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Understanding, Interpreting and Reporting a Total Hip Arthroplasty Radiograph

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Abstract

The number of Total Hip Arthroplasties (THAs) in England is increasing. Careful analysis of THA radiographs, by both orthopaedic surgeons and radiologists, is key to ascertaining both the short and the long-term survival and function of the implants in question. The aim of this article is to provide the reader with a systematic approach to assessing post-operative THA radiographs, with sufficient knowledge to critique the procedure and assess for complications. An outline of the prostheses, role of cement, positioning, and complications is presented. The authors also recommend a format for presenting these radiographs in a clear and structured manner.

Keywords: Hip; Arthroplasty; Interpret; Radiograph

Introduction

The number of Total Hip Arthroplasties (THAs) in England and Wales is increasing. 796,636 procedures were carried out in 2016 [1]; an over 10-fold increase from those carried out in 2013. This number will undoubtedly continue to increase due to the ageing population within the United Kingdom.

Accurate analysis of post-operative radiographs is an important skill for experienced surgeons and radiologists, as well as the junior doctor working on the ward who is often called to assess immediate post-operative radiographs. Careful analysis of THA radiographs is key to ascertaining the long-term survival and function of the implants in question [2]. Clinical assessment alone may be insufficient for evaluating the stability of total hip replacements, as unstable components may not always produce early symptoms [3].

Initial radiographs enable both radiologists and orthopaedic surgeons to acutely evaluate the implant positioning and act as a baseline to which future films may be compared.

The British Orthopaedic Association recommends a combination of both clinical and radiological assessment at year 1 and 5, as well as subsequent serial assessments every 5 years following THA [4]. These films should be checked for long term complications such as loosening and wear.

Although there has been an increase in the use of advanced imaging for assessing failure, including CT, MRI and bone scintigraphy, plain films remain the first-line investigation of choice as they are less expensive and have a lower risk of exposure to ionising radiation.

The authors propose a structured and comprehensive guide to interpreting and reporting post-operative films in patients in with total hip arthroplasty.

Radiographic views

For hip radiographs to be accurately interpreted, a degree of standardisation needs to be applied to the methods used in their capture. Thus, both the positioning of the patient and the point of focus of the x-ray beam are essential to an accurate and reproducible imaging technique. Anteroposterior (AP) and lateral radiographs must both be taken. The former is captured with the patient supine, pelvis fixed on the table, with both hips extended and in 40 degrees of internal rotation. A lateral view must always be requested, although care must be taken while interpreting it as there is a variable level of reproducibility with this view. A *Lauenstein view* may also be used to visualise the hip. In this view the patient is positioned supine with both knees flexed and the ankles placed together in maximum abduction. This method is particularly good at identifying fractures of the head, neck and trochanters of the hip. It is therefore more commonly used in the traumatic setting.

Types of prosthesis: The first task of the reporting physician is to identify the type of implant in use, which in turn determines a number of secondary features that need to be identified on the films. There is a large variety of THA implants available and choice depends on many considerations such as patient factors, surgeon preference, cost and published survival rates.

There are a wide variety of implant types available; for the purposes of radiographic interpretation, they may be broadly classified into three categories:

- Cemented
- Uncemented
- Hybrid

Components of the total hip replacement: Following the identification of the type of implant fixation, the next task is to identify which components are used in the THR implant. These may be made from a variety of materials, each possessing different appearances on an x-ray and each interacting with the materials around it, including the patient's bone, in a different manner. The acetabular component is composed of either polyethylene, which is cemented into the acetabulum, or a metal/metal-backed shell which is implanted uncemented and combined with a bearing-surface liner made from metal, ceramic or polyethylene [5].

The femoral stem is almost invariably made of a titanium alloy, while the head is either made of metal or ceramic depending on the type of acetabular liner used as its counterpart.

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Periprosthetic radiolucency: The term radiolucency refers to the relative permeability of a material to x-rays. It is highly relevant to the study of prosthetic implants and their interaction with the adjacent structures (bone and cement). The level of radiolucency surrounding prostheses is often indicative of complications relating to their implantation and positioning. This may also relate to their relationship with surrounding structures. Detailed scrutiny of post-operative films is therefore necessary in order to detect the presence of radiolucent lines [6].

Periprosthetic radiolucency may be detected around either cemented [7] or uncemented [6] prostheses. It may be detected around the stem or the acetabular component of THAs. The importance of having baseline films cannot be understated, as serial films are often needed to interpret changes in radiolucency which may often be subtle.

Various classification systems have been used to describe lucent lines. The amount of radiolucency surrounding the cement mantle of the acetabular component of THAs was originally described by DeLee and Charnley in 1976 [8] (Figure 1). They divided the acetabulum into 3 zones on the AP film, with the greatest width of radiolucency in each zone being measured and used to describe the extent of radiolucency. This system remains in use today.

Assessing the femoral component is more complex. A system of analysis looking at AP views of the femoral stem was formulated by Gruen et al. [9] (Figure 2). The stem is subdivided into 7 segments which are again inspected for radiolucency. Johnston et al. complicated this system by adding 7 zones on the lateral view (Figure 2) [10].

Causes of increased radiolucency: The causes of increased radiolucency are numerous. They may arise from the interaction between the bone and the implant, the bone and the cement or from a completely different cause, e.g. infection and/or corrosion of the bone. They may also represent areas of osteolysis within the bone itself. Areas of radiolucency should therefore be carefully examined at the bone-cement interface, component-bone interface and within both the femoral and acetabular bone.

