Radiographic evaluation of hip replacements

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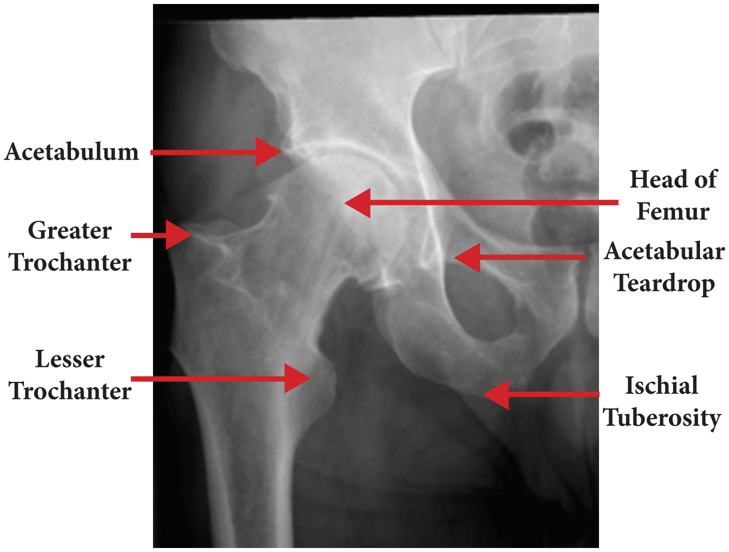

Figure 1: Radiographic anatomy of the hip joint

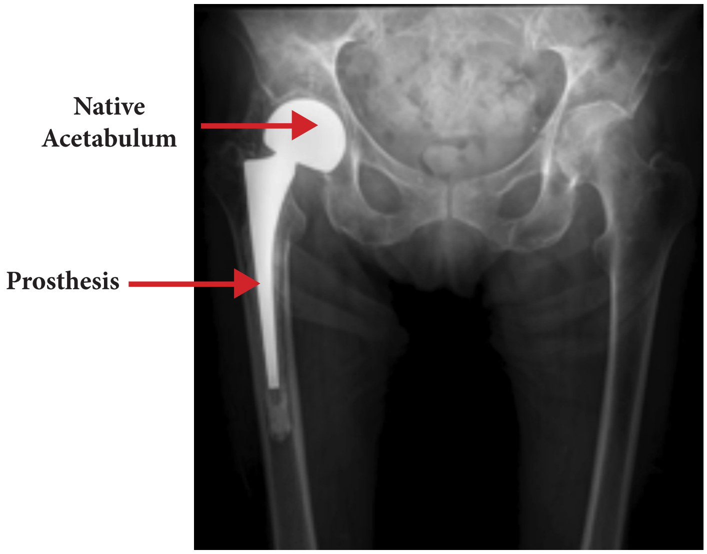

Figure 2: Hemiarthroplasty of the right hip

Introduction

Hip joint replacement surgery has been the most common type of elective and semi-elective orthopaedic operation for nearly 25 years, with approximately 300,000 hip arthroplasties performed worldwide each year.[1] Since their introduction, hip arthroplasties have proven remarkably successful in eliminating pain and restoring function in hips severely affected by conditions such as osteoarthritis.[2] Radiography remains the primary imaging method for the initial evaluation and follow up assessment of hip arthroplasties.[1,3] The initial postoperative radiograph provides information on the components' initial positioning and fixation and can be used as a reference when comparing this examination with radiographs taken later in the life of the prosthesis.[1,4] The objective of this article is to familiarise radiographers with the normal radiographic appearance of hip replacements and to develop a systematic approach to evaluate the immediate postoperative radiograph to ensure optimum diagnostic quality. The radiographic appearance of common complications will also be discussed.

Methodology

Phase one of this research involved a review of pertinent literature utilising a number of electronic resources including MEDLINE, CINAHL and EMBASE. Our search terms included; "image interpretation", "postoperative hip replacement", "radiographic evaluation" and "hip arthroplasty".

