soft tissue collections and guiding aspiration in these cases. Ultrasound can also usually determine whether a superficial collection communicates with the hip joint or not (Figure 3). MRI will often provide better anatomical detail for pre-operative planning in extensive deep collections although the portion of the image adjacent to the prosthesis will be degraded by metal artefact.

Delayed complications

Infection and aseptic loosening are the two main delayed complications. Delayed infection usually manifests

Figure 6. Loose femoral component. There is a fracture of the cement around the distal end of the femoral component indicating loosening.

Figure 7. Loose femoral component. There is a fracture of the prosthesis (arrow).

itself in the first 2 years following replacement whereas aseptic loosening is unusual at such an early stage. However, there is considerable overlap and differentiating these two entities may be difficult. When a patient re-presents with hip pain the two questions to be answered are a) is the pain related to the prosthesis? and b) is there infection present? A combination of clinical, laboratory and imaging criteria is often needed to assess the likelihood of infection. A typical clinical picture with supporting plain film features are usually all that is required but in difficult cases the radiologist may receive requests for scintigraphy, arthrography, local anaesthetic injection, joint fluid aspiration and capsular biopsy.

The main purpose of the plain film is to diagnose loosening of the prosthesis. Femoral component fixation has gone full circle. The original designs were uncemented. Cement was developed to attempt to provide greater longevity but has been implicated in periprosthetic bone loss due to particle induced osteolysis. Modern uncemented prostheses have porous coating to encourage bone in-growth and are increasingly being used in the younger age group. Outcomes with the best uncemented designs are now similar to their established cemented counterparts.

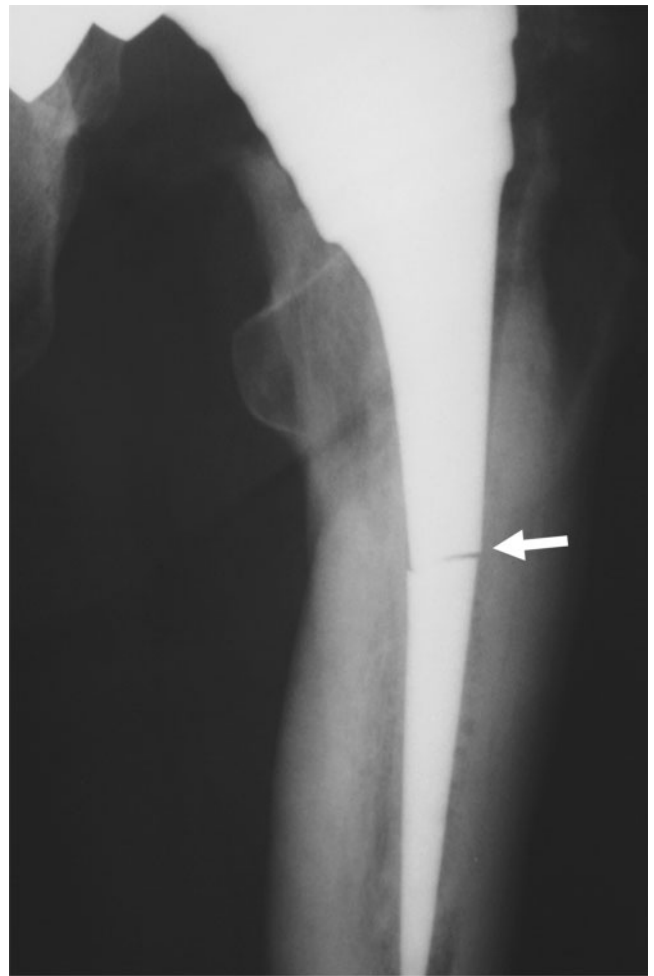In a cemented prosthesis the most common sign of loosening is lucency at the bone–cement interface. The wider and more extensive the lucency, the more probable the component will be found to be loose at surgery (Figure 4). There are no hard radiological rules for diagnosing loosening but stem or cement fracture, 5 mm of subsidence, progressive radiolucency at the bone–cement interface or lucency 2 mm wide or greater than 50% of the interface have been quoted as criteria for femoral stem loosening (Figures 5–7) [1]. The significance of lucency around the acetabular component is less certain. It is generally accepted that a stable lucency of less than 2 mm at the bone–cement interface may be seen with loosening. Lucencies involving only part of the acetabular bone cement interface are also of doubtful significance.

The radiographic appearances of the uncemented differ from the cemented prosthesis. There is a positive correlation between the extent and width of periprosthetic lucency and clinical loosening. However some lucency is commonly seen in the stable hip [2]. There is a range of appearances on the normal uncemented femoral component including cortical hypertrophy, non progressive radiolucent lines less than 2 mm thick, partial and complete sclerotic pedestal at the tip of the femoral prosthesis, and subsidence of less than 2 mm [3]. However these features may also be associated with a failing hip (Figures 8 and 9). Lucency adjacent to the proximal porous coated portion of the stem is more significant. Specific features of
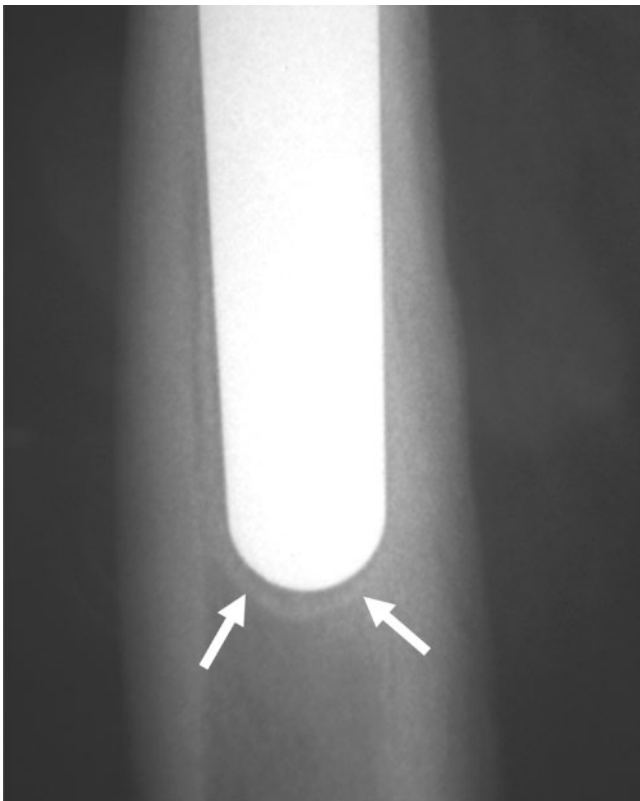
Figure 8. Loose uncemented femoral component. There is excessive lucency seen around the tip of the uncemented prosthesis indicating loosening (arrows).
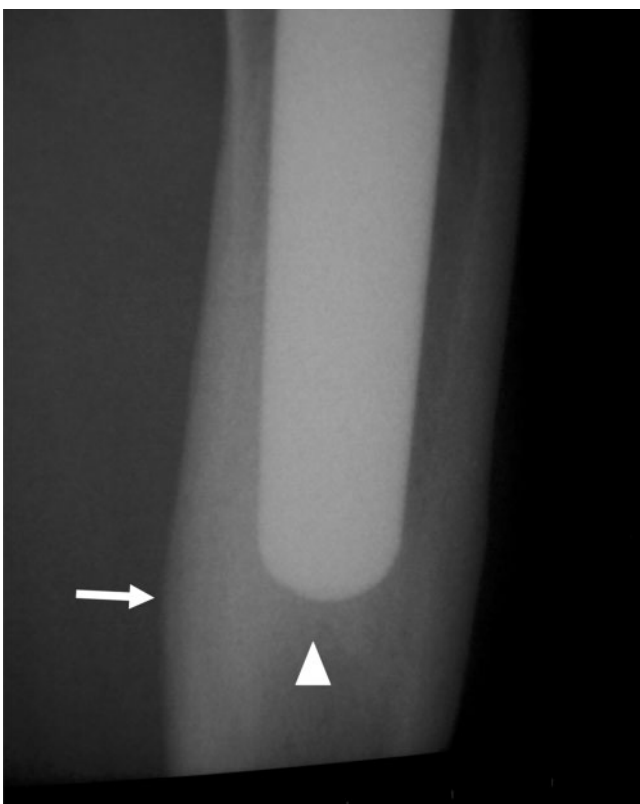