Thin, linear radiolucent zones may also be noted at the cement-component interface, particularly at the proximal-lateral aspect of the stem [11]. Although this may be explained by inadequate contact between the implant and the cement, it may also be explained by the Mach effect [12] – a form of edge enhancement between two areas of different density on x-ray imaging. Other authors have suggested alternative theories, suggesting that necrosis from the heat of polymerization of the cement is responsible for these thin radiolucent lines [13]. A zone of lucency at the cement-component interface with a maximum width of 2 mm may be considered normal, provided it does not enlarge on subsequent reimaging.

In order for the cement to bind firmly to a patient's bone, it must be intimately associated with it. The cement and trabecular bone must firmly interdigitate [14]. This may give a slightly irregular and lucent appearance to the cement-bone interface, which should be considered normal. Progressive enlargement of this area should be reported as loosening. This progressive lucency may represent the formation of either connective tissue between the bone and cement or an infective focus. However, it should be noted that patients with implants that have been in situ for 10 to 20 years, or more, will all have an area of lucency surrounding the implant, which in the presence of an asymptomatic patient can be considered normal.

Osteolytic lesions may also be present and are defined radiographically as being demarcated, non-linear, lytic lesions measuring more than 3 mm in diameter [15]. The cause of these areas of osteolysis is thought to be the penetration of particulate material, produced by implant wear, into the bone-cement or implant-bone interfaces. Joint fluid is thought to carry such particles across these barriers [16,17]. Osteolytic lesions are particularly significant as osteolysis is a self-perpetuating process [16]. Therefore, the detection of such lesions should lead to prompt investigation with Computerised Tomography (CT) imaging, as studies have shown that plain films may often underestimate the degree of osteolysis by up to 20% [18], and the presence of these lesions often precede implant loosening and failure (Figure 3).

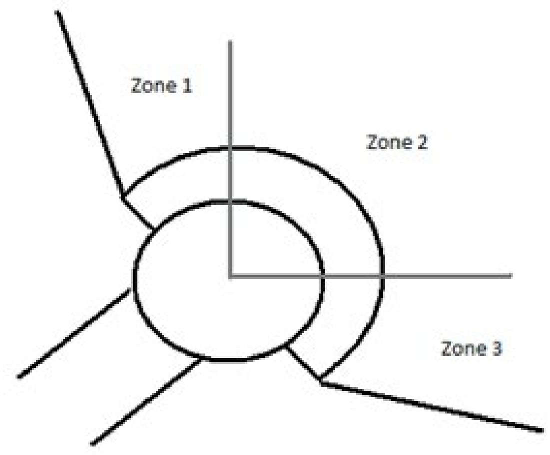


Figure 1: DeLee and Charnley zones.

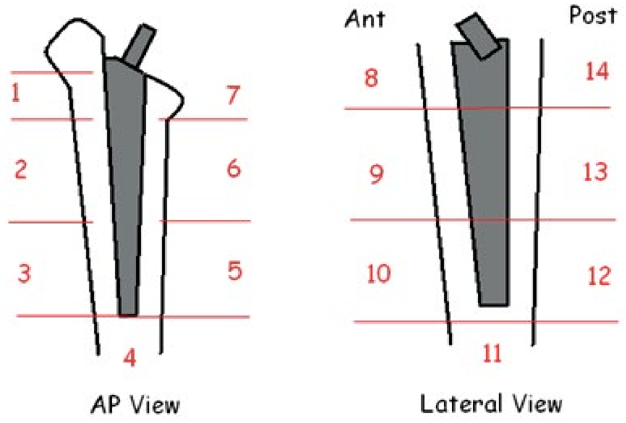


Figure 2: Zones of lucency seen in the Ap and lateral views as described by Gruen [9] and Johnston [10].

Sclerotic reaction

Spot welds are areas of endosteal sclerosis that arise as a direct result of pressure from the distal implant on the femur. They have been found to be good indicators of implant stability [11]. Thickening of the femoral cortical shaft may also occur at the point of contact with the implant's stem. This is a good indicator of fixation.

A transverse sclerotic line lying below the tip of uncemented stems may also be detected. This is known as a *bone pedestal* (Figure 4). Although it may be associated with tip stability, it is also encountered just as frequently in unstable implants [11]. Cautious further evaluation and sequential radiographic follow-up is therefore advisable when this sign is encountered as well as observation for other signs of stability or instability.

Stress shielding

Calcar resorption and stress shielding are also normally observed in the first two years after implantation [19]. These occur because of bone remodelling according to the stresses placed on it. Certain prostheses are designed to transmit forces by bypassing areas of bone leading to a relative osteopenia in these areas. This is particularly true of uncemented components, which demonstrate this phenomenon in both the proximal-medial femur as well as the superior-medial acetabulum [2]. Such findings are normal and are caused by a redistribution of the forces in the prosthetic hip, with stress being diverted away from the proximal femur. The consequences of stress shielding on the longevity of the implant remain undetermined [19].

Uncemented component radiolucency: The detection of initial defects on a postoperative uncemented implant is often more difficult than when doing so with a cemented THA. Obvious bony defects are rare, with changes often being subtle. Because of this, the assessment of adequate fixation ideally requires serial x-rays over the course of several years.