Phase two involved extracting the data from our literature review considered to be of sufficient quality and value to assist in the development of a systematic approach for evaluating immediate postoperative pelvic radiographs.

Findings

Anatomy review

The hip joint is a ball and socket synovial joint formed by the articulation of the femoral head with the acetablulum.[5] The surfaces of both the head of the femur and the acetabulum are covered with a strong but lubricated layer of hyaline cartilage which acts to allow smooth movement of the joint. The joint is stabilised by the acetabular labrum; the fibrous joint capsule; and capsular ligaments such as the iliofemoral, ischiofemoral, and pubofemoral ligaments which are not demonstrated on x-ray examination.[5] The hip joint has the second largest range of motion of any joint in the body. Its range of motion includes flexion, extension, abduction, adduction, internal and external rotation.[5]

Types of hip replacements

There are two general types of hip replacements, Hemiarthroplasty and Total Hip Arthroplasty (THA). The clinical indications for each type are different, and these general types can be identified from radiographs.

Hemiarthroplasty

Broadly, a hemiarthroplasty is an operation that replaces one surface of the joint.[1] In the case of the hip, it is always the femoral surface that is replaced, so that the resulting articulation is between a prosthetic femoral head and the native acetabular cartilage. In this surgical procedure, the native femoral head and neck are resected and the prosthesis is inserted into the medullary canal of the proximal femur.[1] Hemiarthroplasty at the hip is generally performed

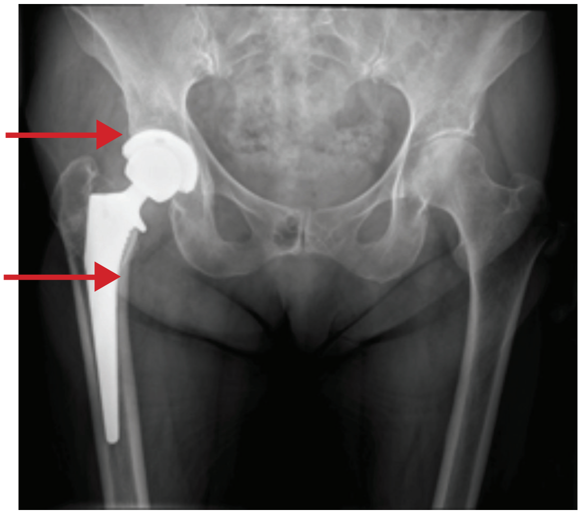

Figure 3: Patient with right total hip arthroplasty

for femoral head disease, not hip joint disease.[1] Common clinical indications for hip hemiarthroplasty include osetonecrosis of the femoral head, femoral neck fractures and resection for tumour.[1,3] Radiographically, hemiarthroplasty can be recognised from x-rays because the native acetabulum remains (Figure 2).

Total hip arthroplasty

A THA is an operation that replaces both surfaces of the hip joint so the resulting articulation is between a prosthetic femoral head and a prosthetic acetabular component.[1,2,3] THA involves the surgical excision of the head and neck of the femur and removal of the acetabular cartilage and subchondral bone. An artificial canal is created in the proximal medullar region of the femur, and a metal femoral prosthesis is inserted. An acetabular component is then inserted proximally into the enlarged acetabular space.[2] The primary indication for total hip arthroplasty is severe pain and the limitation in activities of daily living that it causes, with joint diseases such as osteoarthritis accounting for 70% of cases.[1,2] It is generally preferred that THA are performed on patients older than 60 years because at this age, the physical demands on the prosthesis tend to be fewer and the longevity of the operation approaches the life expectancy of the patient.[2] As both surfaces of the joint are replaced, THA can be recognised from radiographs by the presence of both femoral and acetabular prosthetic components as depicted in Figure 3.

