Radiology of Orthopedic Implants

Sanjeev Agarwal
Gaurav Jyoti Bansal
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To our parents—Rekha and Dev,
Padam and Ramesh
For all what you have done

Preface

The idea for this book owes its provenance to our weekly combined orthopaedic–radiology multidisciplinary meetings. We realised that discussions around radiographs of orthopaedic implants were not accompanied with the usual adroitness of non-implant radiographs and scans.

The array of orthopaedic implants is bewildering, to orthopaedic specialists and radiologists alike, and continues to proliferate. Combining the historical implants, the range of metalwork used by orthopaedic surgeons is so extensive that it is near enough impossible to catalogue the features of all the implants ever used.

The purpose of this book is to give the reader an insight into the radiological features of implants and to pick up any signs of impending failure. In many situations, the orthopaedic specialist who is familiar with the implant may be best placed to interpret the radiological findings. However, close working between radiologists and orthopaedic surgeons is of the essence. With increasing sub-specialisation in orthopaedics, a surgeon who operates on the knee may not be entirely comfortable with interpreting spine radiographs. Hence, the contributors to this book cover the whole range of orthopaedic and radiological specialties.

We hope this book helps improve interaction and promotes a common language between orthopaedic surgeons and radiologists.

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1 Introduction to Skeletal Radiology

Gaurav Jyoti Bansal and Vineet Bhat

Orthopaedic surgery has developed tremendously over the last 100 years.

Many developments in associated specialities have resulted in a significant change to the practice of orthopaedic surgery. Three of these milestones were the development of anaesthesia, asepsis and radiology. Before considering the development of orthopaedics, it is befitting to consider these three disciplines.

Development of Anaesthesia

The first impetus to surgery came from the development of anaesthesia, which initiated following the discovery of nitrous oxide by Joseph Priestley in 1772. Nitrous oxide was initially used for recreational purposes. In 1799, British chemist Humphrey Davy suggested that nitrous oxide could be used for anaesthesia, but the idea was not pursued, and nitrous oxide continued to be used as ‘laughing gas’.

Horace Wells, a dentist in the Unites States, used it for dental extractions and documented its utility as a pain-relieving agent. The gas was collected in an animal bladder and administered through a wooden tube. Wells had his own tooth extraction to prove its safety.

Subsequently, a demonstration was organised in 1815 at the Massachusetts General Hospital in Boston by Horace Wells. The patient was William Morton, also a dentist. However, the gas was not administered properly and failed to produce the desired effect. Diethyl ether, commonly known as ether, had been used by Crawford Long in 1842 for general anaesthesia, but this was not publicised.

Morton continued the search for a suitable anaesthetic agent and tried using ether on himself and his assistants. In 1846, in the same operating theatre, ether was used by William Morton as an anaesthetic for removal of a tumour from the neck. An ether-soaked sponge was used, and the patient inhaled through the sponge. The procedure was witnessed by medical professionals and was successful. Anaesthesia gained rapidly in popularity.

The administration of ether often led to vomiting in patients, and an alternative—chloroform—was tried by James Simpson, an obstetrician in Edinburgh in 1847. This became popular and was widely used. In 1885, the anaesthesia machine was patented. Improvements in equipment continued to make the administration safer and reliable. Intravenous anaesthetic agents were introduced in 1874, and spinal anaesthesia started in the 1890s.

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However, asepsis was not established at the time, and profusion of surgical procedures subsequent to anaesthetic developments still resulted in poor outcomes for many patients.

Development of Asepsis

Asepsis has its origin from the work of Robert Koch (1843–1910) who proposed four postulates establishing the connection between infecting organism and infectious disease. He worked on linking tuberculosis with *Mycobacterium tuberculosis* and was awarded the Nobel Prize for medicine in 1905. Louis Pasteur, a scientist working in France, made significant improvements to the understanding of microbes and infection. His work helped to refute the theory of spontaneous generation and replace it with the germ theory, which links microbes with infection and contamination. He also recognised the ability of carbolic acid to reduce infections.

Joseph Lister, professor of surgery at Glasgow, was influenced by Pasteur's work and started using carbolic acid dressings for wounds in 1867 [1]. He also introduced handwashing, sterilisation of instruments and spraying of carbolic acid in operation theatres, which greatly reduced infection rates. In 1869, a spray of carbolic acid and local anaesthetic was devised. Lister is considered the 'father of antiseptic surgery'.