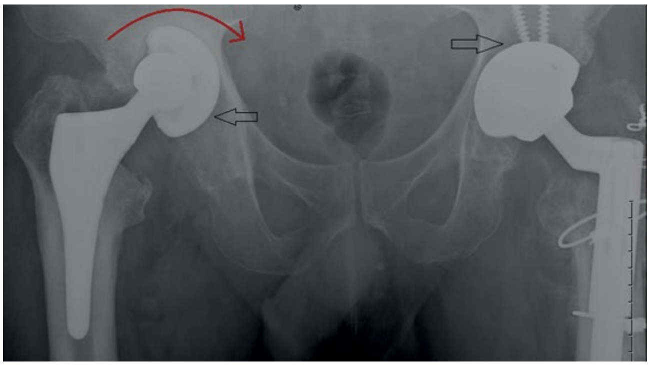


Figure 3: Areas of lucency noted bilaterally around uncemented acetabular components (black arrows). In the right sided prosthesis, this has led to implant failure.

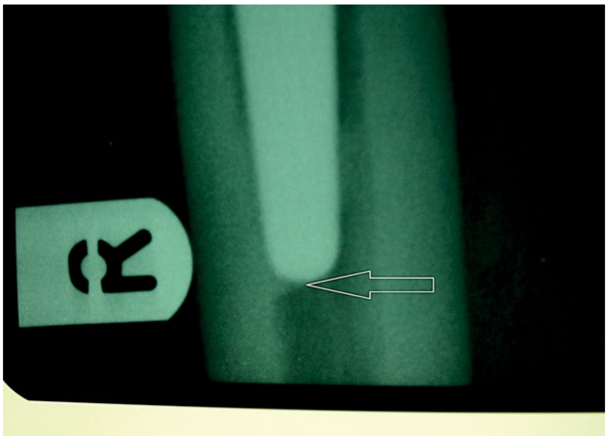


Figure 4: A bone pedestal is noted at the distal tip of the implant.

The presence of radiolucent bands no greater than 2 mm in diameter may be considered normal if they do not progress after 2 years. These bands are often well delineated and surrounded by a thin, sclerotic margin. This change is thought to represent fibrous ingrowth.

Because of the nature of the biomechanics involved with uncemented cups, they are required to be impacted into the acetabulum. Over-exuberant impaction of the cup may rarely result in an acetabular fracture [20] which may in turn result in an early loss of position.

Regarding the femoral component, radiolucent areas surrounded by sclerotic lines may also be considered normal but need to be monitored closely in order to exclude loosening. In uncemented stems, osseointegration should occur in up to 95% of stable implants [21], the remainder gain their stability from fibrous fixation. It has been suggested that large areas of radiolucency, when associated with vertical migration of the femoral component, are often indicators of aseptic loosening [3]. However, while the presence of reactive radiolucent lines around the porous portion of an uncemented implant may be considered a sign of instability, their presence along smooth portions of the stem is less relevant, as bone ingrowth is not expected in that particular segment of the stem (Figure 5).

Remodelling and osseointegration

As described by Wolf in 1892, bone remodels in accordance to the forces applied through it [22]. The implantation of a THA changes the forces applied through the hip joint. Hip prostheses are designed to transmit forces by selectively loading different areas of bone [2]. Evidence of sclerosis and osteopenia in different parts of the bone may therefore be observed [19]. Remodelling occurs over the first 2 years post implantation and indicates that the prosthesis is well fixed within the joint. The presence of stress shielding, a decrease in acetabular radiographic density in DeLee and Charnley Zone II, is also thought to be indicative of osseointegration between the implant and the native bone. Moore et al. [19] defined a system whereby 5 features are identified on postoperative x-rays to indicate the likelihood of osseointegration:

- Absence of (reactive) radiolucent lines

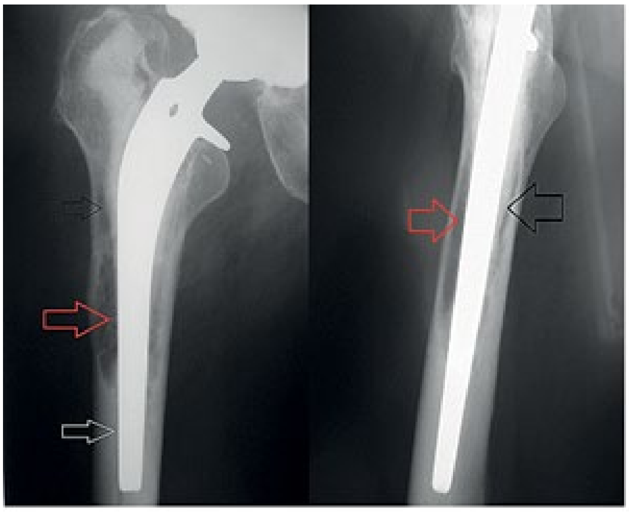


Figure 5: A failing cemented implant. Areas of lucency are seen in multiple Gruen zones (red arrows). These are seen in both the AP and the lateral views. They represent deficiencies within the cement mantle. Black arrows demonstrate failure of the bone cement interface. A continuous and uniform area of lucency demonstrated by the white arrow may be considered normal if it does not widen on serial x-rays.