Fixation of hip replacements

The prosthetic components of hip replacements must be firmly fixed into the bone using either a cemented or cementless method.[1] Bone cement is commonly used as an adhesive, literally gluing the prosthetic component to bone.[1] Alternatively, it may also be used to fill spaces and contribute to a closer interference fit. Bone cement is radiopaque, but will appear less dense than metal on x-rays (Figure 4). Prosthetic devices have also been developed that achieve fixation without cement either by "press-fit" or by biologic ingrowth methods.[2] With the press-fit technique, stabilisation is achieved by interference fit of the implant into the femur.[2] Componeats are held in position by the shape of the components and the space into which they are tightly fitted.[1,2] With biologic ingrowth, fixation relies on the principle that remodelling

Figure 4: Hybrid THA demonstrating cementless acetabular component and cemented femoral component

bone can attach itself directly to the component, therefore holding it in place. The components have a coated or roughened surface on all or part of the stem which is designed to stimulate bone growth into the surface.[2,3] There are a number of special surface coatings used in modern implants. However, these coatings are not visible on radiographs.[6] Noncemented devices are most frequently used in young patients with high physical demands where a revision surgical procedure in the future is more likely.[2] Alternatively a combination of cement and cementless fixation known as hybrid total hip arthroplasties are often used.[6,3] As cemented acetabular components have a tendency to loosen over time, the combination of a cementless acetabular component with a cemented femoral component is more commonly used.[6] The reasons behind the choice of prosthesis are many and are beyond the scope of this review.

Post operative hip radiographs

Assessment of the initial postoperative radiograph is an important part of hip replacement surgery and is a prerequisite before the patient's discharge. The initial radiograph provides information for the surgeon on the type of prosthesis used, and the initial component positioning and fixation.[1,4,6,7] The image is also used to search for immediate complications or problems and can be used as a reference when retrospectively comparing this radiograph with others taken later in the life of the prosthesis.[1] At all large tertiary hospitals in Brisbane, including the Princess Alexandra Hospital (PAH), the initial postoperative protocol is an AP pelvic radiograph only. The AP view of the pelvis is taken with the patient supine, hips in extension and

