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Victor N. Cassar-Pullicino
A. Mark Davies *Editors*

Measurements in Musculoskeletal Radiology

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VCP providing illumination while AMD attempts to restore power

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Editors

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This book is dedicated to Wendy Pullicino

Preface

From the birth of imaging with Roentgen to the latest molecular imaging, there has always been a desire to obtain measurements that can be compared with further observation over time or with other cases. In their first edition of the *Atlas of Roentgenographic Measurement*, Lusted and Keats stated that "The interpretation of a roentgenogram remains an art ………. To this interpretation the objective evidence of the roentgenographic measurement can make an important contribution". This remains as true today as when first published almost 60 years ago. The difference now is that our knowledge of what is normal or abnormal and pathology in general has expanded almost exponentially hand-in-hand with equally dramatic advances in imaging techniques using both ionising radiation (e.g. CT and PET) and non-ionising modalities (e.g. US and MRI).

It is true to say that way back in the early 1980s, as radiologists in training, we were at best lukewarm to the concepts of measurement and their role in musculoskeletal disorders. Increasingly over the years as advances in imaging and musculoskeletal diseases have continuously evolved, we have often quoted Lord Kelvin's wise words; "To measure is to know" and "If you cannot measure it, you cannot improve it". However if a measured parameter is deemed important in science, research and clinical practice, it is imperative to realise that its value rests entirely on the adequacy, precision and accuracy of its measurement. The purpose for which the measure is intended must be clearly understood and the inferences that can be drawn need to be examined in an objective and critical manner before any conclusions are reached. All too often measurements are introduced and employed without examining their validity, which requires that rigorous steps are put in place to understand the meaning and usefulness of the measured values. The main aim of this book is to critically and clearly bring this knowledge under one roof.

As our understanding of disease processes and the sophistication of imaging techniques have improved with time, there is a need to continuously update radiologists, orthopaedic surgeons and the other allied healthcare professionals working in this field. To this end this book takes a trident approach. The first five chapters are devoted to the differing imaging techniques highlighting the strengths and weaknesses when employed to measurement. There are then 12 chapters dealing with the major anatomical areas where the relevant distilled knowledge and data are presented critically in a template format. The final four chapters are devoted to the wide range of imaging that can be applied in varied disease states.

We are particularly grateful to the international panel of authors for their expert contributions to this book, which aims to provide a comprehensive and up-to-date overview of measurements and their value in musculoskeletal radiology. The subject is diverse and complex, and the relevant publications are found scattered across multiple scientific and medical disciplines. To this end we are especially grateful to the dedicated Francis Costello Library staff at the Robert Jones and Agnes Hunt Orthopaedic Hospital, namely Marie, Fiona, Siobahn, Scott, Amanda, Karen P, Pauline, Samantha, Lis, Louisa, Karen J and Kenna, who gave every assistance and guidance in procuring the original publications. The support that we received from Springer Verlag by Ute Heilmann and her team was instrumental in seeing this book to fruition. Special thanks must also go to the immeasurable support that we received from a number of secretaries but namely Wendy and Erica. We also wish to acknowledge the endless patience, skills and unflagging fortitude of the Medical Illustration Department at the Robert Jones and Agnes Hunt Orthopaedic Hospital headed by Andrew Biggs, namely Alun, Nia, Jon and Tony, who had the task of redrawing all the figures from a variety of sources. Last and by no means least, this would not have been possible without the encouragement, patience and unselfish nature of Wendy Pullicino who was always there along the long journey—words cannot define how much we valued her support.

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Part I

Measurement Techniques

1 The Radiograph

Eric Hughes, Prudencia N. M. Tyrrell, and Victor N. Cassar-Pullicino

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1.1 Introduction

Radiographs have been used in diagnosis for over 100 years. Despite the many technical advances in imaging, they retain an important role in the diagnostic workup of many ailments particularly in bone and joint pathology. They are often used in imaging follow-up of disease states to evaluate progression, monitor treatment or assess metalwork or implants following surgery. It is possible from the radiographs to make measurements which aid in diagnosis or subsequent management of a condition. Sometimes, these measurements are crude representing an observation such as the presence of prevertebral soft tissue swelling in a patient with a history of cervical spine injury where that observation signals a very high probability of either bone or soft tissue injury. On other occasions, precise measurements may be required such as in leg length evaluation which may determine the degree and extent of surgical intervention if indeed any. They also are often used for measuring distances and angles in musculoskeletal work to assist in the planning of management including surgery. There are inherent advantages in using radiographs for such measurements, but there are also certain limitations often related to technical factors of which clinicians and radiologists need to be aware. This chapter addresses the general role of radiography in measurements undertaken in musculoskeletal work. The specific role of radiography in measurements of different anatomical and pathological states is made in the relevant chapters.