- Presence of a superolateral buttress
- Presence of medial stress-shielding
- Presence of radial trabeculae
- Presence of an inferomedial buttress

The cement mantle

The cement mantle surrounding the acetabulum should ideally be of even thickness (2-5 mm) in all three Charnley Zones. *In vitro* studies by Oh et al. [23-25] concluded that the optimal thickness of a cement mantle should be 3 mm in all three zones. Sandhu et al. [26] demonstrated that achieving a perfect mantle in practice is often difficult and the majority of acetabular cups are placed slightly eccentrically. A phenomenon known as "pooling" of the cement in Charnley Zone 3 may often indicate inadequate medialisation of the acetabular cup and is also associated with deficient cement in Charnley Zone 1. This in turn may be an early indicator of implant failure [27].

Areas of cement protrusion must also be noted, in particular through the acetabular floor. These may indicate that an implant could be more complicated to revise in future, due to the proximity of pelvic vascular structures and the possibility of cement adhesion, as well as a lack of remaining bone stock available for the revision.

The cement surrounding the femoral component should ideally be evenly distributed throughout the 14 aforementioned zones (7 on AP view, 7 on lateral view). Ideally the stem itself should sit evenly between these zones in the middle of the femoral canal. Areas of isolated radiolucency within the cement mantle may indicate that air or blood has become trapped within the cement during the pressurization process. These "bubbles" may in turn act as stress risers for fatigue fractures [28].

Barrack et al. [29] devised a scoring system to assess the quality of the cement mantle filling the femoral canal in the aforementioned zones. Studies have stipulated that poor scores, and thus a poor cement mantle, in these zones (particularly in zones 5 and 6) are associated with early failure [30].

Assessment of the implant

The first and most obvious finding in THA radiographs is whether or not the joint is dislocated/subluxed, and in the immediate post-operative period this is the first thing to note. There are several factors to identify to ensure both the acetabular and femoral implants are positioned well.

Acetabular positioning: The position of the acetabular component needs to be assessed for version, inclination and centre of rotation. Sub-optimal positioning in any of these planes may affect wear rates, dislocation and range of motion [31,32]. These terms have been defined by Murray [33]. He defined inclination as the angle between the face of the cup and the transverse axis and version as the angle between the acetabular axis and the coronal plane.

The inclination is calculated measuring the angle created by the intersection of a transverse pelvic reference line with a second line, traced between the medial and lateral margins of the acetabular cup [34] (Figure 6). It is also possible to use the longitudinal axis to measure the angle of inclination. The acceptable angle of lateral inclination is said to be between 30 and 50 degrees [34]. An angle of 45-55 degrees is thought to confer the best range of motion [35].

The acetabular version is assessed on lateral views. It is defined as the angle between the acetabular axis and the coronal plane. The optimal angle lies between 15-20 degrees [36]. The ability to accurately measure cup position depends heavily on the spatial orientation of the pelvis on the X-ray table, and its variability could introduce significant errors into cup measurements [37]. A number of authors have attempted to standardize the position of the pelvis with respect to the X-ray table in clinical studies on both patients as well as cadaveric models [37]. In these studies, the anterior superior iliac spines and the pubic tubercles were used to position the pelvic reference plane parallel to the film. Despite these attempts, the fact that even a small amount of rotation can considerably alter the interpretation of the plain film means that a CT scan is always a more accurate method of assessing version.

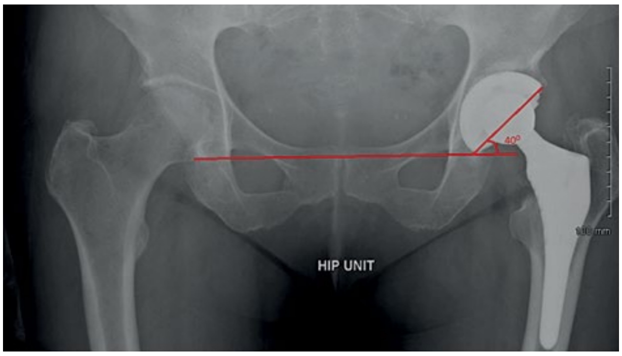


Figure 6: The inclination is calculated measuring the angle created by the intersection of a transverse pelvic reference line with a second line, traced between the medial and lateral margins of the acetabular cup.

The relevance of acetabular version relates to the risk of dislocation. Excessive anteversion of the acetabular component has been associated with an increased risk of dislocation [38]. Although certain authors would argue that it is the combined femoral/acetabular version that is associated with dislocation, rather than acetabular anteversion alone [39].

The vertical centre of rotation of the acetabular component should also be reported. It is measured by comparing the vertical distance between the centre of the femoral head and the teardrop shadow or an alternate medial landmark. This distance must equal that recorded on the contralateral hip [3].

Acetabular wear: Wear within the acetabular liner is a common problem with total hip replacements and may eventually lead to implant failure and subsequent revision. The rate of wear is variable and may be determined by a number of factors, notably the choice of material used in the acetabulum as well as the femoral head [40]. Although polyethylene is known to be a radiolucent material, changes in acetabular liner thickness may be detected by observation of the femoral head position. This may be harder to detect in a metal backed acetabular component.