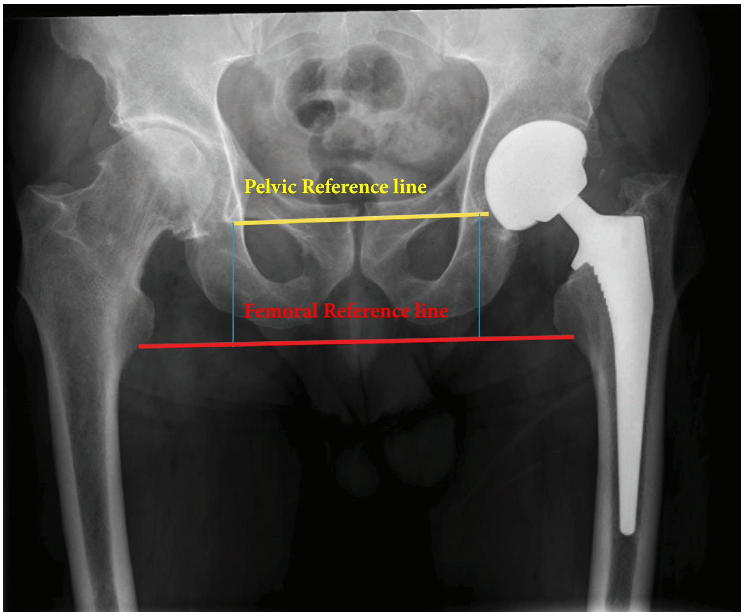

Figure 5: Leg length measurement

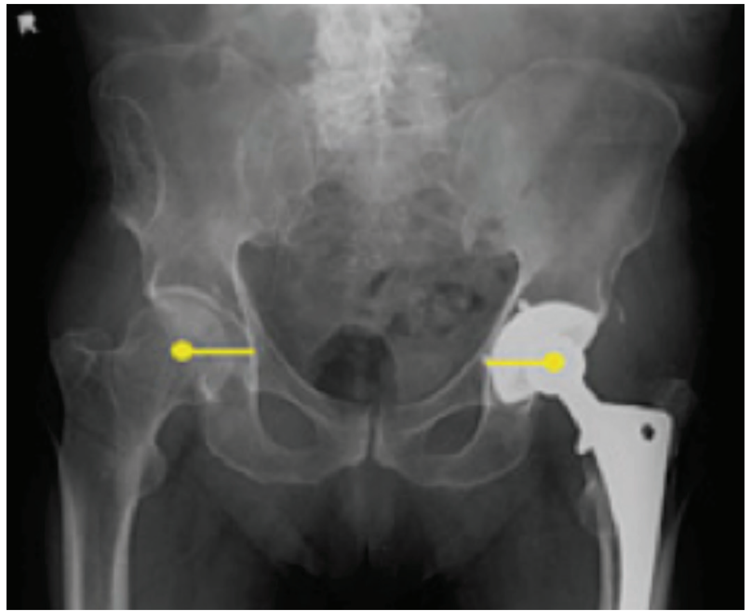

Figure 6: Horizontal centre of rotation

15° internal rotation, with the centre of the x-ray beam focused on the pubic symphysis to ensure the inclusion of the entire hip prosthesis and cement.[4] It is of high importance that a diagnostic AP pelvic projection should be non-rotated to avoid inaccuracies in orthopaedic evaluation. Unfortunately, the magnification factor for each patient varies with body habitus and the thickness of the mattress. To minimise variability in magnification the distance of the x-ray source to the detector must be standardised to a set distance.[8] Additionally, a scaling device can be utilised to offer improved accuracy of measurements when evaluating post-operative radiographs.[9] Furthermore, some orthopaedic departments maintain the accuracy of their post-operative hip examinations by calibrating the known diameter of the prosthetic femoral head.[8] An optimal radiographic exposure should demonstrate good bony detail alongside the pelvic soft tissue shadows. Orthopaedic surgeons at the PAH believe a lateral hip projection provides no additional information of prosthetic positioning and fixation and the patient positioning required to achieve this projection significantly increases the risk of dislocation of the prosthetic hip.

Radiographic evaluation of hip replacements

Initial placement of the prosthetic components should mimic the normal positions of the native acetabulum and femoral head and neck.[6,7] Specific anatomical landmarks and measurements are used to verify correct placement. In the initial evaluation of hip arthroplasties, the following elements are assessed:

1 Leg length
2 Horizontal centre of rotation
3 Acetabular inclination
4 Femoral stem positioning
5 Cement mantle.

1 Leg length

Leg length inequality is common after hip arthroplasties, with the literature quoting up to 50% of patients with leg length inequality greater than 1 cm.[4] A discrepancy of up to 1cm is thought to be acceptable and well tolerated by patients, but often patients may notice or be concerned by even small discrepancies.[4,6] Measurement of leg length takes place on the AP pelvic radiograph. A pelvic reference line is drawn transversely connecting the inferior borders of the acetabular tear drops (Figure 5). On the AP radiograph, the teardrop shadow is formed by the cortical surfaces of the anteriorinferior portion of the acetabular fossa, contributed to by the ishium and pubic bone.[10] A point on the femur, usually the lesser trochanters, is then used as a femoral reference line. A perpendicular line is then drawn from the femoral reference to the pelvic reference line and both sides are measured and compared.[1,4,7,10] A higher placement of the prosthesis results in a shorter leg and less effective muscles crossing the hip joint, where as distal placement may stretch these muscles to the point of spasm, increasing the risk of dislocation.[2,6]