Figure 9. Uncemented femoral component. Cortical thickening (arrow) and pedestal formation (arrowhead) at the tip of an uncemented femoral prosthesis. Although associated with loosening these signs can be seen in asymptomatic hips.
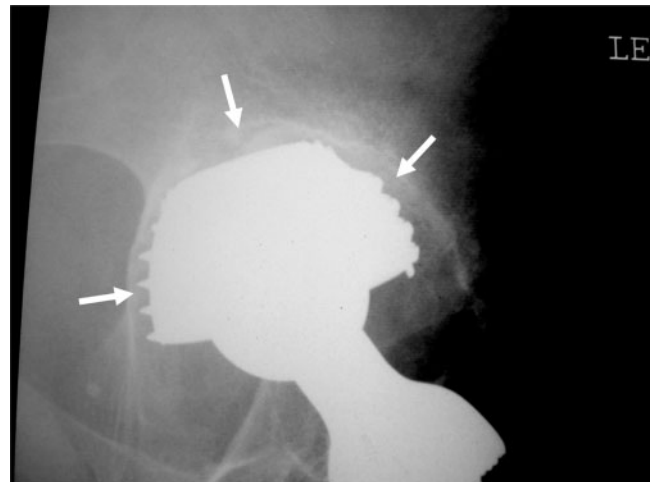

Figure 10. Loose uncemented acetabular component. This threaded screw design had a high failure rate. There is extensive lucency around the component (arrows).
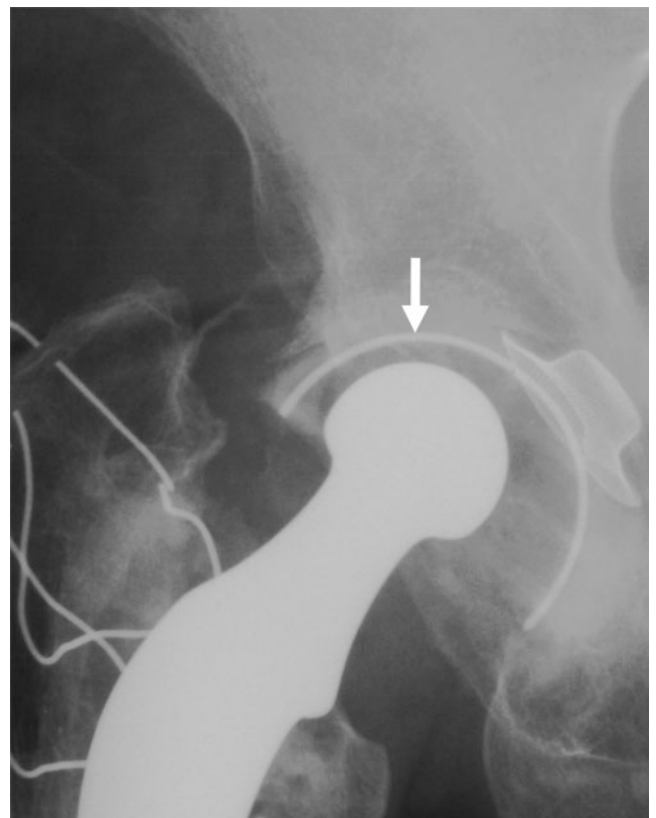

Figure 11. Wear of polyethylene liner. There is marked loss of the liner superiorly (arrow). The resulting microscopic fragments may stimulate granuloma formation.

prosthetic failure include a radiolucent line greater than 2 mm in width, progression of lucencies and the appearance of new lucency after 2 years from insertion [4] (Figure 10). As progression of any lucency over a period of time is a good indicator of loosening it is important to compare the current film with previous radiographs. As with the cemented variety any excessive migration also is indicative of loosening.
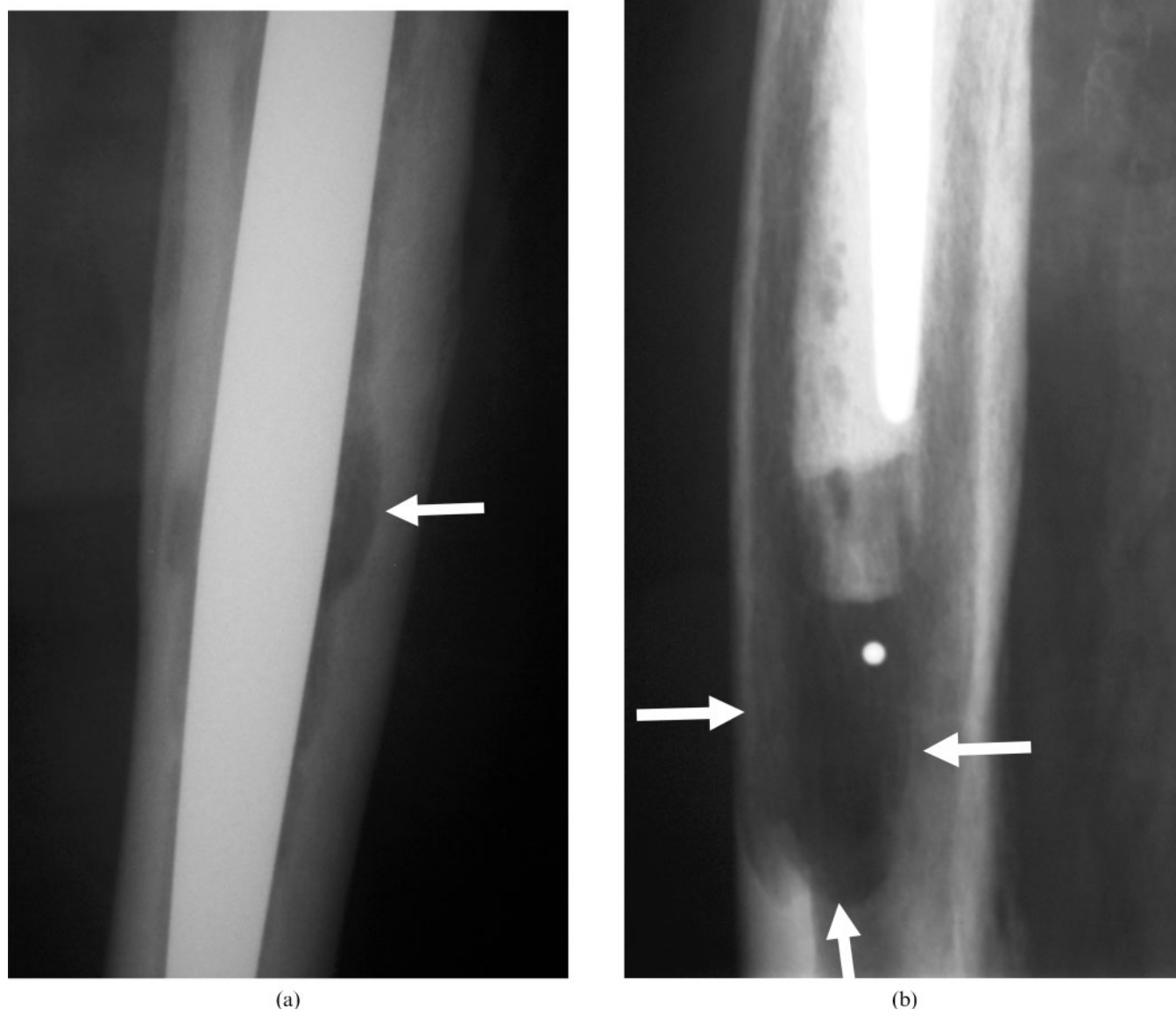
(a)

(b)

Figure 12. Granuloma formation. (a) Focal endosteal scalloping at the distal end of the prosthesis indicating histiocytic granuloma formation (arrow) and (b) more extensive bony destruction distal to the tip of the femoral prosthesis (arrows).