The femoral head should sit symmetrically within the acetabular cup. The superior and inferior distance between the centre of the femoral head and the acetabular edge should therefore be equal (Figures 7 and 8). Acetabular wear may be noted when a difference develops in these measurements over time [41]. Some components are normally placed slightly inferiorly or laterally in the acetabular cup, therefore serial x-rays are essential to differentiate between this phenomenon and acetabular wear. It should be noted that displacement of the femoral head may also be caused by displacement of the polyethylene liner from the metal backing. There is a direct relationship between a high rate of

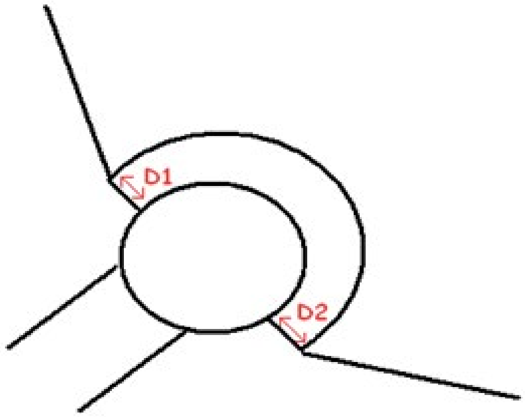


Figure 7: The difference between the superior and inferior distance between the head of the prosthesis and the acetabular surface should be equal. An increasing difference between D1 and D2 indicates acetabular wear.

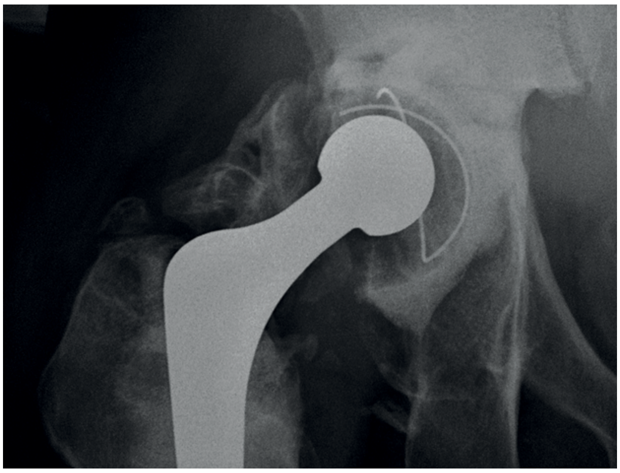


Figure 8: The difference between D1 and D2 can clearly be seen on this film. Type 3 heterotopic ossification is also noted.

wear and the presence of osteolysis [42]. Further investigation in such patients is therefore essential.

Femoral component positioning: The femoral stem must be inserted in a neutral position relative to the shaft of the femur. To try and mimic normal hip anatomy, the neck may be placed in slight anteversion, between 10-15 degrees [43]. Excessive anteversion has been associated with an increased rate of dislocation [44]. High rates of failure and loosening have been reported in both cemented [45] and uncemented [46] prostheses when the femoral component has been inserted with excessive varus inclination. However, in modern cemented designs, and certain uncemented designs, varus malpositioning has not been found to be a major issue [47]. The alignment of the femoral stem is assessed on the AP views and is checked and compared to the neutral axis of the femoral diaphysis.

Rarely, difficulties during reaming of the femur may result in penetration of the stem, with or without cement, through the femoral diaphysis so that it no longer lies within the femoral canal. This is a risk particularly with poor bone density. It is essential to identify this, which can be a subtle sign on malpositioned radiographs.

As with the acetabular component, a CT scan is a more accurate method of measuring the version of the femoral component due to variability in positioning.

Leg length: Leg length discrepancy is a well-recognised postoperative complication in THAs. Its incidence has been found to be as high as 27% in studies [40]. Any discrepancies in leg length should be noted by the reporting physician. A discrepancy of 1 cm is usually acceptable and should not cause clinical symptoms. It is however well documented that even such a small change in leg length may give a patient an unsatisfactory outcome [48]. It is therefore important to report any significant discrepancy in leg length.

The AP film is used to assess leg length. As mentioned above, correct positioning of the patient is necessary for accurate interpretation of plain films. The patient's legs are positioned in a neutral, parallel position in order to eliminate any apparent difference in leg length. A horizontal line should be drawn between the inferior acetabular tear drops, connecting them. This line is used as a reference, but alternative lines such as the bi-ischial line may also be used [2]. A set point on the femur, usually the lesser trochanter, is then selected and a line is drawn between this point and the contralateral equivalent point. This line is known as the *femoral reference line*. Perpendicular lines are drawn between the pelvic and femoral reference line and compared on each side. Any difference in length should be noted by the reporting physician (Figure 9).

Subsidence: The femoral component may sink either within the femoral shaft along with the cement mantle or within the cement itself [49]. This phenomenon is known as subsidence and is often a direct result of the properties of the materials used and of the design of the implant itself. Several studies have suggested that it is a consequence of the viscosity of the cement used [50]. Cementless stems may also subside within the femoral shaft, though this is much less common [5]. Sinking, or subsidence, of the femoral implant is measured either by comparison to the intertrochanteric line or in comparison to the trans-ischial line. Another way to measure subsidence is with the use of a reference line drawn between the shoulder of the implant stem and the greater trochanter [51]. Subsidence itself may be normal in the first 2 years after implantation. Subsidence that occurs after this period of time, or that is greater than 10 mm is suspicious and needs further investigation.

Modes of Failure

Radiographic signs of abnormal positioning of the stem within the femoral shaft may be an indicator of implant failure. Gruen et al. [9] described four principal methods of implant failure, which can be seen on radiographs:

Pistoning

Vertical movement of the stem within either the bone or cement, and applies to cemented (Figure 10) or uncemented (Figure 10) implants.

Medial mid-stem pivot

Medial migration of the proximal stem in association with lateral displacement of the distal stem tip (Figure 10).

Calcar pivot

Either medial or lateral movement of the distal tip of the embedded stem with reasonable support proximally (Figure 10).