2 Horizontal centre of rotation

The horizontal centre of rotation assesses the acetabular component of the prosthesis and is evaluated by measuring the distance from the centre of the femoral head to the acetabular teardrop (Figure 6).[1,4,7,10] The distance from the centre of the femoral head to the teardrop should be equal bilaterally. The ligaments and tendons which maintain the position of the femoral head in the socket normally passes just lateral to the centre of the femoral head. If the surgeon fails to place the acetabular component in a sufficiently medial position, these ligaments and tendons will cross medial to the femoral head centre of rotation. Muscle contraction in this configuration tends to force the head from the socket, increasing the probability of dislocation and may also cause the patient to limp.[6,7]

3 Acetabular inclination

Acetabular inclination is defined as the angle between the face of the cup and the transverse axis.[4] Measurement of this angle can be achieved by drawing a line through the medial and lateral margins of the acetabular cup and measuring the angle this makes with the transverse pelvic axis by using the bi-ischial pelvic reference line

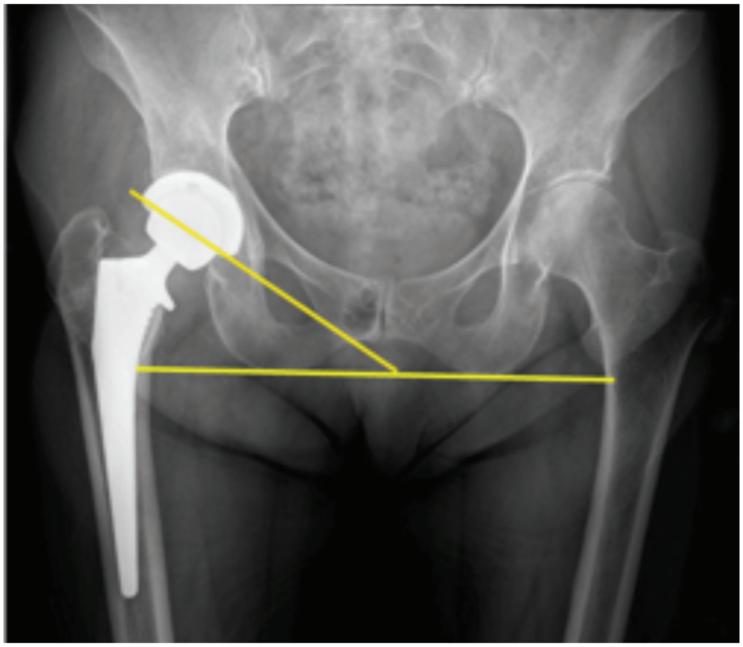

Figure 7: Acetabular inclination

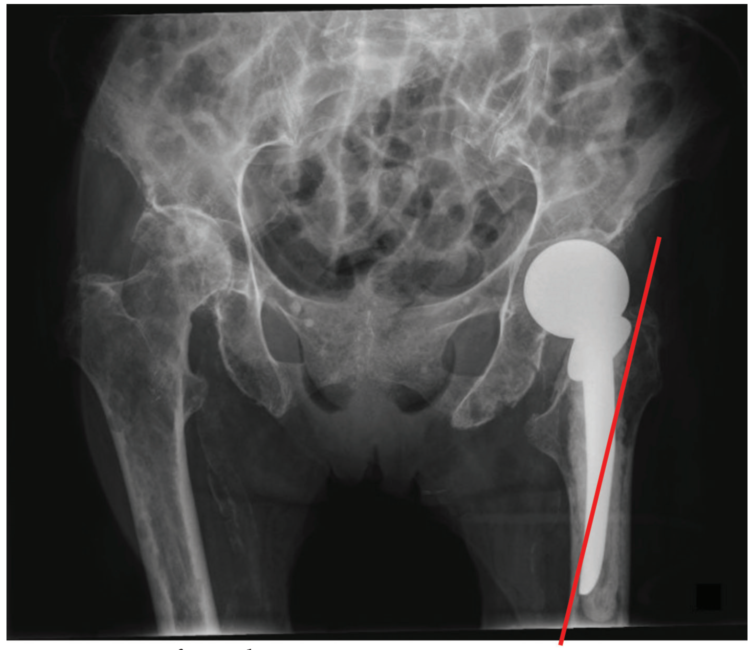

Figure 8: Varus femoral stem positioning

(Figure 7). The bi-ischial line is a transverse line drawn through the ischial tuberosities, and has also been described as an alternate pelvic reference line, although patient rotation can make this line inaccurate.[4] The inclination should measure between 30–50°.[4,7,10] Less angle results in a stable hip but limited abduction, and greater angulation substantially increases the patients risk of hip dislocation.[7]

4 Femoral stem position