Another feature indicating impending failure in both cemented and uncemented prostheses is focal osteolysis. This is due to granuloma formation as a response to microsopic particles of cement, polyethylene or metal. Wear of the polyethylene acetabular cup is thought to be a common cause of this complication (Figure 11). Osteolysis is usually seen as focal endosteal scalloping at the femoral site or bone destruction under the acetabular component. Massive osteolysis with soft tissue mass may occur [5] (Figure 12).

There is a recognised convention for describing the position of periprosthetic lucencies (or any other abnormality) that divides the acetabular component into 3 zones and the femoral into 7 zones [6, 7] (Figure 13).

Arthrography used to be commonly performed to diagnose loosening but this technique has been abandoned by many centres. Loosening is diagnosed if dye is seen to extend into the periprosthetic lucency. Digital subtraction

techniques can be used to increase the sensitivity. Unfortunately the test does not add significantly to the plain film findings for the femoral component [8] and is non specific for the acetabular component [9]. Positive results are seen in patients without pain and false negative results are common. Communication with the trochanteric bursa, which is common, further reduces sensitivity as a good intra-articular pressure cannot be established (Figure 14).

Injecting local anaesthetic into the joint is an easy procedure to perform. A positive response to intra-articular injection of local anaesthetic may help predict that a revision will be successful [10].

The revision rate for infection is around 1%. Although usually seen within 2 years of surgery delayed infection may occur due to haematological seeding from a remote site [11]. The diagnosis of infection can prove to be difficult on both clinical and imaging grounds [12]. The
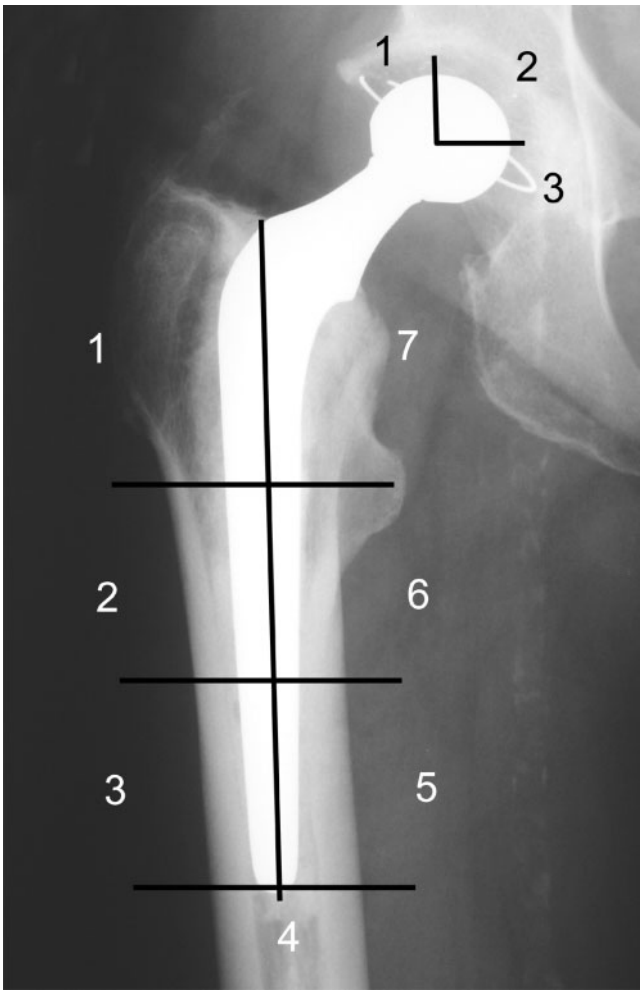
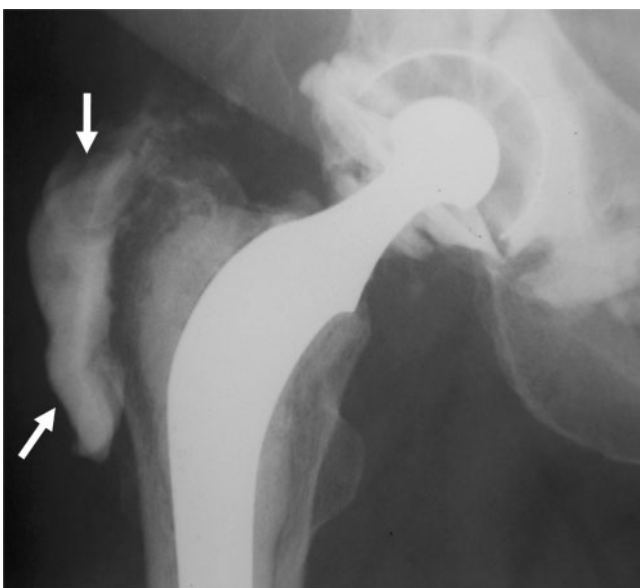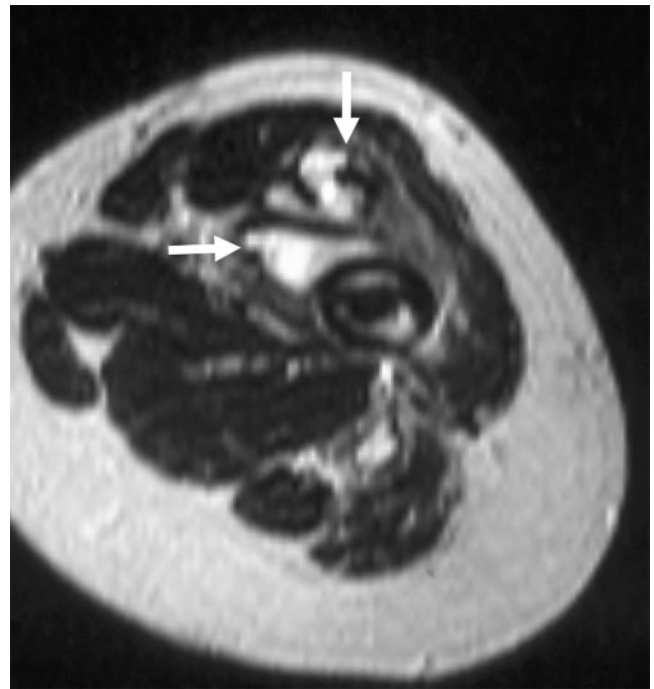**Figure 13.** The seven femoral and three acetabular zones as described by Gruen and Delee [6, 7].