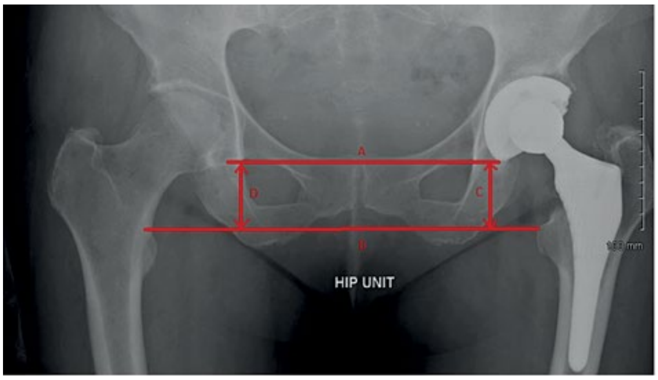
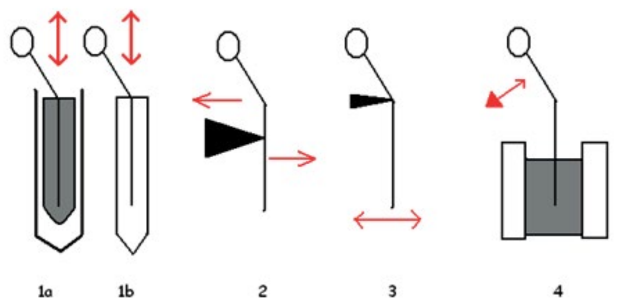


Figure 9: A reference line (A) is drawn between the inferior acetabular teardrops and compared with an equivalent line connecting the lesser trochanters (B). The difference between the perpendicular lines connecting the two is calculated (C-D) and this indicates the difference in leg length.



Figures 10: Modes of failure of the femoral component as described by Gruen et al. [9].

Distal pivot

Loss of proximal support while the distal end remains fixed. This is usually followed by medial migration of the proximal stem (Figure 10). Radiographic identification of these four methods of failure have been found to correlate well with clinical findings at revision [35].

Soft Tissue Abnormalities

Heterotopic ossification

The incidence of heterotopic ossification following THA is high, with up to 50% of patients developing ossification of the soft tissues around the hip postoperatively. Approximately 70% of these patients are symptomatic [11]. Certain factors are thought to increase the chances of heterotopic ossification developing. These include male gender, ankylosing spondylosis, post-traumatic arthritis, previous heterotopic ossification, previous hip fusion, diffuse idiopathic skeletal hyperostosis, Paget's disease, extensive osteophytosis, head injury, and Parkinson's disease [11].

The Brooker Grading System describes 4 different classes of heterotopic ossification:

Grade 1: Small islands of bone around the hip.

Grade 2: Bony spurs emanating from either the pelvis or the proximal femur with a distance of at least 1 cm remaining between the opposing bone surfaces.

Grade 3: Bony spurs from either the pelvis or proximal femur, with the space between bony surfaces reduced to less than 1 cm.

Grade 4: Complete bony ankylosis (Figure 11).

Metal bead shedding

This phenomenon is the result of the insertion process of porous-coated uncemented femoral stems, where the outermost layer is shed by abrasion against the femur. Opaque micro-fragments of metal may be observed within the soft tissues surrounding the implant on immediate postoperative films, this is a benign finding. However, when this phenomenon is observed sometime after the insertion of the implant, it should prompt further investigation for stem loosening, as micromotion of the stem within the femur can cause similar findings.

Periprosthetic fractures

The incidence of periprosthetic femoral fractures is on the increase. The overall reported incidence is 0.1% to 6% of THAs [52]. The number of periprosthetic fractures is set to rise with the increase of primary procedures performed. Because of the challenging nature of periprosthetic fracture sequalae, early detection and accurate classification is essential. Careful scrutiny of the postoperative films combined with clinical examination is therefore necessary.

Identification of the fracture location is crucial to guiding treatment and implant selection. In the femur, this is achieved using the Vancouver Classification System (Figure 12), which describes both the fracture location and the implications on stem stability [53,54]. Although management of periprosthetic fractures is beyond the scope of this paper, it is useful to be able to classify them using the Vancouver Classification System as illustrated below:

Callaghan [55] described the different patterns observed during the insertion of acetabular components. These include anterior wall, transverse, inferior lip, and posterior wall fractures (Figure 13).

Systematic presentation of findings on a postoperative hip x-ray: The clinical history must always be taken onto consideration, including:

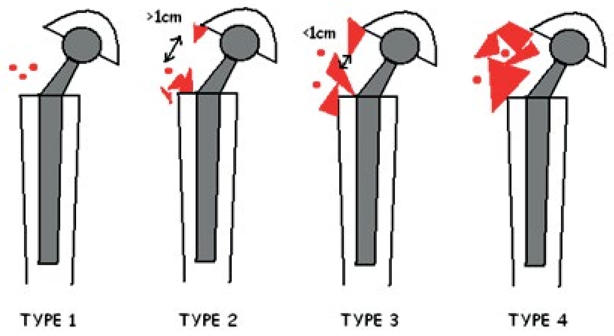


Figure 11: Degrees of heterotropic ossification.