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1.2 Advantages of Radiographs

Radiographs are cheap and readily available. Standardisation of the radiograph is possible such that they can be directly compared both within a department and between different departments. Thus, they are reproducible and in this context can be used in research. The conventional radiograph can be used to monitor progress of a condition such as rheumatoid arthritis by documenting joint space narrowing and number of erosions. It can be used to monitor healing of bone injury documenting new bone formation and progressive consolidation or otherwise. It can be used to monitor the effect of therapy or response to treatment such as may be seen with effective antibiotic treatment in osteomyelitis or appropriate biochemical or endocrine treatment in osteomalacia. Serial lateral radiographs of the thoracic and lumbar spine are used in the monitoring of osteoporosis. Grading systems have developed and employed radiographic appearances to denote severity of disease which is used in therapeutic decision making, e.g. trauma and avascular necrosis. The earliest changes of disease processes, however, may not be seen on radiographs, such as avascular necrosis, and other imaging modalities such as magnetic resonance imaging may need to be employed. Once the radiographic features are detectable, then the radiograph may be used for disease monitoring in some instances. Many surgical instrumentation procedures are monitored over time with periodic radiographs. This is perhaps most commonly seen in patients who are being followed up post arthroplasty. Monitoring of disease with serial or sequential radiographs provides objective evidence as a guide to decision-making for operative or nonoperative treatment. In the examples given above, eyeballing the radiograph to assess status can be adequate. However, there will be many instances where accurate measurements are required in order to determine planning of corrective surgery, for example, in children with unequal leg lengths. Accurate measurements are also required to facilitate evidence-based studies. This can be seen in patients with spinal infection where the disc has been destroyed with associated loss of vertebral body height. Should vertebral body collapse with kyphotic deformity progress to a particular level, then surgery with instrumentation may be necessary to stabilise the spine and prevent further deformity. Such objective evidence with measurement of the degree of angulation facilitates evidence-based outcomes of treatment.

Assessment of bone age and potential for growth in the immature skeleton is important in treatment planning. This can be done using a number of indices. The Greulich and Pyle atlas of hand radiographs (Greulich and Pyle 1959), or the Sauvegrain method of bone age estimation on elbow radiographs (Sauvegrain et al. 1962) between the approximate ages of 11 and 16 years, are just two of a number of methods available. All methods of estimating skeletal age involve comparing radiographs of the patient with standards in an atlas. This estimation is only moderately accurate. In the Tanner and Whitehouse method (Tanner et al. 1975), 20 indicators on hand and wrist radiographs are assessed and given a score, yielding a total score from 0 to 100. The Risser sign relates to the degree of ossification of the iliac apophysis (Risser 1958). This is a commonly used marker of skeletal maturation especially in the treatment of scoliosis. A bone age estimation in isolation is meaningless. The measurement needs to be compared with the chronological age and ideally the rate of annual growth in standing height assessed.

One particular advantage of plain radiographs, not readily available with other imaging modalities, is the facility to obtain dynamic views in, for example, flexion and extension. This allows a rapid evaluation of stability. Abnormal movement can be detected by eyeballing the radiograph or discrete measurements can be obtained if necessary. Stress views, e.g. at the knee or ankle, can be used for the evaluation of ligamentous integrity.

Radiographs are good for providing both an informal and formal assessment of measurement, but there are a number of technical issues which need special consideration when highly accurate measurements are required. These are addressed in detail below.

1.3 Limitation of Radiographs for Measurement

Despite the many advantages of radiographs for use as a measuring tool in orthopaedic and musculoskeletal work, there are a number of limitations. To understand the nature of these limitations and how they may be overcome, it is helpful to reflect on how X-rays are produced. Although many departments are now using some form of digital radiography, basic principles of both film and digital imaging are covered. In line with commonly used terminology, this text refers to focus film or object film distances, and use of the term film in this instance can refer to a film cassette, computerised radiography plate or a direct digital radiography detector plate.

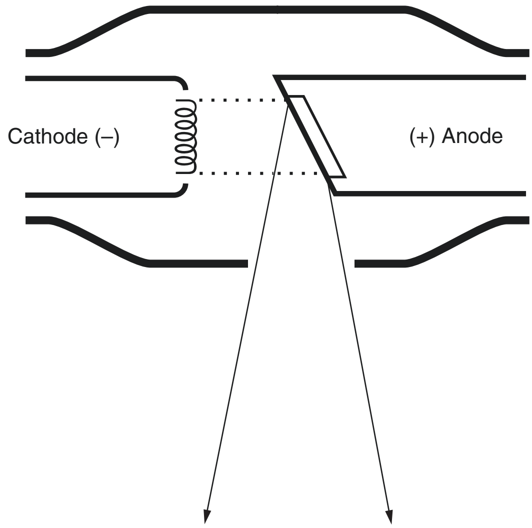

Fig. 1.1 X-ray tube simplified representation

Basic Principles of X-ray Production

A focused beam of electrons is accelerated between the cathode and anode of an X-ray tube striking the anode at high speed within a small area to produce what is as close to a point source of X-rays as is possible within the efficiency limitations of the system (Fig. 1.1).