Figure 15. MRI of periprosthetic abscess. T_2 weighted axial image showing a high signal collection adjacent to the femur (arrows). Note that there is only minimal artefact from the prosthesis.
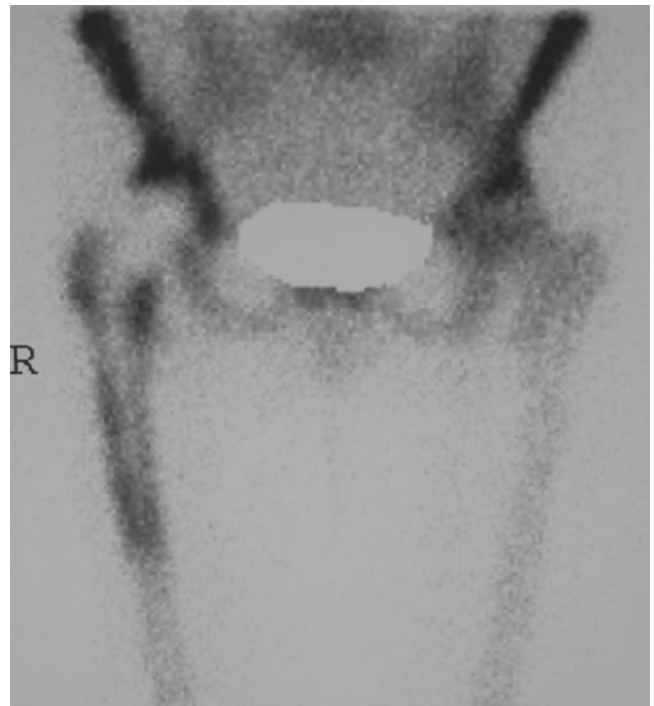

Figure 14. Arthrogram showing communication with the trochanteric bursa (arrows).

Figure 16. Bone scan showing diffuse uptake around the femoral prosthesis. Although this pattern may suggest infection it is also seen in aseptic loosening.

patient usually complains of persistent pain in the early life of the prosthesis. Plain radiographs may be normal or reveal periprosthetic lucency, periostial reaction and bone destruction. The infection is often indolent and confined to
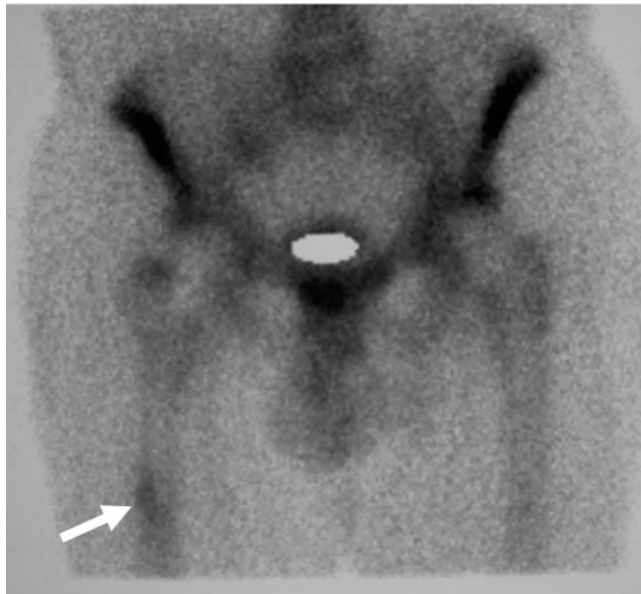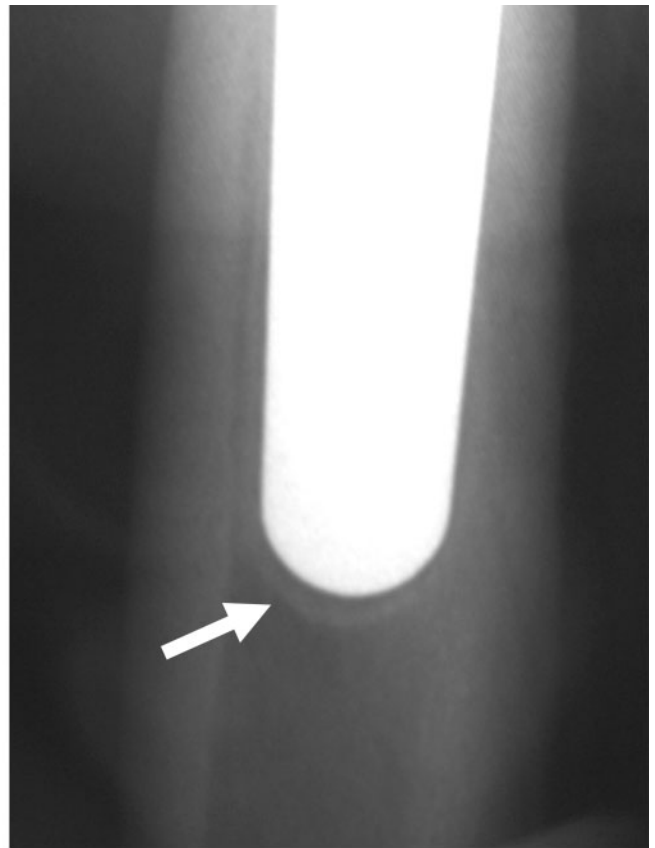
Figure 17. Bone scan in a patient with a painful uncemented total hip replacement. (a) There is focal uptake at the tip of the uncemented prosthesis. (b) Plain film shows a lucency and sclerotic reactive line adjacent to the tip (arrow).

Figure 18. Normal appearances of a metal-on-metal surface replacement.

the hip joint. In more advanced cases there may be soft tissue swelling, and abscess formation. A simple technique is to aspirate the joint fluid under fluoroscopic guidance. If microbiological analysis of the fluid is negative then capsular and periprosthetic bone biopsy may improve the diagnostic yield. Frozen section at time of revision is a reliable method of identifying infection. If positive a two stage procedure will be performed [13].

Ultrasound and MRI are useful in assessing the extent of any soft tissue abscess although metal artefact will obscure the image near the prosthesis on MRI (Figure 15). On ultrasound infection should be suspected if there is a large joint effusion with or without extra-articular extension of fluid [14].

In difficult cases bone scintigraphy may be useful as a normal study is a good indicator that the hip is not loose or infected. A positive result is less useful and is seen in normal prostheses for at least 1 year after replacement. The significance of minor focal periprosthetic uptake is not established. Diffuse intense increased uptake favours infection but can be seen in aseptic loosening (Figure 16). Focal increased uptake around the tip of the femoral component is a sign of loosening in cemented prostheses but is a less reliable sign in uncemented designs (Figure 17). Blood pool images can be positive in aseptic loosening and infection [15].

A number of other nuclear medicine techniques have been advocated to diagnose chronic infection. Gallium scanning is sensitive but not very specific, being positive in aseptic inflammatory conditions. Labelled white cells has a low sensitivity and specificity but is more accurate if combined with a marrow scan to negate the effect of normal marrow leukocytes. Unfortunately this test is costly and time consuming [16]. Labelled antigranocyte monoclonal antibodies is a new agent but early work raises doubts regarding sensitive and specific for bone infection

Figure 19. Failed hemiarthroplasty. The head has migrated medially into the pelvis (arrow). There is also lucency at the cement–bone interface (arrow heads).

[17, 18]. ^{18}F-FDG PET scanning is a promising technique being both sensitive and specific for infection related to hip prostheses [19].

Loosening, infection and osteonecrosis are complications that may be seen in the surface replacements. In the past surface replacements have had a high rate of loosening due the excessive wear of the polyethelene liner so modern designs have a metal acetabular socket (Figure 18).

Femoral hemiarthroplasty used in the elderly with intracaspular fractures usually out-survive the patient. However, wear of the native acetabulum may occur in active patients and conversion to total hip replacement may be indicated (Figure 19).