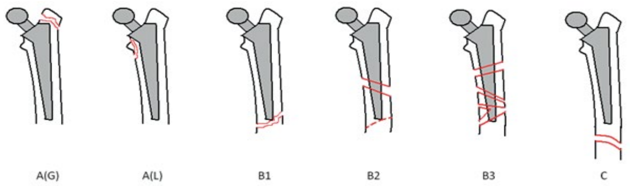


Figure 12: The Vancouver classification system – for the classification of periprosthetic fractures.

Figure 13: An A(G) periprosthetic fracture involving the greater trochanter.

- Symptoms (pain/stiffness)
- Immobility
- Instability
- Infection

Having systematically and thoroughly considered each of the sections described in this study, the reporting physician should consider presenting the findings of the radiographs in a structured report. We propose the following format:

- Adequacy of the films
- Patient Positioning
- Exposure
- Description of the type of implant used
- Cemented/Uncemented/Hybrid
- Implant position
    - o Implant dislocation
    - o Acetabulum: Version/Lateral inclination/Centre of Rotation
    - o Femoral stem positioning: Anteversion/Leg length/Position in canal (varus/valgus/neutral/central)
- Findings around the implant
    - o Cement mantle (if cemented)
    - o Zones of radiolucency: Cement/component/bone/other
    - o Zones of sclerosis
- Additional features
    - o Soft tissue abnormalities
    - o Acetabular wear
    - o Periprosthetic fractures

Conclusion

The final section of the report should be a clinical impression. This should include a summary of the findings as well as a comparison with previous films if these are available. Any component migration must be noted at this point. If a mode of failure is noted it should be described along with any recommendations made.

References

1. (2016) National joint registry report.
2. McBride T, Divya P (2011) How to read a postoperative total hip replacement radiograph. Postgrad Med J 87: 101-109.
3. Massin P, Schmidt L, Engh CA (1989) Evaluation of cementless acetabular component migration. An experimental study. J Arthroplasty 4: 245-251.
4. British Orthopaedic Association (2006) Primary total hip replacement: A guide to good practice.
5. Pluot E, Davis ET, Revell M, Davies AM, James SLJ (2009) Hip arthroplasty. Part 1: prosthesis terminology and classification. Clin Radiol 64: 954-960.
6. Smith TO, Williams TH, Samuel A, Ogonda L, Wimhurst JA (2011) Reliability of the radiological assessments of radiolucency and loosening in total hip arthroplasty using PACS. Hip Int 21: 577-582.
7. Aliabadi P, Tumeh SS, Weissman BN, McNeil B (1989) Cemented total hip prosthesis: Radiographic and scintigraphic evaluation. J Radiology 173: 203-206.
8. DeLee JG, Charnley J (1976) Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res 121: 20-32.
9. Gruen TA, McNeice GM, Amstutz HC (1979) “Modes of failure” of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 141: 17-27.
10. Johnston RC, Fitzgerald RH, Harris WH, Poss R, Müller ME, et al. (1990) Clinical and radiographic evaluation of total hip replacement. A standard system of terminology for reporting results. J Bone Joint Surg Am 72: 161-168.
11. Pluot E, Davis ET, Revell M, Davies AM, James SLJ (2009) Hip arthroplasty. Part 2: normal and abnormal radiographic findings. Clin Radiol 64: 961-971.
12. Jasty M, Maloney WJ, Bragdon CR, Haire T, Harris WH (1990) Histomorphological studies of the long-term skeletal responses to well fixed cemented femoral components. J Bone Joint Surg Am 72: 1220-229.
13. Dolinskas C, Campbell RE, Rothman RH (1974) The painful charnley total hip replacement. Am J Roentgenol 121: 61-68.
14. DeSmet AA, Kramer D, Martel W (1977) The metal-cement interface in total hip prostheses. Am J Roentgenol 129: 279-282.
15. Maloney WJ, Galante JO, Anderson M, Goldberg V, Harris WH, et al. (1999) Fixation, polyethylene wear and pelvic osteolysis in primary total hip replacement. Clin Orthop Rel Res 369: 157-164.
16. Schmalzried TP, Jasty M, Harris WH (1992) Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. J Bone Joint Surg Am 74: 849-863.
17. Anthony PP, Gie GA, Howie CR, Ling RS (1990) Localised endosteal bone lysis in relation to the femoral components of cemented total hip arthroplasties. J Bone Joint Surg Br 72: 971-979.
18. Robertson DD, Sutherland CJ, Lopes T, Yuan J (1998) Preoperative description of severe acetabular defects caused by failed total hip replacement. J Comput Assist Tomogr 22: 444-449.
19. Moore MS, McAuley JP, Young AM, Engh CA (2006) Radiographic signs of osseointegration in porous-coated acetabular components. Clin Orthop Relat Res 444: 176-183.
20. Haidukewych GJ, Jacofsky DJ, Hanssen AD, Lewallen DG (2006)

Intraoperative fractures of the acetabulum during primary total hip arthroplasty. J Bone Joint Surg Am 88: 1952-1956.