The aim of femoral stem positioning in hip arthroplasties is to place the stem in a neutral position within the shaft.[4,10] On an AP pelvic radiograph the prosthetic stem should appear to be in neutral alignment with the longitudinal axis of the shaft and the tip should be in the centre. The component is considered to be in a valgus position if the proximal portion rests against the lateral endosteum and its distal portion rests against the medial endosteum.[7] Varus positioning is present when the proximal portion of the femoral component rests against the medial endosteum and the distal portion rests against the lateral endosteum (Figure 8). Valgus positioning is generally not a significant problem but varus positioning puts the prosthesis at greater risk of loosening and fracture as demonstrated in Figure 9.[7] It is important to note that assessment of the femoral stem position cannot be performed if the distal tip of the prosthesis is not present on the radiograph. It is therefore necessary that this area is clearly demonstrated on all pelvic and hip x-rays.

5 Cement mantle

Normal findings in cemented hip arthroplasties differ from those in non-cement prosthesis as the native bone shows more reactive change to non-cemented prosthesis.[6] The shape of the cement mantle that surrounds the femoral stem influences the manner in which load is transmitted from the stem through the cement to the surrounding bone. This in turn influences the likelihood of fracture of the cement or the formation of gaps (seen on radiographs as radiolucencies), both of which have been associated with loosening and clinical failure

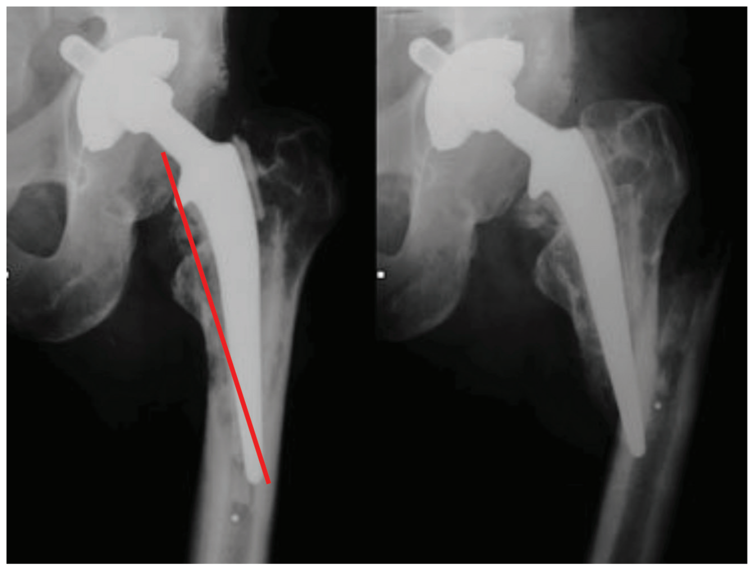

Figure 9: Valgus femoral stem positioning[6]

of prosthetic components.[11] When assessing the cement mantle it is important to consider the cement thickness. The optimal thickness of the acetabular cement mantle is 3 mm, which has been verified to yield the best strain characteristics and reduces the risk of cement cracking and therefore loosening.[4] Femoral cement mantles should ideally be 2–3 mm thick as this thickness has been proven to bear good long term radiographic and clinical outcomes.[4]