Assessment of revision prostheses poses further problems as residual radiolucent zones are common. The diagnosis of loosening has to be made by comparing the width and extent of the lucent zones on serial radiographs (Figure 20).

A complication that may affect any type of prosthesis is periarticular heterotopic ossification. Patients with ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis (DISH) and hypertrophic osteoarthritis are at higher risk [20]. Although minor ossification may be of no clinical significance, extensive ossification may result in
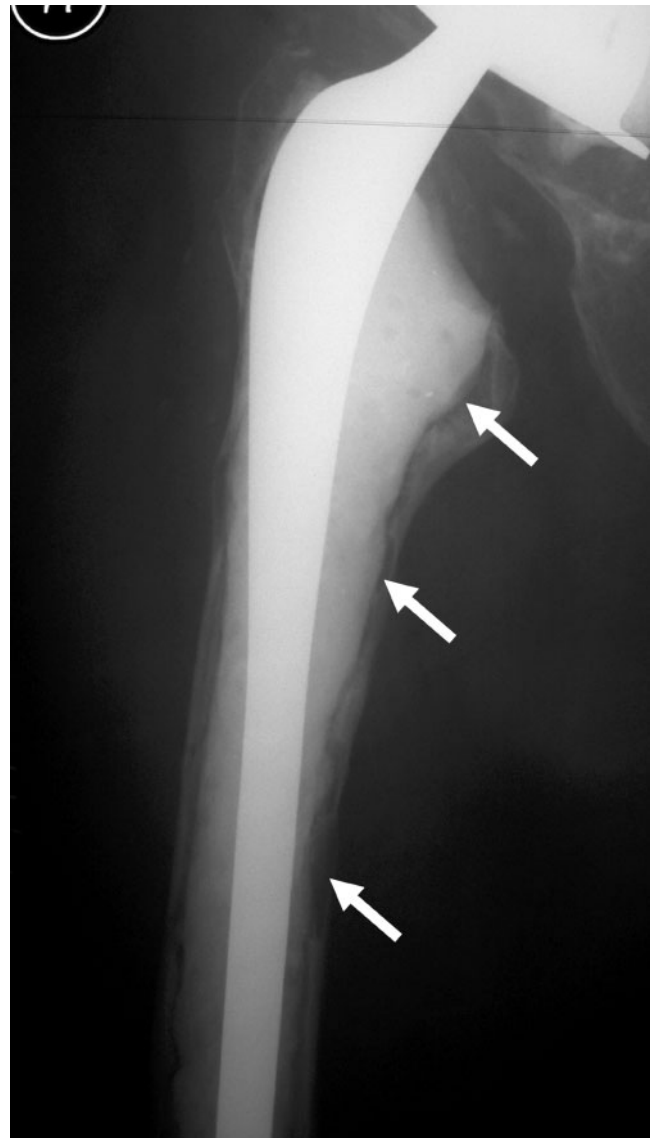

Figure 20. Revision total hip replacement. There is a wide lucency around the femoral component (arrows) which may be a normal appearance following revision.

reduced range of movement and even fusion of the joint (Figure 21).

The knee

It is estimated that more than 35 000 knee replacements were performed in the UK in the year 2000. Imaging follows similar principles to that of the hip, with one or two additional features relating to the design of the prosthesis. Most prosthetic knees consist of metallic femoral and metal backed polyethylene tibial components (which may be cemented or non-cemented). A patella button may be used where necessary. As with the hip, aseptic loosening and infection are the most common complications. Ongoing pain in the knee without features of loosening is also recognised.

Although the radiological criteria for loosening are not as well established as that for the hip, a scoring system for monitoring progression has been developed by the Knee
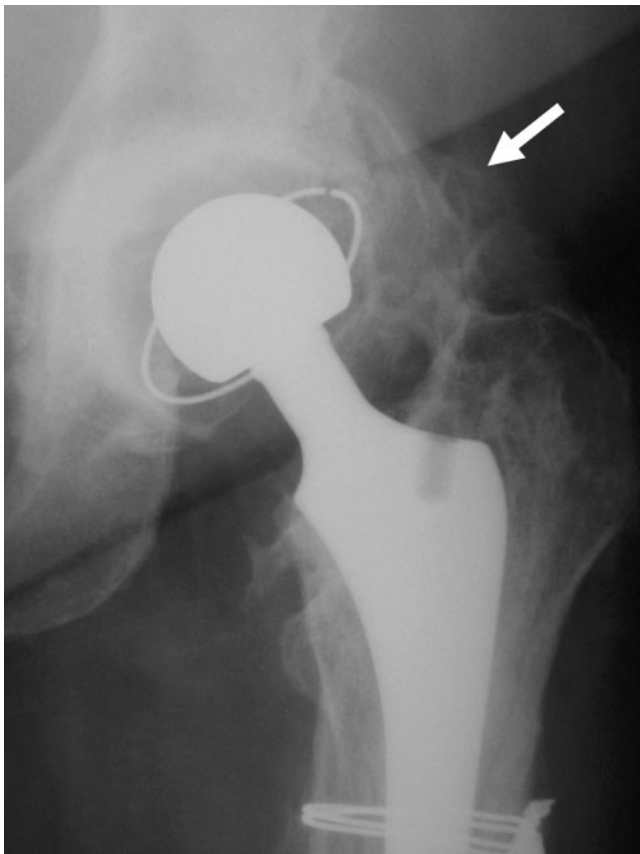
Figure 21. Heterotopic ossification following total hip replacement. There is extensive soft tissue ossification laterally which has fused the hip joint (arrow).
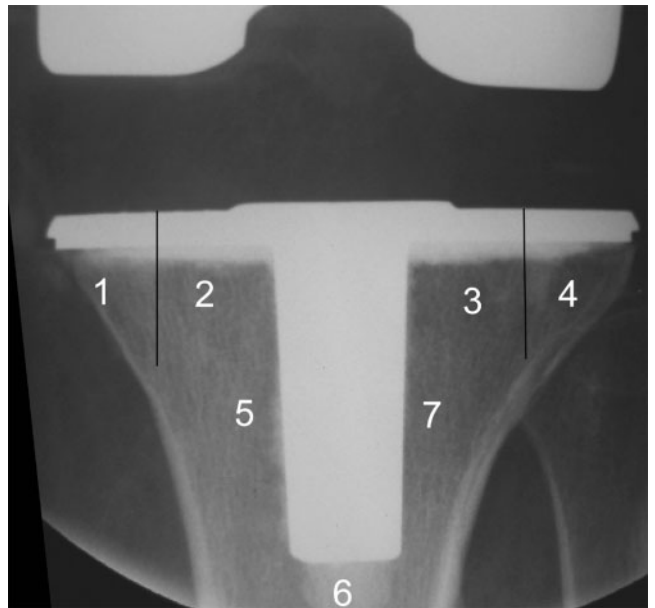

Figure 22. The seven zone of the tibial component used by the Knee Society scoring system.