The resultant X-rays are emitted in all directions but are contained within the housing of the X-ray tube with the exception of a small window which, with the addition of adjustable lead slats, can result in a directed divergent adjustable beam of X-ray. The portion of the beam which is passed through the object without being deflected forms the shadow image on a film or an image receptor plate. Scattered radiation reaches the film in a random way and does not contribute to the useful image. This scattered radiation may need to be reduced by the use of a lead-slatted grid.

In order to reduce the amount of radiation required to form the image and reduce the radiation dose to the patient, the use of film has been supplemented by the use of intensifying screens which convert each X-ray photon into several light photons. It is therefore the light emitted by the intensifying screens which forms the majority of the image on the film. Conventional film screen cassettes produce an analogue image recorded on film and developed using a photographic process. These are viewed on a lightbox. All the information is in the hardcopy image only and the image cannot be manipulated. Within PACS digital systems, a similar effect is generated by the use of mathematical algorithms. In the technique of computed radiography (CR), a photostimulable phosphor contained within a cassette is exposed in the same way as conventional film and then removed to be read remotely by a laser mechanism. Direct digital radiography (DDR) uses solid-state detectors to record the latent image, but this is linked directly to the readout device, therefore requiring much higher costs for replacing the X-ray imaging hardware. Digital radiographs, whether produced by CR or DDR, can be manipulated, contrast enhanced and edges sharpened, and with appropriate software, measurements can be readily obtained.

MRI, CT and nuclear medicine are digital imaging techniques where the information contained in the image is stored in numerical form and thus can be manipulated in order to enhance contrast resolution. Spatial resolution can also be controlled by altering pre-imaging parameters. This technological advancement has been slower in conventional radiography, and there are at present a number of options for recording and thus measuring from the radiographic image.

1.4 Technical Limitations of Radiographs for Measurement

These fall into three categories:

1. Resolution—contrast and spatial
2. Magnification
3. Distortion

Resolution: Contrast and Spatial

The resolving capability of a particular radiographic material or fluorescent screen image is a measurement of the degree of fine detail which can be recorded. It is related to the unsharpness characteristics of the material as it is a measure of the ability to differentiate between adjacent positional detail. Resolution is often expressed as the number of lines per millimetre that can be seen as separate elements of an image. Spatial resolution is high for detailed conventional radiography as compared to CT where the degree of spatial resolution is limited by the field of view and matrix size employed.

The attenuation of the X-ray beam is inversely proportional to the square of the atomic number of the object/tissue being imaged. Therefore, the higher the atomic number, e.g. cortical bone, the greater will be the attenuation of the X-ray beam, and the lower the atomic number, the less the beam is attenuated as it passes through the tissue. In conventional radiography, tissues with a wide difference in density, such as cortical bone and soft tissue, can be readily appreciated. Tissues with a narrower difference in density such as fat and muscle can be differentiated but will require optimum viewing conditions to appreciate. Tissues with potentially a very narrow difference in density such as muscle and a non-metallic foreign body such as glass will require close attention by the radiographer to exposure factors (kilovoltage (kVp) and milliampere seconds (mAs)) and optimum viewing conditions for the reporting radiologist. The kilovoltage used is a major determinant of contrast resolution. In conventional radiography, contrast can be altered by adjustment of exposure parameters and is very much less than that which can be achieved with computed axial tomography (CT). Radiography is excellent for the evaluation of bone detail, whereas the soft tissue detail is poor. A large knee joint effusion is seen as distension of the suprapatellar pouch, but it can be extremely difficult if not impossible to identify if the joint distension is due to serous fluid from an arthritic process, due to pus from an infected joint or due to blood following trauma. If a haemarthrosis occurs in association with a fracture, then a fluid-fluid level due to layering of different density materials may be identified on a horizontal shoot-through radiograph.

Contrast and image sharpness have both subjective and objective connotations. Subject contrast is mainly influenced by kilovoltage and scattered radiation. The degree of scatter can be reduced by the use of grids.

Image sharpness is affected by the geometry of the equipment including the size of the focal spot and the relative distance between the focal spot, the subject and the film. The degree of geometric unsharpness can be controlled in several ways:

1. By using a smaller focal spot.
2. By decreasing the object to film distance.
3. By increasing the focus to object distance. In practice, this is equivalent to increasing the focus to film distance.

Focus Size

The production of X-rays is an inefficient system with approximately 98% of the energy used being produced as heat. With temperatures of the tube anode reaching close to 3000 °C during exposure, there is a need to dissipate heat effectively from the anode. This is achieved by use of a rotating angled anode and the ability of the operator to select one of two electron distribution areas on the anode referred to as the broad or the fine focus. Modern imaging units have an effective fine focus of the order of 0.4–0.6 mms and a broad focus of the order of 1.0–1.5 mms. The use of an X-ray source of a finite size leads to penumbra effect which diffuses the edge of an object rendering it less distinct than if a point source was used (Fig. 1.2). At an operational focus to film distance of 100 cm or more, the effective width of the penumbra is minimal, but the smaller the value of the focus to film distance, the greater the penumbra effect.