Further advances in asepsis came with the work of Scottish Surgeon William Macewen, who used steam to clean surgical instruments. He advocated instruments made entirely of steel, which could be heated to a high temperature for decontamination. Rubber gloves were introduced in the late 1890s, prior to which surgeons used to operate with bare hands. Laminar flow was introduced in the operation theatres with the pioneering work of Sir John Charnley in Wrightington, England. With modern techniques of asepsis, maintaining normothermia in the anaesthetised patient and the use of prophylactic antibiotics, infection rate in orthopaedic surgery is lower than ever before.

Development of Radiology

Radiology owes its origin to the work of Wilhelm Roentgen, a German physicist.

Roentgen was working with cathode ray tubes in 1895 and noticed fluorescence on a barium platinocyanide plate on one side of the tube. He placed different objects between the tube and the plate. When placing his wife's hand in the path of the rays, he observed an image of the hand, showing the shadows thrown by the bones of her hand and that of a ring she was wearing. This famous image was the first 'roentgenogram' ever taken. Because the nature of these rays was then unknown, Roentgen called them 'X-rays'. Later, Max von Laue and his pupils showed that they are of the same electromagnetic nature as light but differ from it only in the higher frequency of their vibration. X-rays had been observed by many others before Roentgen, but he was the first to interpret the results and realise the importance of the discovery. Roentgen received the Nobel Prize in 1901. The uptake of radiographic imaging was dramatically quick following this discovery, and within months, many hospitals had set up X-ray machines.

The next major step in radiology was the development of cross-sectional imaging. Dr Godfrey Hounsfield, an engineer in Middlesex, England, was trying to determine the contents of a closed box using X-rays projected from different directions. Instead of using photographic plate, he developed a computer, which could record multiple images. This work led to development of a computed tomography (CT) scanner, and in 1971, a CT scanner was installed at a hospital in Wimbledon, London.

Hounsfield shared the Nobel Prize in 1979 with Alan Cormack, who was a physicist in Cape Town, South Africa, and worked out the theoretical mathematics for cross-sectional imaging. The radiodensity scale used in CT scans is named after Hounsfield (Hounsfield Unit, HU) with air being −1000 HU, water is 0 HU and dense cortical bone is +1000 HU.

Nuclear magnetic resonance (NMR) was discovered by Felix Bloch and Edward Purcell for which they shared the Nobel Prize in 1952.

Magnetic resonance (MR) creates a strong magnetic field leading to magnetisation of small biological magnets (protons) within the nucleus of the hydrogen atom within the body. In the 1970s, medical application of this technology gave rise to magnetic resonance imaging (MRI). MRI uses harmless radio waves to change the steady-state orientation of protons. Radio waves are then detected to register the body's electromagnetic transmission. Lack of ionising radiation makes MRI superior to CT scan for many clinical applications. The first image of two tubes of water was produced by Paul Lauterbur at Stony Brook University, USA, and further work by Peter Mansfield of University of Nottingham, UK, led to both scientists sharing the Nobel Prize for medicine in 2003. Lauterbur was credited for using magnetic field gradients for spatial localisation that led to rapid acquisition of 2D images and Mansfield for the mathematical formalism. The actual work that won the prize was performed 30 years earlier in Stony Brook University, where Lauterbur was a professor of chemistry.

The first whole-body MR scanner was built by a Scottish Professor John Mallard [2] and his team in 1970 at the University of Aberdeen. In August 1980, they used this machine to produce the first clinically useful image of the chest, abnormal liver and secondary cancer in bones. This machine was later used at St Bartholomew's Hospital, UK, between 1983 and 1993, leading to widespread popularity of MRI.

Ultrasound (US) is a nonionising, non-invasive technique which is now widely used in orthopaedic practice. In 1794, Lazzaro Spallanzani was the first to study ultrasound physics by deducing that bats used ultrasound to navigate by echolocation. In 1826, Jean Daniel Colladon, a physicist, used an underwater church bell to calculate speed of sound through water. He proved that sound travelled faster through water than air. In 1880, Pierre and Jacques Curie discovered the piezoelectric effect, which is a basic principle of modern ultrasound.

Karl Dussik, neurologist and psychiatrist at the University of Vienna, is generally regarded as the first physician to use ultrasound for medical diagnosis (of brain tumours) in 1942. In 1948, George Ludwig, an internist, first described the use of ultrasound to diagnose gallstones. The use of ultrasound for obstetrics and gynaecology conditions was pioneered by Ian MacDonald in 1958.