Society. The score for a component is the sum of the maximum width of lucency for a given specified zone (Figure 22). For the commonly affected 7-zone tibial component a score of greater than 10 implies impending failure whereas a score of less than 4 without progression can be regarded as not significant [21] (Figure 23). Areas of ill defined bony resorption suggest infection (Figure 24).
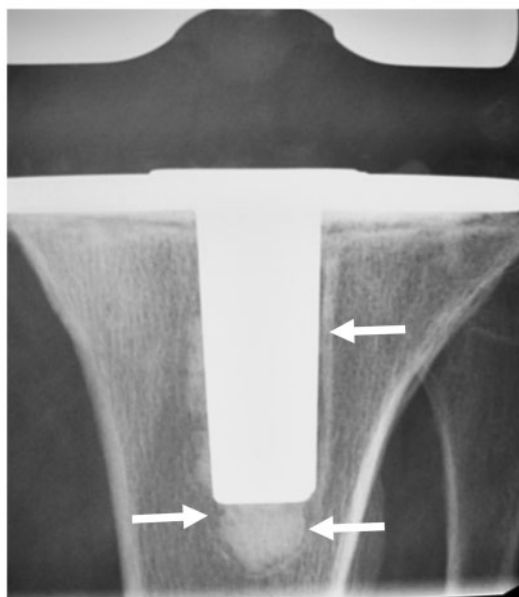
Figure 23. Aseptic loosening of a total knee replacement. (a) Normal immediate post-operative film. (b) 3 years following surgery there is a wide radiolucency under the tibial plate and around the stem at the bone/cement and prosthesis/cement interfaces (arrows).
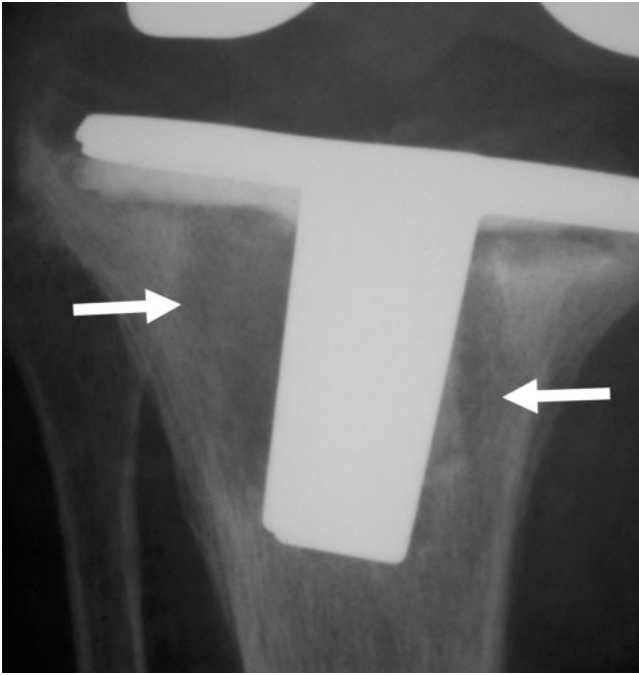
Figure 24. Infected total knee replacement. There is extensive bony destruction around the tibial component (arrows).
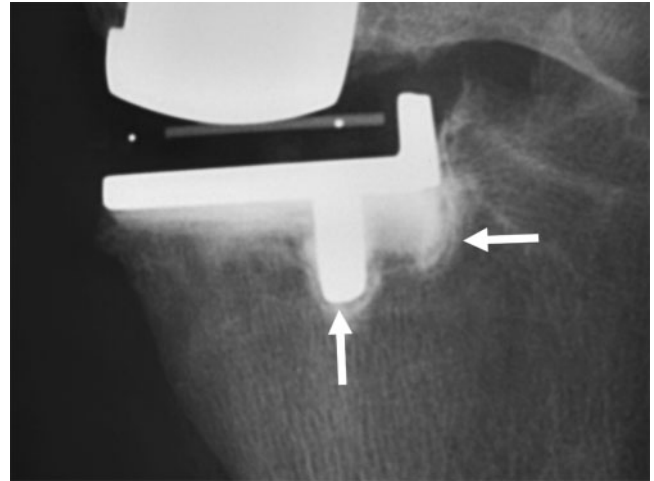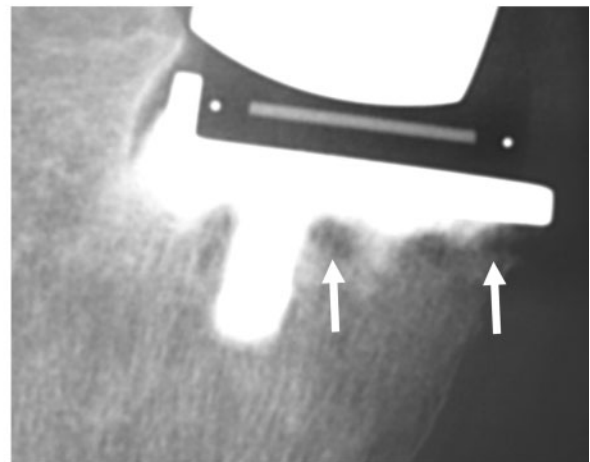

Figure 25. Unicompartmental knee replacement. There is lucency at the bone/cement interface of the tibial component which is within normal limits for this particular design.

As with all prostheses, migration or marked osteolysis also indicates impending prosthetic failure.

Unicompartmental replacements are used predominately for medial osteoarthritis when lateral joint space is preserved as determined by pre-operative valgus stress

(a)

(b)

(c)

Figure 26. Infected unicompartmental knee replacement. (a) The immediate post-operative pictures show normal replacement. (b) 1 month later there is bone destruction under the tibial plate (arrows) and (c) loss of lateral joint space.
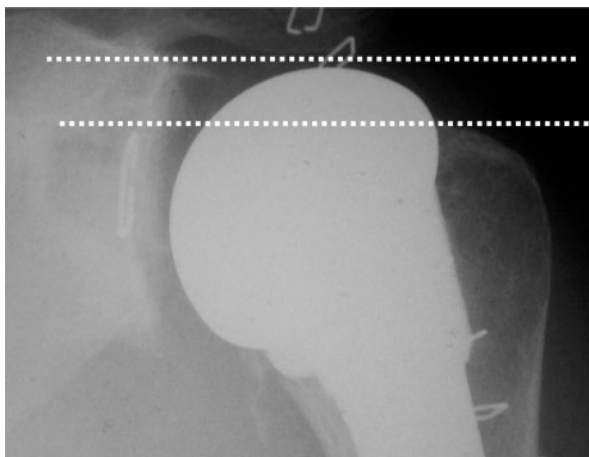
Figure 27. Normal post-operative appearance of a total shoulder replacement. The superior end of the humeral component lies above the superior tip of the greater tuberosity (dotted lines).
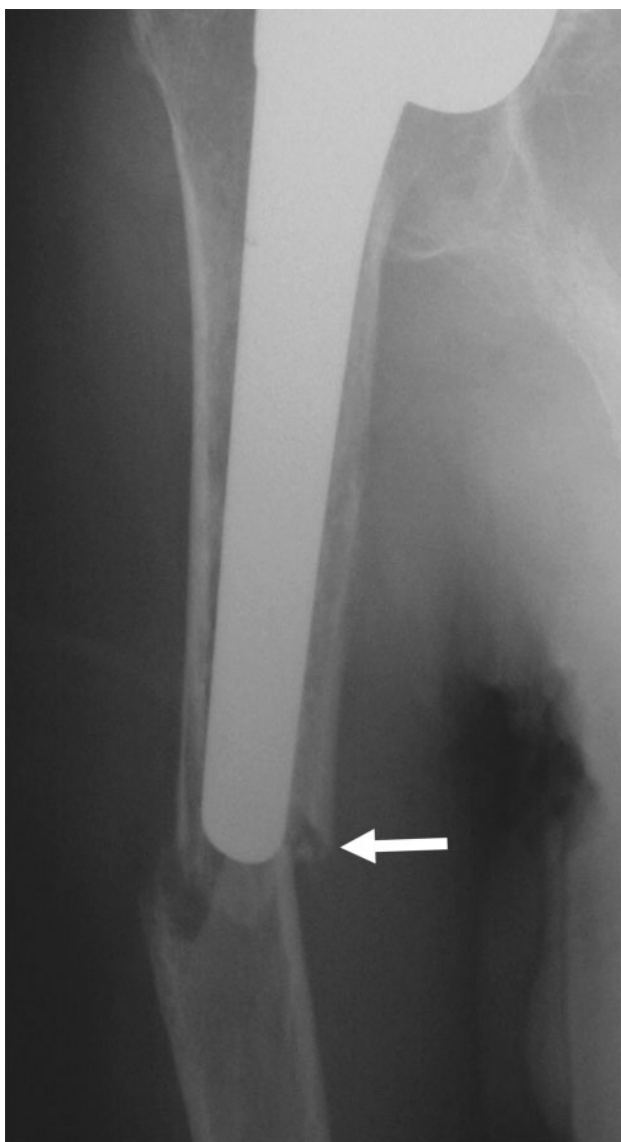