Another cause of slight unsharpness of an object image when using film is the parallax effect. Radiographic film is made up of two separate emulsion coatings separated by a film base. X-irradiation or light striking the film will form two images. These can only be directly superimposed when viewed at the same angle as that at which the image forming radiation fell onto the film. Any slight offset between the two images is known as the parallax effect. Movement of the patient during the exposure and also the duration of the exposure itself may contribute to slight variations in image sharpness.

The use of intensifying screens can also be used to improve detail of the image. An intensifying screen consists of crystals suspended within a binding material. Faster screens which require a reduced number of photons to form the image have larger crystals which emit light when struck by an X-ray photon. The larger crystals limit the ability of the resultant image to resolve smaller structures. Slower intensifying screens which are designed to provide high detail have smaller crystals and a dye within the screen to limit the diffusion of light within the binder. This enables such a system to resolve between smaller structures.

For CR or DDR systems, the resolution of the system is dependent on the physical limitations of the plate reader (CR) or the photostimulable material used (DDR) to collect the image. Generally, digital systems are inferior to film in resolution, but this reduction in image quality is overridden by the flexibility offered by PACS software systems.

Some radiographic measurements are dependent on both spatial and contrast resolution. Exposure factors are very important here, and this is particularly in relation to measurements such as cortical thickness, joint space, size of erosions and prosthetic-bone-cement interfaces.

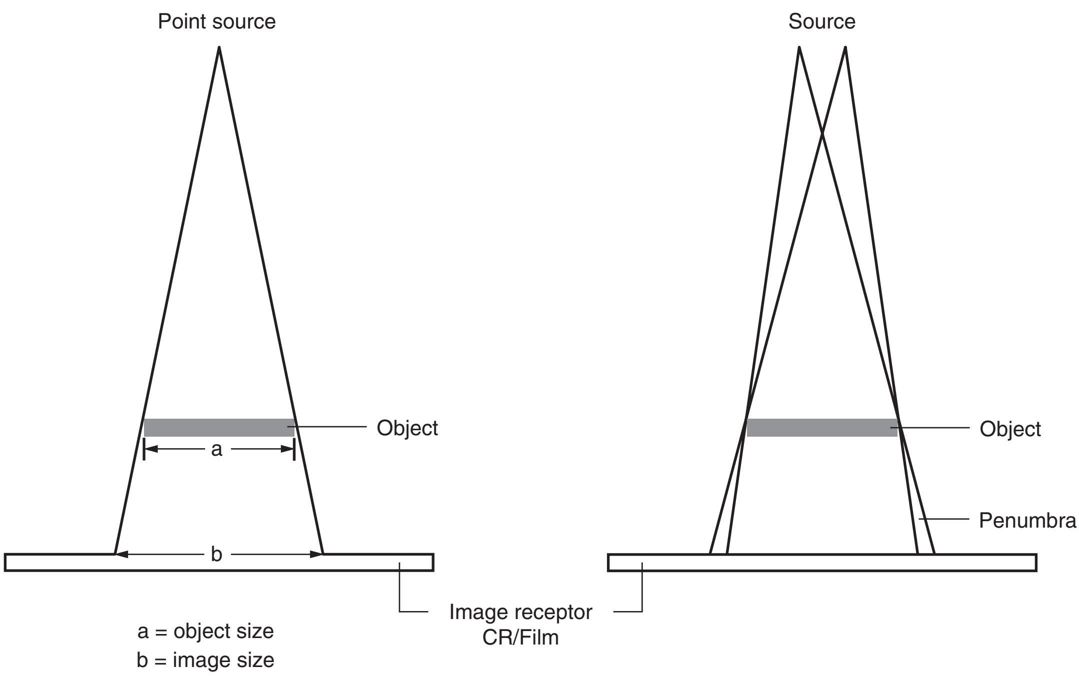

Fig. 1.2 Penumbral effects (see text)

Distortion

Image distortion results from the oblique projection of the image and can be produced in one of two ways:

1. Radiography using an angled beam (Fig. 1.3)
2. Radiography of an object not parallel to the film (Fig. 1.4)

Such image distortion can interfere with measurement, for example, in evaluation of the joint space where there may be a degree of flexion (deformity or positional). In a routine radiograph of the knee joint, the tibial condylar region slopes downwards by approximately 15° posteriorly, and therefore, in the standard anteroposterior view of the knee joint, the tibial plateau is not seen tangentially. Tibial plateau/condylar fractures can be overlooked on this account. An AP projection with 15° caudal angulation produces a tangential view of the plateau and facilitates observation of depressed fractures. Objects can also be angled in relation to the film in more than one plane and can therefore be distorted in more than one plane, e.g. scoliosis and kyphosis.

Magnification

The X-ray beam diverges from the focus of the X-ray tube in straight lines so that the cross-sectional area of the beam increases with increasing distance from the X-ray source (Fig. 1.5). Therefore, the radiographic shadow image is always larger than the original subject and hence subject to a degree of magnification. The degree of magnification is calculated by the focus to film distance divided by the focus to object distance. The actual size can then be calculated:

Actual size = image size/magnification.