It is also important to consider both the cement-bone and the cement-prosthesis interfaces (Figure 10). Both interfaces should be systematically inspected for any gaps or lucencies.[3] In general, a radiolucent zone greater than 2 mm wide at either interface is indicative of probable loosening.[4,6,7,10] The most common system for assessing radiolucencies within the acetabular mantle is the Charnley-Delee system.[4,6] Using this method, the acetabular cement mantle is divided

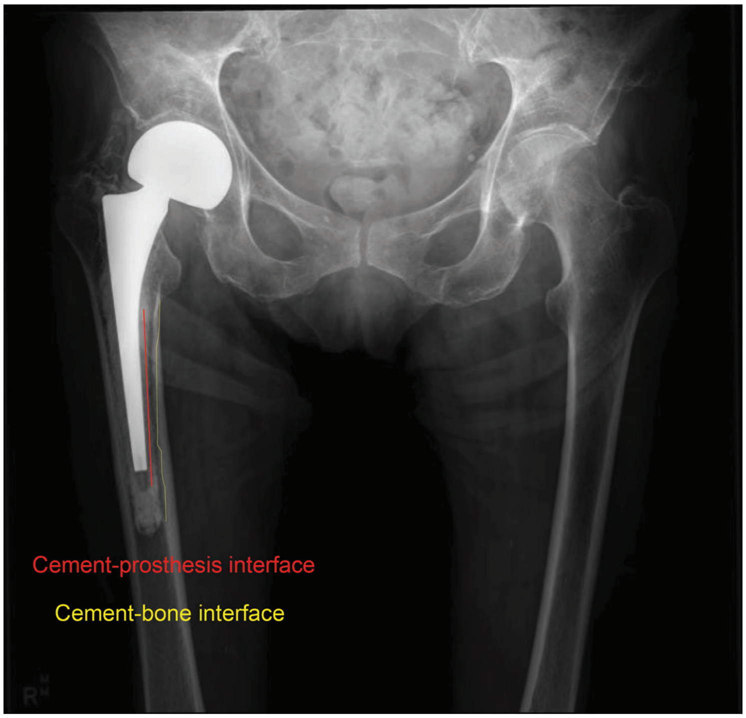

Figure 10: Cement mantle interfaces

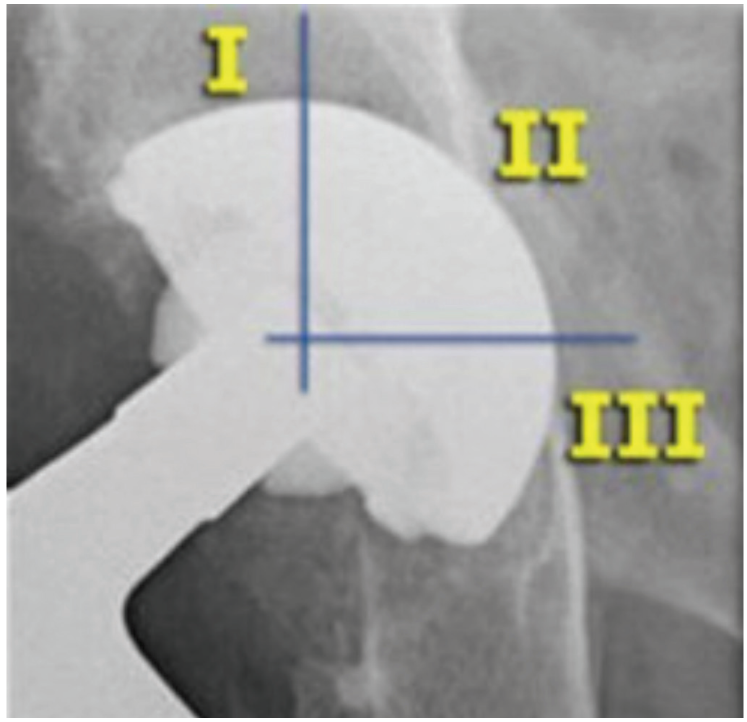

Figure 11: Acetabular zones according to De Lee and Charnley[6]