Figure 28. Periprosthetic fracture at the tip of the humeral component (arrow).
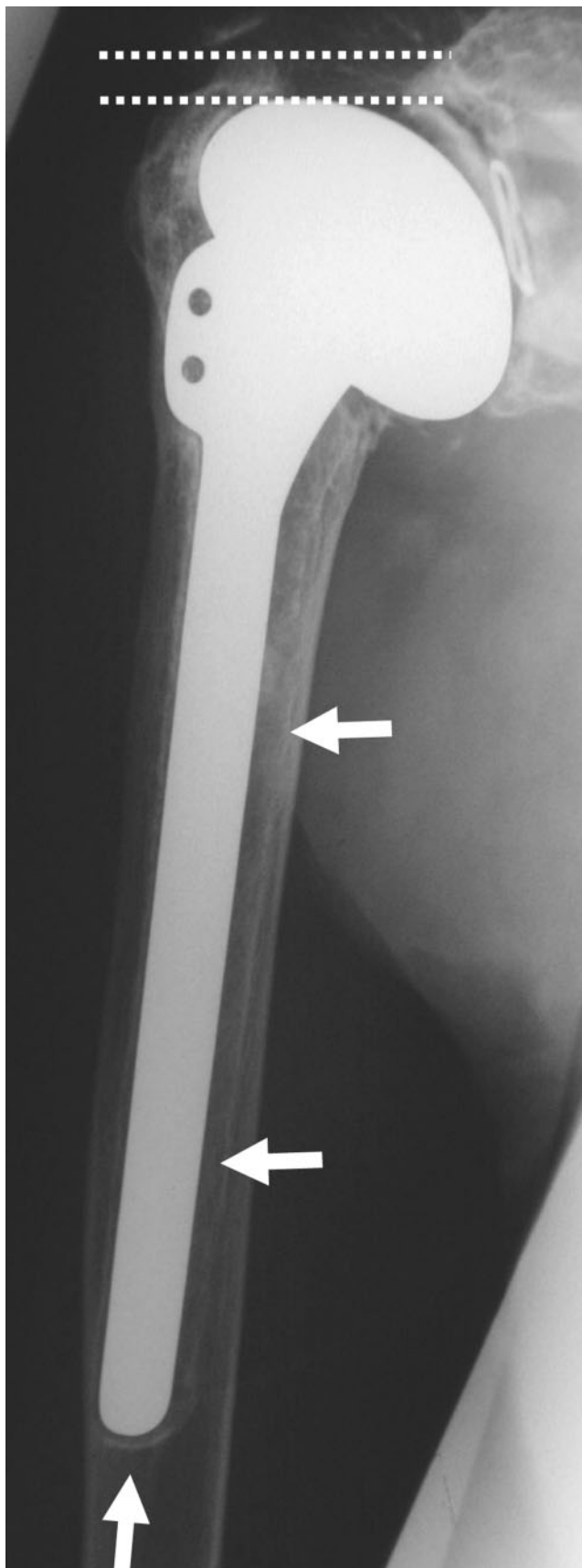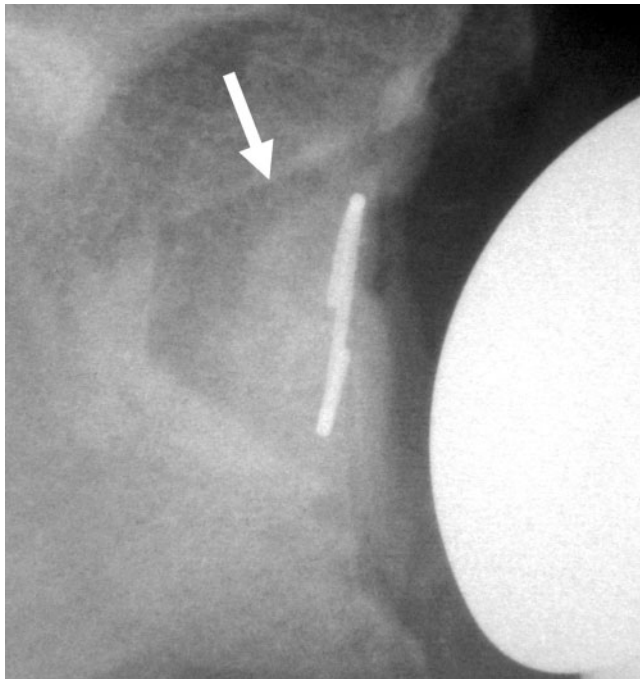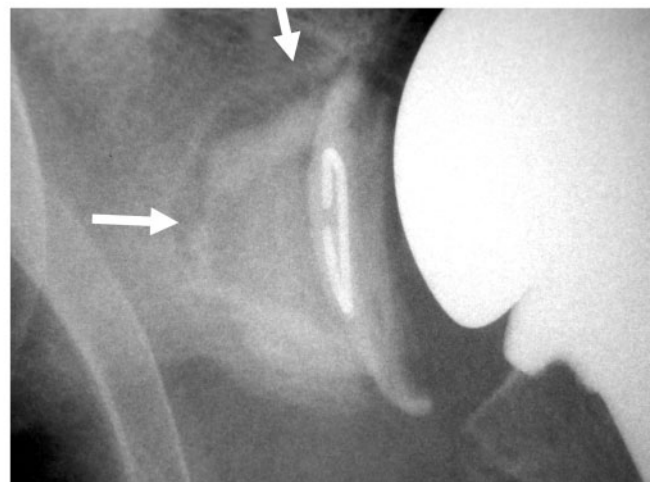

Figure 29. Loose total shoulder replacement. There is subsidence with the head positioned below the superior tip of greater tuberosity (dotted lines). There is a wide lucency seen around the prosthesis (arrows).

Figure 30. Displacement of humeral component of total shoulder replacement. The component is loose and has rotated approximally 180˚.

view or MRI. The signs of loosening and infection are similar to those seen in total knee replacements except that lucency around the tibial component of the commonly used Oxford prosthesis is a normal finding (Figures 25 and 26).

The shoulder

Shoulders may be replaced to relieve pain related rheumatoid or osteoarthritis or to reconstruct a joint following trauma. Like the hip, the chosen prostheses may be a hemiarthroplasty or a total replacement depending on the state of the glenoid and the rotator cuff. Hemiarthroplasty is usually used in humeral head fractures and osteoarthritis if the glenoid is relatively unaffected. In massive rotator cuff tears a hemiarthroplasty is appropriate as eccentric forces on the glenoid component due to a high humeral head will predispose to loosening of a glenoid replacement. Total replacements are performed in inflammatory arthropathies with intact cuff.