Within an imaging department, there are factors which will affect magnification:

1. Different manufacturer equipment and models will have different tabletop to film distance.

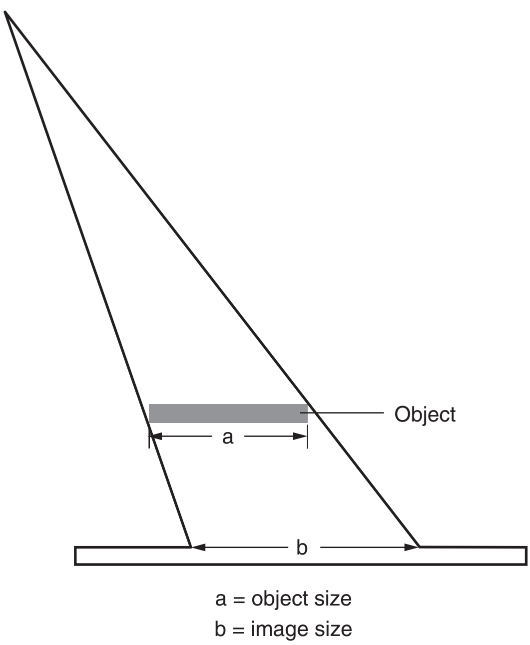

Fig. 1.3 Distortion, angled beam (see text)

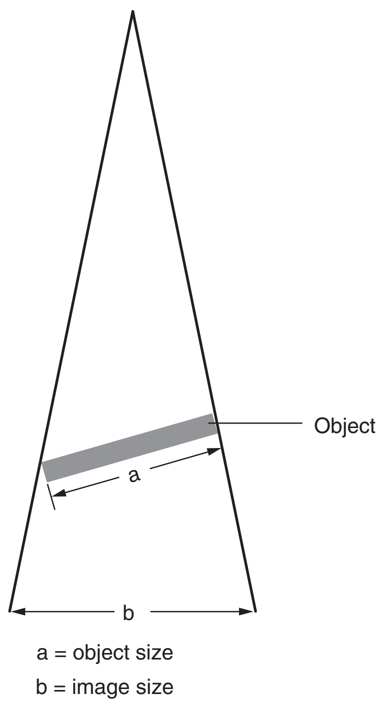

Fig. 1.4 Distortion, object not parallel to the film (see text)

This will contribute to the total object to film distance.
2. Physical size of the patient.
3. Departmental standard focus to film distance and the radiographer adherence to the standard. It must not be assumed that the presence of a standard guarantees that each image will be undertaken at the correct distance. It will vary between X-ray rooms in the same department.

Measurements taken direct from a radiograph are always subject to a degree of magnification. Even with radiography where the object imaged is in direct contact with the film, for example, weight-bearing views of the feet, there will always be a degree of magnification involved because the object imaged always has some thickness. The user must be aware that if taking a measurement from an uncalibrated image, they will not know the extent of magnification to which the object has been subjected. Many methods exist to calibrate an image. The favoured method is using a spherical object (as this is not subject to projectional distortion) of a known size placed at the same object to film distance as the object to be measured, e.g. in planning prosthetic requirement. The magnification to which the calibrating sphere has been subjected is calculated by magnification equalling measured size divided by actual size. In certain situations where direct measurements are required, such as for leg lengths, a measuring ruler can be placed beside the patient and radiographed beside the leg such that any magnification incurred will relate to both the image structure and the ruler measure facilitating a more accurate measurement. For PACS systems, plate (and therefore pixel size) is known and it may appear that there is increased accuracy in using measurement systems inbuilt within the PACS software. These systems however are not calibrated and some assume a magnification factor in the order of 10%. PACS imaging is subject to the same physical factors which affect radiographic film imaging.

Accurate measurements of joint space can be very important when trying to measure rate of disease progression in arthritis and particularly when this is part of a trial to evaluate the effect of disease modifying drugs in arthritis. The use of the semi-flexed anteroposterior view, using a horizontal X-ray beam to produce a beam tangential to the tibial plateau and using fluoroscopy to achieve reproducible alignment, has been valuable (Buckland-Wright 1995). Microfocal radiography has been shown to improve reproducibility of joint space width measurement compared to standard radiography. The chief advantage of microfocal radiography is its spatial resolution, of the order of 10–100 µm, as compared to 300–1000 µm for standard radiography. The first longitudinal study of rates of joint space narrowing measured using microfocal radiography was carried out by Ward and Buckland-Wright (2008) which showed a lowered variability of the rate of joint space narrowing but the high cost and low availability of microfocal equipment remains a barrier to its more widespread use.