21. McAuley JP, Culpepper WJ, Engh CA (1998) Total hip arthroplasty. Concerns with extensively porous coated femoral components. Clin Orthop Relat Res 355: 182-188.
22. Wolf J (1986) The law of bone remodelling. Springer, Berlin Heidelberg, New York.
23. Oh I, Treharne RW, Sander TW (1983) Acetabular cement strain for different cement thickness and shapes of the cement mantle: In vitro strain gage study. Trans ORS 8: 65.
24. Sander TW, Oh I, Treharne RW (1983) In vitro strain gage studies on varying the thickness and shape of the acetabular bone cement mantle. Biomedl Eng 2: 353.
25. Oh I (1983) A comprehensive analysis of the factors affecting acetabular cup fixation and design in total hip replacement arthroplasty. Hip, pp: 129-77.
26. Sandhu HS, Martin WN, Bishay M, Pozo JL (2006) Acetabular cement mantles and component position: Are we achieving “ideal” results? J Arthroplasty 21: 841-845.
27. Assunção RE, Bolland BJRF, Edwards S, King LJ, Dunlop DG (2011) Radiographic assessment of primary hip arthroplasty. Orthopaedics and Trauma 25: 353-362.
28. Jafri AA, Green SM, Partington PF, McCaskie AW, Muller SD (2004) Preheating of components in cemented total hip arthroplasty. J Bone Joint Surg Br 86: 1214-1219.
29. Barrack RL, Mulroy RD, Harris WH (1992) Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty. A 12-year radiographic review. J Bone Joint Surg Br 74: 385-389.
30. Ritter MA, Zhou H, Keating CM, Keating EM, Faris PM, et al. (1999) Radiological factors influencing femoral and acetabular failure in cemented Charnley total hip arthroplasties. J Bone Joint Surg Br 81: 982-986.
31. D’Lima DD, Urquhart AG, Buehler KO, Walker RH, Colwell CW (2000) The effect of orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. J Bone Joint Surg Br 82-A: 315-321.
32. Woo RY, Morrey BF (1982) Dislocations after total hip arthroplasty. J Bone Joint Surg Am 64: 1295-306.
33. Murray DW (1993) The definition and measurement of acetabular orientation. J Bone Joint Surg 75: 228-232.
34. Weissman BN (1983) The radiology of total joint replacement. Orth Clin North Am 14: 171-191.
35. Cameron HU, McNeice GM (1980) A correlation of radiographic “modes of failure” with clinical failure of cemented stem-type femoral components. Clin Orthop Relat Res 150: 154-158.
36. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, et al. (2005) Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 87: 762-769.
37. Blendea S, Eckman K, Jaramaz B, Levison TJ, Digioia AM (2005) Measurements of acetabular cup position and pelvic spatial orientation after total hip arthroplasty using computed tomography/radiography matching. Computer Aided Surgery 10: 37-43.
38. Turner RS (1994) Postoperative total hip prosthetic femoral head dislocations. Incidence, etiologic factors, and management. Clin Orthop Relat Res 301: 196-204.
39. Komeno M, Hasegawa M, Sudo A, Uchida A (2006) Computed tomographic evaluation of component position on dislocation after total hip arthroplasty. Orthopaedics 29: 1104-1108.
40. Bose WJ (2000) Accurate limb-length equalization during total hip arthroplasty. Orthopedics 23: 433-436.
41. Manaster BJ (1996) Total hip arthroplasty: Radiographic evaluation. From the RSNA refresher courses. Radiographics 16: 645-660.
42. Dumbleton JH, Manley MT, Edidin AA (2002) A literature review of the association between wear rate and osteolysis in total hip arthroplasty. J Arthroplasty 17: 649-661.
43. Fackler CD, Poss R (1980) Dislocation in total hip arthroplasties. Clin Orthop Relat Res 151: 169-178.
44. Ritter MA (1976) Dislocation and subluxation of the total hip replacement. Clin Orthop 121: 92-94.
45. Munuera L, Garcia-Cimbrelo E (1992) The femoral component in low friction arthroplasty after ten years. Clin Orthop 279: 163.
46. Vresilovic EJ, Hozack WJ, Rothman RH (1994) Radiographic assessment of cementless femoral components: correlation with intraoperative mechanical stability. J Arthroplasty 9: 137-141.
47. Khalily C, Lester DK (2002) Results of a tapered cementless femoral stem implanted in varus. J Arthroplasty 17: 463-466.
48. Konyes A, Bannister GC (2005) The importance of leg length discrepancy after THA. J Bone Joint Surg 87(B 9): 155-157.
49. Alfaro-Adrian J, Gill HS, Murray DW (1999) Cement migration after THR. A comparison of charnley elite and exeter femoral stems using RSA. J Bone Joint Surg Br 81:130-134.
50. Glyn-Jones S, Hicks J, Alfaro-Adrian J, Gill HS, McLardy-Smith P, et al. (2003) The influence of cement viscosity on the early migration of a tapered polished femoral stem. Int Orthop 27: 362-365.
51. Biedermann R, Krismer M, Stöckl B, Mayrhofer P, Ornstein E, et al. (1999) Accuracy of EBRA-FCA in the measurement of migration of femoral components of total hip replacement. Einzel-Bild-Rontgen-Analyse- femoral component analysis. J Bone Joint Surg Br 81: 266-272.
52. Berry DJ (1999) Epidemiology of periprosthetic fractures after major joint replacement: Hip and knee. Orthop Clin North Am 30: 183-190.
53. Hou Z, Moore B, Bowen TR, Irgit K, Matzko ME, et al. (2011) Treatment of interprosthetic fractures of the femur. J Trauma 71: 1715-1719.
54. Brady OH, Garbuz DS, Masri BA, Duncan CP (2000) The reliability and validity of the Vancouver classification of femoral fractures after hip replacement. J Arthroplasty15: 59-62.
55. Callaghan JJ (1997) Periprosthetic fractures of the acetabulum during and following total hip arthroplasty. J Bone Joint Surg 79: 1416–1421.