Author(s): Lewis, Stephen J

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The use of radiography in osteological measurement

Stephen Lewis

Abstract

Radiographs provide a means of obtaining permanent images of objects. These images may be readily and repeatedly copied, disseminated or used in a variety of ways without the need further to disturb the original material. Although measurements are frequently taken from such images for metrical analysis, it must be remembered that these images are only representations of the original object. To obtain accurate data, one must be aware of the sources of error inherent in the image-forming process so that radiographs can be used in the appropriate way. This paper outlines the factors involved in the production of radiographic images and applies this to the generation of accurate metrical data.

Introduction

The primary intention of this paper is to introduce the use of radiography in producing osteological images, to fill in some of the gaps, perhaps, for those who have wondered how it is done, and to detail some of the important points that must be remembered if these images are to be used to take measurements.

Radiographs are useful in a variety of ways. For example, they can be viewed and measured repeatedly without exposing the specimen to additional wear-and-tear and they are especially useful in that one can send copies to collaborators without fear of loss or damage to one's specimens in transit.

One has to go about the task of measurement in the appropriate way. Just as one would not dream of taking a photograph and holding a ruler up against it in order to obtain data, neither should one do this with radiographs. However, although it should not be done, it certainly has been done. Under certain circumstances, this is tolerable but one must first be aware of the range of factors involved in producing the X-ray image and to act accordingly.

It is necessary to address firstly the production of the radiographic image; secondly practical considerations involved in measuring the radiograph.

Matters concerning radiation protection will not be addressed since, wherever X-ray facilities exist, there are clear local rules and guidelines concerning safe practice. Suffice it to say that a good principle is that the more one keeps out of the way of any radiation, the better.

The production of the radiographic image

The very first thing to point out is that radiographic images are simply shadow pictures. Hence, one of their early, now defunct, names - skiagrams. But instead of using light to cast the shadows, like patterns made with one's hands onto a wall, one uses a form of electromagnetic radiation that is more penetrating than light, one that can penetrate soft tissue easily but bony tissue less easily. Hence, bones tend to cast dense, white shadows while the soft tissues cast only faint ones. These are "dense white" because the image one sees on an X-ray film is a negative. Just as in a camera the film is exposed in proportion to the amount of light that reaches it, so too an X-ray film is exposed in proportion to the amount of X-radiation that reaches it. Since bones block that radiation so as to cast shadows, they show up white. This is fortunate since one obtains an image that is not only bone-shaped but bone-coloured.

The second thing to mention at this point is that radiographic images are produced using radiation but not using radioactive materials. X-rays are produced electrically using an X-ray tube which, to all intents and purposes, is just a special form of the diode valve that used to be in old radio sets. (In fact, it was not unknown for these valves also to give out X-rays!)

The simplest form of X-ray tube is the stationary anode X-ray tube and is shown in Figure 1. This comprises an evacuated glass envelope containing a heavy copper block - the anode - into which has been inlaid a rectangular tungsten plate, and a tungsten filament - in principle much like that of an electric light bulb. These components are situated in an electrical circuit in principle like that in Figure 2.

The X-rays are produced quite simply. The filament is heated by an electric current which causes electrons to boil off into the surrounding vacuum. (The current that does this is small and measured in milliamps.) A potential difference is applied between the filament and the anode and a field of electric attraction is set up which draws these boiled-off electrons towards the anode. Because these electrons are moving, they have kinetic energy. When they reach the anode, however, they hit the tungsten plate which causes them to give up this energy - largely in the form of heat (about 99% of the overall kinetic energy is lost as heat) and also as X-rays. (With only about 1% conversion into X-rays, the process is quite inefficient.)

Two parameters are worth pointing out: mAs and kV, which are generally referred to as exposure factors. mAs stands for "mA times s", or "current times length of exposure." This, in effect, represents the number of X-rays produced since this controls the number of electrons boiling off the filament and which can be drawn towards the anode. The more electrons that get across the tube, the more X-rays will be produced. kV stands for kilovolts (or, thousands of volts) and is the strength of the electrical field through which the electrons are drawn. This determines the maximum penetrating power of the X-ray beam, in particular, its wavelength.