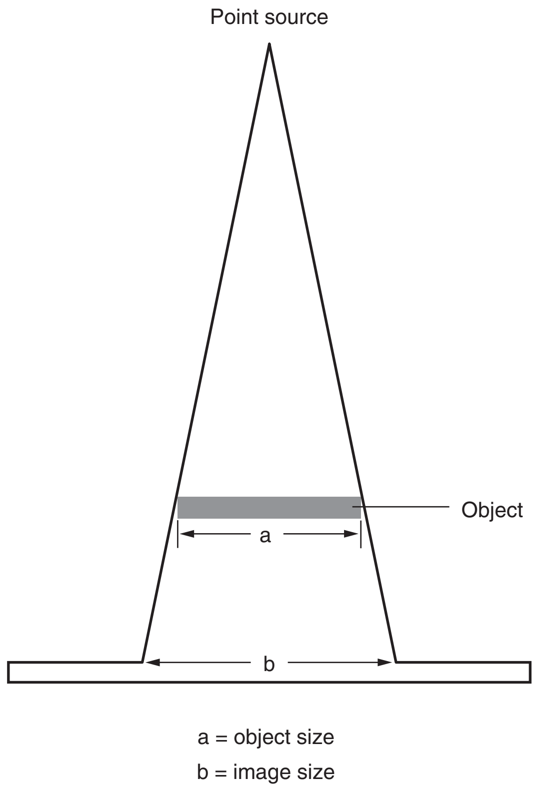

Fig. 1.5 Magnification effects (see text)

1.5 Anatomical Determinants

Anatomical features in certain areas of the body are associated with difficulties in obtaining accurate radiographic assessment and measurement. Such areas include:

1. The patellofemoral joint. Knee flexion to varying degrees has been advocated for the assessment of patellofemoral joint alignment. The conventional radiographic technique of a skyline view in 45° flexion with the X-ray beam angled 30° towards the floor (Merchant's view) (Merchant et al. 1974) has been largely superseded by CT or MR assessment in varying degrees of flexion (10–30°), as at 45° the patella is forced into the intercondylar notch even when prone to subluxation or maltracking (Walker et al. 1993).
2. The hip joint when evaluating for SUFE. An X-ray image is a two-dimensional view of a three-dimensional object. By taking two views at right angles to each other, a three-dimensional image can be built up visually. However, the axial or Z projection is not obtainable, and thus, measurements that might be valuable in this plane cannot be obtained. The angle of slip in SUFE is well seen on axial CT or MR images.
3. Weight-bearing views. These are more accurate for the depiction of joint space narrowing especially in arthritic states. It is important that when comparative assessments are made that like is compared with like, i.e. weight bearing with weight bearing.
4. Dynamic views. A linear measurement in orthopaedics is taken between two bone points of interest. At rest, this measurement can be within the normal range implying that the stabilising soft tissue structures are intact. Dynamic views unmask the loss of soft tissue integrity by showing differing measurement between the same bone points which lies outside the normal range, as may be found, for example, following a spinal injury, or in cases of instability arising in other conditions such as rheumatoid arthritis (Fig. 1.6).

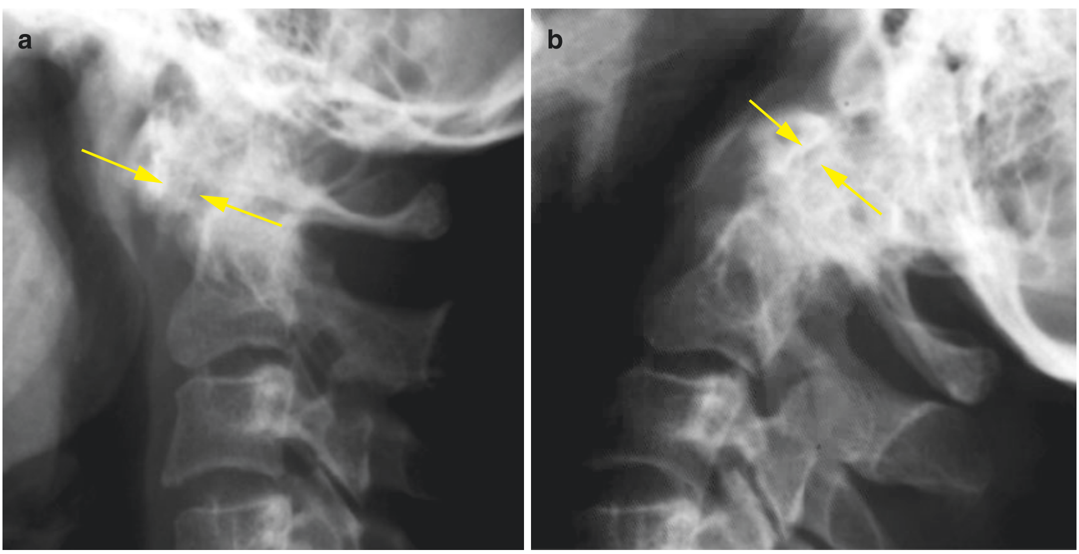

Fig. 1.6 (**a**, **b**) Lateral radiographs of the cervical spine in (**a**) flexion and (**b**) extension in a patient with rheumatoid arthritis. Note the abnormal movement at the atlanto-axial junction (arrows), with marked widening in flexion indicating anterior atlanto-axial instability

1.6 Orthopaedic Templating

Orthopaedic templating is an important element of pre-surgical planning for arthroplasty surgery where the appropriate size of implant to be used must be determined prior to surgery.