Ultrasound can be used as a primary diagnostic tool and as an adjunct to other radiological modalities. Apart from its excellent diagnostic capabilities, ultrasound can also be used for joint aspirations, drainage of abscesses/collections and targeted biopsies. Musculoskeletal ultrasound can visualise superficial/deep soft tissues and can diagnose soft tissue abscesses, fasciitis, pyomyositis, bursitis and soft tissue tumours. Following implant or prosthesis surgery, the presence of metalwork makes it difficult to interpret CT and MRI imaging due to degradation of image quality. Ultrasound is less affected and can be helpful in evaluating fluid collections or joint effusions and can be used to guide aspiration for microbiological diagnosis.

Radioisotope scanning started in 1961, when Fleming produced the first bone scintigraphic image using strontium 85, which is a gamma ray-emitting radionuclide. On the basis of these scans, he was able to diagnose metastasis and fractures. The use of technetium-99-labelled methylene diphosphate was proposed by Subramanium and McAfee in 1971. This, along with high-technology gamma cameras, has vastly improved the application and utility of bone scanning.

Increasing research is being carried out to assess the usefulness of positron emission tomography (PET) in osteomyelitis, and the results are encouraging. The accuracy of PET in the diagnosis of musculoskeletal infections was 94% compared with 81% for combined bone and white blood cell scan [3]. A recent meta-analysis found PET to be the most accurate diagnostic modality for osteomyelitis.

Orthopaedic surgery could not develop without adequate anaesthesia, asepsis and radiology, and once these aspects were developed, the profusion of orthopaedic implants has been tremendous.

Development of Orthopaedic Implants

Various substances were tried for use as orthopaedic implants. Some—like gold, silver and aluminium—were not strong enough. Others like nickel and copper caused local reactions. In the late eighteenth century, two French surgeons, Lapejode and Sicre, used brass wire for cerclage wiring of long bone fractures. This is one of the earliest attempts at internal fixation using metalwork. In 1843, Malgaigne devised a claw-shaped metal instrument, which could be used to approximate the two fragments of patellar fractures.

One of the earliest pioneers of internal fixation was Albin Lambotte (1866–1955) from Belgium. He devised internal and external fixation methods and carefully kept records of his operations. He coined the term 'osteosynthesis' and is considered the 'father of modern fixation methods of the bone'.

Sir William Arbuthnot Lane, working at Guy's Hospital, London, devised methods to internally fix displaced fractures using wires and screws. He published his results in his book entitled *The Operative Treatment of Fractures* in 1905. He used aseptic techniques and specified dressings to reduce infection rate. He also used long steel plates fixed with screws for fracture fixation. Stainless steel had not been discovered, and Lane's implants were made of ordinary steel, which was prone to corrosion.

In 1912, William Sherman devised self-tapping fully threaded vanadium machine screws. He laid down exact dimensions for screw design, which were largely similar to the screws used in metal and wood industry. He also designed a plate for use with screws, which remained in use for nearly 50 years.

The development of orthopaedic implants was closely linked to improvements in metallurgy. Stainless steel with 12.8% chromium and 0.24% carbon was first made by Harry Brearley in 1913. In 1926, stainless steel was used for orthopaedic implants for the first time. In 1936, Venables and Stuck introduced cobalt-chrome alloy. Martin Kirschner, a German surgeon, devised steel wires for fixation, which remain in use even today.

Gerhard Kuntscher, working in Hamburg, Germany, developed the intramedullary nail. He used a hollow nail with a clover leaf cross section to achieve fixation in the medullary canal. His work was presented in 1940, but the Second World War delayed general knowledge and acceptance of his work. Prior to development of the nail, standard treatment of femoral shaft fractures involved traction and cast. A faster recovery was made possible with the use of nail and avoidance of casts.

Robert Danis, a Belgian surgeon, made design changes to the Sherman screws to adapt it for use in orthopaedics in 1940s. He also developed the compression plate and laid down the principles of internal fixation—accurate reduction, rigid fixation, early mobilisation and healing without callus formation—also known as healing by primary intention. One of his students—Maurice Muller—took his concepts and, along with his colleagues, formed the AO (*Arbeitsgemeinschaft fur Osteosynthesefragen*) group in Switzerland in 1958. The AO group was instrumental in advancing orthopaedic trauma management. Over the years, the AO group has continued to innovate and expand the armamentarium.

The development of hip replacements by John Charnley and knee replacement implants by Insall and Walker made these procedures reliable and immensely popular. The profusion of implants over the last three decades has been truly exponential, and the range of tools available to the orthopaedic surgeons today would have been unimaginable few decades back.