Figure 12: Femoral zones according to Gruen[6]

into three equal zones labelled I, II, III from lateral to medial (on anteroposterior views) as depicted in Figure 11.[10] Each zone should be inspected for cement-bone and cement-prosthesis lucencies or deficiencies. It is common to see a radiolucent line in zone 1, but lucencies should not appear in zone 2 or 3.[4,6,10] Similarly the femoral cement mantle can be divided into 7 zones on an AP view according to the Gruen method which is depicted in Figure 12.[4,6] It is very common to see a radiolucency in zone 1 and occasionally in zone 7 but it should not occur in the subtrochanteric regions of zones 2–6.[4,6] Radiolucencies in zone 1 may result from incomplete contact between the cement and the stem at the time of surgery. This finding should be considered normal if stable, but any enlargement of this radiolucent area at follow-up is indicative of loosening.[10] At the cement-bone interface a thin fibrous layer may form as a response to local necrosis of the osseous tissue due to the heat of the cement during implantation.[4,10] On radiographs this layer is seen as a thin, radiolucent band less than 2 mm thick, outlined by a sclerotic dense line running parallel to the stem.[4,6,10] If this lucency remains less than 2 mm for two years it is considered normal. However, progressive widening of the radiolucent band is indicative of loosening.[4,6,10] It should also be noted that cement-bone deficiencies in the immediate period postoperatively may not be the result of loosening but rather due to remnants of cancellous bone having been left at the time of surgery.[4] A stable lucent zone is good, but if the deficiency enlarges or develops at the interface during follow up examinations, then it is a sign of loosening.[6]

Cementless components

Assessing the initial fixation of cementless components is more difficult than those with cement.[4] The initial postoperative radiograph is unlikely to show any obvious bony defects. Assessing fixation is really only possible on follow up radiographs as the native bone shows more reactive change to non-cemented prosthesis.[4,6] One common finding in cementless components is a thin isolated radiolucent band (< 2 mm) around the rough surface of the prosthesis. This lucency is frequently well delineated by a thin sclerotic margin and if non-progressive after two years this finding is considered normal.[10] Though suboptimal, this appearance indicates fibrous ingrowth and is thought to provide sufficient stability.[10]

Follow up radiographs

Follow up radiographs are a major part of the ongoing assessment of a prosthetic joint and are of significant diagnostic value in determining changes in the appearance of the prosthetic components and bone which may indicate impending failure.[1,4,6] At the PAH, patients present for radiographic follow up in the form of AP and lateral x-rays at 6 weeks, 12 weeks, 6 months and 12 months. After this period, patients present for further follow up x-rays only if they are symptomatic. Radiographic follow up and comparison with post-operative films is the most valuable method in determining complications of hip arthroplasties.

Conclusion

Hip replacement surgery has been one of the most common orthopaedic operations for the past 25 years. Radiography remains the mainstay of imaging evaluation of hip arthroplasties, with an AP pelvic radiograph the common protocol in the post operative setting. It is imperative that post operative radiographs are of high diagnostic quality with the patient non rotated, supine, hips in extension and 15° internal rotation. The centre of the x-ray beam needs to be focused on the pubic symphysis to ensure the inclusion of the entire hip prosthesis and cement. The literature unanimously agrees that there are five key elements which should be evaluated in order to determine if initial component positioning and fixation is adequate. These include leg length, horizontal centre of rotation, acetabular inclination, femoral stem positioning and assessment of the cement mantle (Figure 13). This article provides a systematic framework for radiographers to assess and evaluate the quality of a hip arthroplasties and highlights the need for high quality diagnostic radiography.

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Radiographic evaluation of hip replacements

1 Leg length
2 Horizontal centre of location
3 Acetabular inclination
4 Femoral stem positioning
5 Cement mantle

Figure 13: Take home points

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