This has traditionally been undertaken using acetate templates provided by implant companies which were placed over conventional X-ray images. The acetates enabled the selection of the appropriate-sized implant with measurements in theatre contributing to the final choice of implant. These acetates assume a standard magnification for all radiographs of a particular joint, e.g. 10% for hip images.

With the advent of PACS, the overlay of an acetate template is no longer possible. A number of commercial software packages have been developed which will work within or separate to PACS enabling the user to assess the size of implant required. For accuracy, the magnification of the image must be calculated. This can either be by assessing the magnification of an object of a known size (e.g. a metallic ball) or by calculating the magnification by measurement of the focus to film distance and the object to film distance.

For the use of an object of a known size, accurate calibration relies on the placement of the object at the same distance from the film as the anatomical feature to be measured, in this case the head of femur. Such systems are therefore reliant on the careful placement of the calibrating object.

There is evidence to suggest (Franken et al. 2010) that more accuracy can be gained by measurement of the focus to film and object to film distances and calculating the magnification in this way. This can be achieved using callipers or commercially available products.

Some PACS systems will make an assumption in relation to magnification if no calibration is supplied, and care must be taken to ensure that where accurate measurement is required, e.g. the provision of custom implants, these are only taken using calibrated images.

Many companies are now developing the functionality of the software packages beyond orthopaedic templating to enable the determination of angles and the ability to aid surgical planning by estimating the appropriate size required for:

1. Plates
2. Nails
3. Screws

Many packages now offer the ability to determine osteotomy planning and specific paediatric planning and may prove to be more reliable than conventional methodology (Hankemeier et al. 2006).

Where CT images are available, orthopaedic templating is also available using 3D information. It is anticipated that the use of such software packages will grow in direct relation to the increasing use of PACS systems.

1.7 The Role of the Radiograph Related to Other Imaging Techniques

As outlined earlier in this chapter, radiographs have many advantages as a technique for measurement of various parameters in musculoskeletal conditions. There are limitations however which are largely related to contrast (largely related to the soft tissues) and also to image sharpness which can lead to blurring of image margins and hence a reduction in accuracy of the measurement. The advantages of other specific imaging modalities will be addressed in later chapters. Ultrasound is particularly good for superficial soft tissue measurements. CT with its superb contrast resolution particularly cross-sectional assessment of bone structures facilitates measurement in all imaging planes including the Z projection. MR with its particular soft tissue contrast allows evaluation of both soft tissue and marrow measurements again in all three imaging planes and indeed also in oblique planes as required. Conventional radiography however is readily available in most departments, is universal and can be reproduced at minimal relative cost. This ensures that it will remain as a mainstay in both diagnostic and evaluation processes for some time. However, even with the advent of PACS, care must be taken as regards calibration and ensuring accuracy of measurement techniques.

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2 Computed Tomography

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Contents

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2.1 Introduction

Measurements relevant to the musculoskeletal system that can be made on CT include distances and angles from the scout view, distances, angles and CT numbers from individual axial sections and more complex three-dimensional distances and angles from separate axial sections or reformatted images. Volumes can be estimated from the measured dimensions of the tissue in question or by summing the product of cross-sectional area measurements and slice spacing. CT number measurement gives rise to tissue density estimation, the accuracy of which can be improved by dual-energy scan techniques.

The use of computed tomography for distance and angle measurements has both advantages and limitations compared with plain film radiography, ultrasound and magnetic resonance imaging. Because X-rays travel in straight lines, the location of points defined by axial CT images should not be distorted in the *X* or *Y* directions, unlike MR images where image distortion by magnetic field variations occurs. The geometric magnification that occurs in conventional radiography does affect the CT scout view, as described below. Point location in the *Y*-axis (along the direction of table travel) may be less accurate on axial images, due to the slice thickness, but multislice spiral scanners are

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capable of isometric (*X*, *Y* and *Z* plane) resolution so that measurements between points located on different axial slices should be of comparable accuracy to in-plane measurement. CT utilises ionising radiation, the minimum number of axial sections and lowest mA and kV settings that can produce acceptable images should routinely be used.

There is little recent literature confirming the in vitro accuracy of CT length and angle measurements, with most of the early studies published in the German literature. This chapter is therefore illustrated with in vitro scans depicting measurements that have been compared with the results of calliper and protractor measurements of the scanned objects.

2.2 Scout View Measurements

The scout view is generated by smooth, uniform velocity movement of the scanner table through the scanner aperture, whilst a thinly collimated fan beam of X-rays from the stationary tube is projected across the aperture to the detectors. The data acquired from the detectors at each point in time forms one line across the final image, the location of which within the image is directly related to the table location at that point in time. Consequently, measurements along the long axis of the scanner are potentially as accurate as the table location, which is calibrated to an error of less than 0.5 mm. Measurement across the image is, however, distorted by the fan beam geometry, with objects closer to the X-ray tube being magnified in this direction relative to those nearer the detectors. The image is calibrated to give accurate measurement across the image at the gantry isocentre; consequently table height adjustment to bring the structure being measured as close to the isocentre as possible is necessary for the most accurate result. Figure 2.1 illustrates the effect of altering table height on scout view measurements, using a femur as a test object. Small metallic markers were placed on the top of the femoral head, on the top of the femoral neck, on the lesser trochanter and on the back of each femoral condyle. These can be seen in Fig. 2.1a. Figure 2.1b–d shows the scout view appearances with the table as low as possible (closest to the