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2 Hip Implants

Sridhar Kamath, Sanjeev Agarwal,
and Ashish Mahendra

Hip replacements became popular in the 1960s following pioneering work by Sir John Charnley at Wrightington, England. Over the last 50 years, there has been a profusion of various types of hip implants alongside the number of operations performed worldwide.

The radiological assessment of hip replacements is based on anteroposterior (AP) view of the pelvis and lateral view of the hip joint.

The parameters to note are:

1. AP pelvis radiograph:
   - Acetabular abduction angle
   - Distance of the acetabular component from the medial wall
   - Degree of covering/uncovering of the acetabulum
   - Cementation of the acetabular component
   - Femoral stem placement in the canal
   - Cementation of the femoral component and any radiolucencies in the cement mantle
   - Level of femoral neck cut
   - Leg length discrepancy
   - Periprosthetic fracture
   - Restoration of offset of the femur
2. Lateral view of the hip:
   - Acetabular version angle
   - Femoral stem placement in the canal—quality of cementation
   - Any impinging osteophytes along the anterior acetabular margin
   - Periprosthetic fracture
3. On long-term follow-up radiographs, note:
   - Evidence of loosening of the femoral/acetabular component
   - Wear of the acetabular liner—as evidenced by eccentric migration of the femoral head
   - Periprosthetic fracture
   - Stress shielding
   - Remodelling of the bone around the implant

The acetabular version is an important determinant of the stability of the hip. The version is the angle between the face of the acetabular component and the coronal plane of the patient. Most studies indicate the desired version is between 5 and 30°. Hip replacements done through a posterior approach are more reliant on adequate version to maintain stability.

The anteversion of the acetabular component gives the opening (equator) of the cup an elliptical appearance on the AP radiograph (Fig. 2.1). If the equator appears as a straight line, it implies that it is parallel to the radiographic beam and is in neutral alignment (Fig. 2.2).

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Fig. 2.1 Left total hip replacement with a cementless acetabular component and cemented femoral component. The equator of the acetabular component has an elliptical outline, as is desirable. The acetabular component has a polyethylene liner, and no screws were used for fixation of the acetabular shell into the pelvis

Fig. 2.2 The equator of the acetabular component has a nearly straight projection. This implies that the equator of the component is parallel to the beam and is in neutral version. Anterior or posterior tilt of the pelvis would also influence the projection of the acetabular component

A lateral radiograph is essential to accurately assess anteversion, as a retroverted acetabular component may appear similar to anteverted radiograph on the AP radiograph (Fig. 2.3a–c). The positioning technique for shoot-through lateral radiograph of the hip is demonstrated in Fig. 2.4. In this view, the angle between the equator of the acetabular component and a line drawn vertically represents the acetabular version. Methods to measure anteversion are described later in this chapter.

Hemiarthroplasty of the Hip

Hemiarthroplasty of the hip is replacement of the femoral head with a metal prosthesis. It is commonly done for displaced intracapsular fractures of the femoral neck in the elderly.

The mode of fixation of the implant to the femur depends on whether the implant is designed for use with or without cement. Examples of uncemented hemiarthroplasty are the Austin Moore and the Furlong Hemiarthroplasty (JRI Orthopaedics, Sheffield, UK). Cemented hemiarthroplasty includes Thompson's prosthesis.

In addition, hemiarthroplasty can be unipolar or bipolar. A unipolar prosthesis is made of a single block of metal without an inbuilt articulation—like the Austin Moore and the Thompson's prosthesis. These were widely used in the past few decades but have now largely been replaced with modern designs which allow better cementation/fixation and offer a wider range of stem sizes and offsets.

The Austin Moore prosthesis (Fig. 2.5) was designed by Austin T. Moore in early 1950s. It is inserted without cement, and the surface does not have any special coating to encourage bone ingrowth or ongrowth. It has two large fenestrations in the stem which theoretically allow the bone to grow through for stability, and a hole proximally which is to aid removal of prosthesis if required. The prosthesis has a collar which rests on the cut surface of the femoral neck and the calcar. Although widely used in the past, the use of this prosthesis is now largely historical as it provides inadequate fixation in the femur.

The Thompson prosthesis was introduced by Frederick Thompson at St. Luke's Hospital, New York, in the early 1950s. This is generally cemented (Fig. 2.6) although it can be inserted without cement in narrow femoral canals. It has a narrower and shorter stem than the Austin Moore prosthesis and does not have the holes in the stem. There is no hole proximally for extraction.

Currently used cemented hemiarthroplasty implants allow better cementing with the use of appropriately sized broaches to prepare the femoral canal (Fig. 2.7).