The main complications are loosening, infection and fracture. The glenoid component is particularly prone to loosening. An additional complication specific to the shoulder joint is that of impingement which may be due to poor positioning of the humeral prosthesis or subsidence. Impingement may occur if the most superior aspect of the prosthesis lies below the level of the superior tip of the greater tuberosity (Figures 27 and 29).

Periprosthetic fractures are usually obvious, and may occur at the time of surgery or following injury (Figure 28).

The radiographic signs of loosening is a lucent line around either the humeral or glenoid component.

(a)

(b)

Figure 31. Loose glenoid component of a total shoulder replacement. (a) Immediate post-operative film showing normal cemented component without lucency. (b) Film 18 months later shows marked lucency around the component indicating loosening.
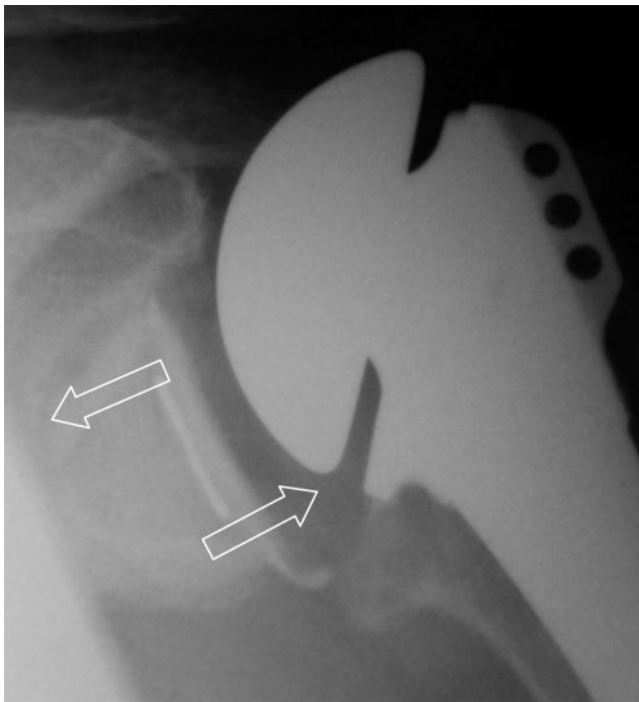
Figure 32. Loose glenoid component of a total shoulder replacement. The humeral head has migrated superiorly due to rotator cuff tear. The glenoid is loose and tilted due to the eccentric contact with the humeral component. Arrows demonstrate direction of rotation.

For the humeral component the criteria for loosening are similar to those used for the hip with periarticular lucency, subsidence and displacement being the key features (Figures 29 and 30). Lucency at the glenoid is harder to interpret. Lucency is often seen here on the immediate post operative film which is thought to be due to insufficient preparation of the bone bed. Reliable signs of loosening of the glenoid component are progressive periprosthetic lucency and migration (Figures 31 and 32). The rate of glenoid loosening is around 10% at 10 years.

Elbow

Elbow replacements are done almost exclusively for rheumatoid arthritis or trauma. Two main categories of prosthesis are the linked and the non-linked designs. The non-linked prosthesis requires adequate bone stock and intact ligaments to prevent instability, subluxation and dislocation.

Generally the complication rate is higher than that for hip or knee prostheses. Intraoperative complications include condyle fractures and shaft perforation, as well as ulnar nerve damage. Loosening may predominately involve the humeral or ulnar component depending on the individual design (Figure 33) [22, 23].

The ankle

Ankle arthroplasty is a relative newcomer to the gamut of joint replacements. It was developed in the 1970s with the idea of allowing more mobility than arthrodesis. However, until recently the procedure has had limited success, with a high failure rate and limited symptom

Figure 33. Loose hinged total elbow replacement. There is wide lucency around the humeral component (arrows) indicating loosening.

relief. A number of new devices on the market are resulting in satisfactory long term results [24].

The radiological criteria for identifying complications have not been well documented, but progressive lucency and migration are reliable signs of loosening (Figure 34). Cavity formation under the tibial component and fracture of the medial malleolus are other recorded complications (Figure 35) [25].

Conclusions

The imaging of complications of prostheses may be challenging. Fractures, dislocations and most cases of aseptic loosening can be diagnosed with a combination of clinical and plain radiographic features. Differentiating aseptic loosening from infection may be impossible on clinical or imaging criteria and biopsy of the periarticular tissue either prior to or at the time of surgery may be necessary.
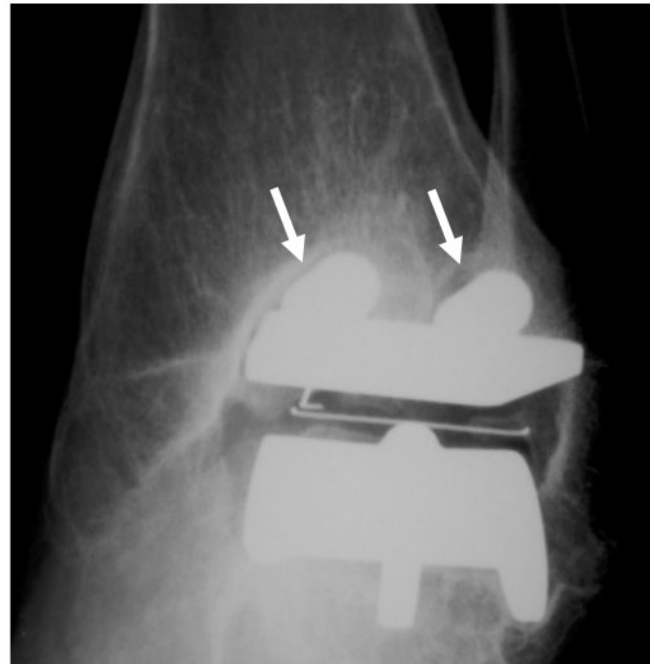
Figure 34. Loose Scandinavian Total Ankle Replacement (STAR). Frontal radiograph showing (a) the normal post-operative appearances and (b) marked lucency around the tibial component (arrows) indicating loosening.
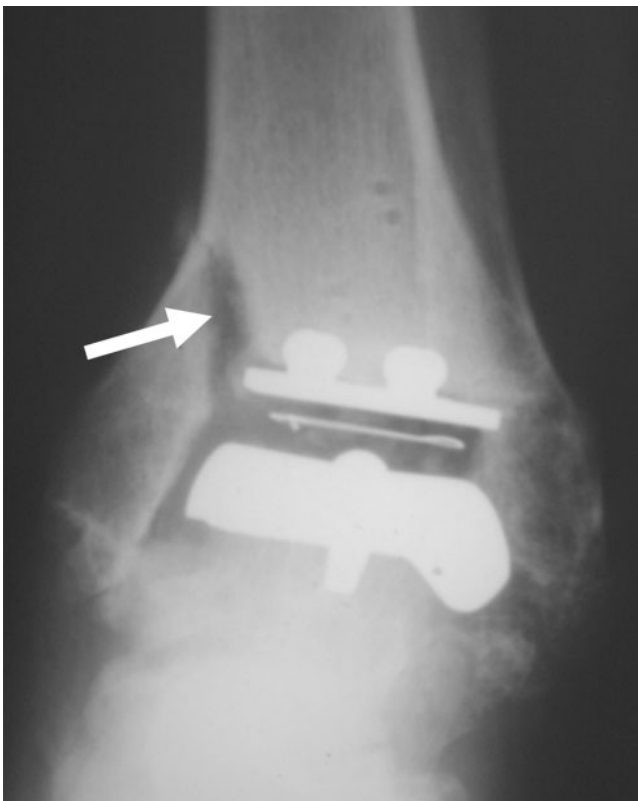

Figure 35. Total ankle replacement complicated by a fracture of the medial malleolus (arrow).

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