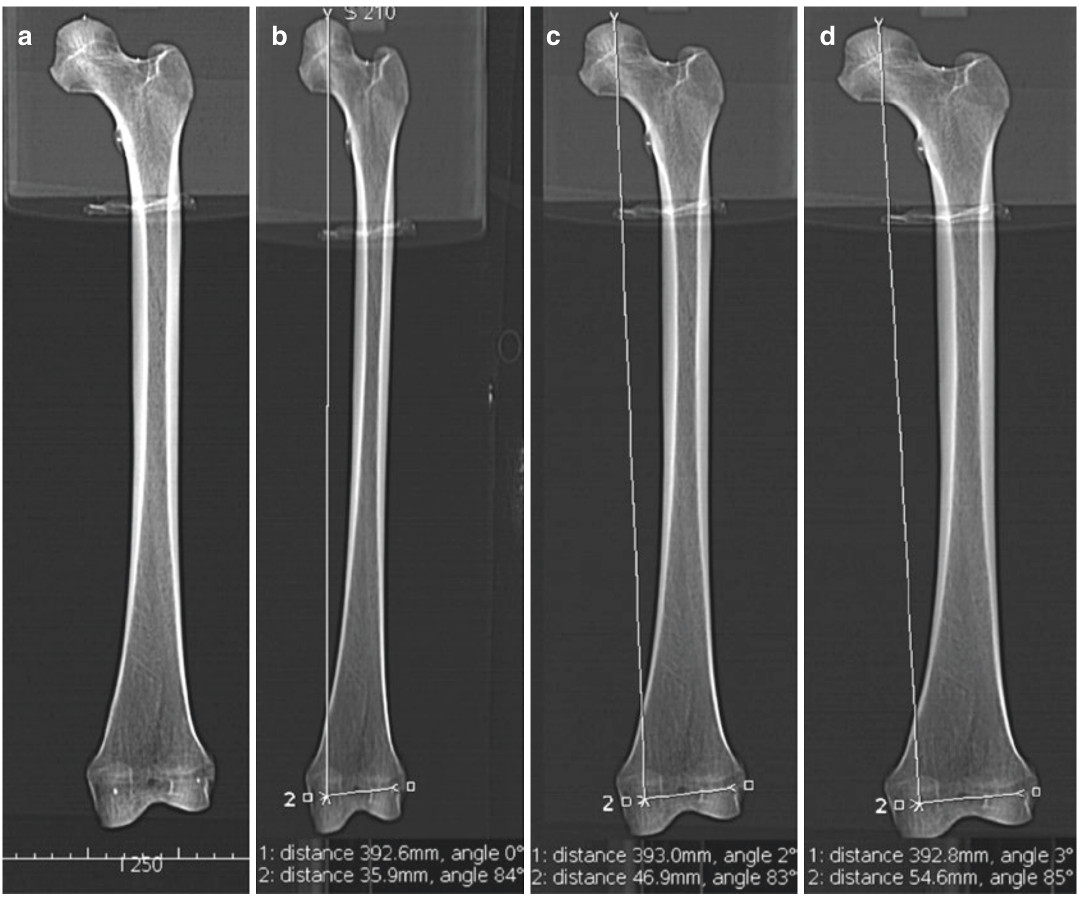

Fig. 2.1 Scout view (scan projection radiographs) of a dry femur at various table heights, demonstrating distortion across the image by geometric magnification. (**a**) With the femur at the isocentre. Note small metal markers are present on the head, neck and condyles for measurements. The apparent length of the bone is not altered in any of the subsequent views. (**b**) Table at its lowest setting. (**c**) Table adjusted to put the femur at the isocentre. The apparent width between the condyle markers is the same as that measured on the specimen. (**d**) Table at its highest setting. The apparent width of the bone is increased

detectors), at the isocentre, and as high as possible (close to the tube). The length of the femur, between the top of the head and the marker on the medial femoral condyle, is not significantly different between these scans, and results of 392.6, 393 and 392.8 mm are all within a reasonable measurement error of the 392 mm distance measured with callipers on the femur. The measurement between the condyle markers varies from 35.9, through 46.9 to 54.6 mm with the different table heights, compared with a calliper measurement of 47 mm, confirming the accuracy of measurement at the isocentre but showing errors of −23% to +16% at the other positions. Angles measured from scout views will have composite errors, from distortion by magnification across the image and also a projection error if the points being measured represent structures at different heights from the tabletop (i.e. if the plane of the measurement points is not perpendicular to the centre of the fan-beam).

Scout views are equivalent to digital radiography, using highly efficient solid-state X-ray detectors on modern multislice scanners. Consequently, a satisfactory image can be achieved at lower radiation doses than required for conventional radiography. When used for lower limb length measurement, further effective dose reduction can be achieved with the use of gonad protection.