One should be aware of these rather technical details because they affect the image quality. For example, a more penetrating X-ray beam produced using a higher kV will produce an image of flatter contrast because less of the beam will be stopped by the intervening tissue. A less penetrating beam, on the other hand, requires more X-rays, that is, a greater mAs, to produce an image of the same overall photographic effect because, this time, more of the beam can be stopped by the intervening tissue. As a rule of thumb, one may say that the more "contrasty" one requires an image to be, the lower the kV one should use and vice versa. Wherever possible, experiment with exposure factors.

The X-ray tube produces the shadow-casting rays but the shadow cast is not detectable to the human eye and must be recorded on a sheet of X-ray film. There is no fundamental difference between X-ray film and ordinary (black-and-white) camera film. Different films have different "speeds" and have different inherent "contrasts". For example, slow films give finer image quality because the photosensitive crystals in the photographic emulsion are smaller. Consequently, they also require a greater exposure to produce an image. For specimen work requiring the finest quality images with a good contrast range, one can use industrial X-ray film, those used in industry for non-clinical purposes such as examining welds. For example, excellent results may be obtained using Kodak's Industrex CX X-ray film. Figure 3 shows what is called 'the line-focus principle'.

It is important to notice that the X-ray source is not a point source - it has finite size. The quantities of heat produced cannot be confined to too small a target area for fear of it melting. Therefore, the target is set at an angle so that its effective image-forming dimensions are smaller than its actual heat-absorbing dimensions.

Since the X-ray source is not dimensionless, this gives rise to an important factor affecting image quality: penumbra or geometric unsharpness (Figure 4). One can imagine this in terms of a car's headlights. Each casts its own shadow so that somebody standing between the headlights and a wall, for example, would cast, not a single clear shadow, but two shadows out of register with each other. Importantly, the closer the person is to the wall, the less separated (sharper) the shadows will be.

There are two other kinds of unsharpness - those inherent in the film and those resulting from movement in any part of the set-up. Assuming that one is using high quality film and that the specimen being X-rayed is perfectly still, only the penumbra or geometric unsharpness effect remains. For practical purposes, this is not a significant problem, especially if one keeps one's specimens as close to the film as possible. To continue with the metaphor of the car headlights, the shadow cast is also larger than the person it represents, i.e. there is a certain amount of projection. This gives rise to the next important factor in determining the image, its magnification (Figure 5). For purposes of measurement, this is the most important factor which needs to be controlled.

Practical considerations involved in measuring the radiograph

Although a radiographic image will always be slightly larger than the object it represents, one can take steps to reduce this to a minimum. One should adhere to the following points:

1. Keep the distance between the object and the film to a minimum.

Alternatively, one could extend the distance between the X-ray source and the object to a maximum. This requires increased exposure, though, and can exceed the working limits of some X-ray machines.

2. The object must be placed in the centre of the X-ray beam. Since the X-ray beam diverges, its projection effect is not the same for all parts of the area it covers (Figure 6). Since this projectional effect is less the closer one gets to the centre of the beam, one should keep the object to its centre.

3. The plane in which measurements are to be taken must be perpendicular to the centre line of the X-ray beam. Angulation of the object out of this plane leads to foreshortening of its image because it presents less of itself face-on to the image-producing beam (Figure 7).

4. Having adhered to these first three points, one can also determine the degree of magnification present and correct for it. To do this, all one need do is simply place a graduated (notched) metal ruler (or other radiopaque object of known size) next to the object being radiographed, in the plane in which the measurements are going to be taken, so that an image of this is produced, too. Measuring the image of this standard object and relating this to its known size, one can calculate the degree of magnification (Box 1).

A radiopaque object frequently used for this is a disc as it is impossible to foreshorten a disc. Radiographs are two-dimensional representations of three-dimensional objects and, as is frequently the case in highly irregularly shaped bone, certain structures may overlap or merge into other structures. It is, therefore, very important to know in advance the points between which one will be measuring and align the object in the X-ray beam accordingly, to make those points as visible on the resulting image as possible.

Even when one cannot control all variables, there is still merit in adopting a constant technique as one will, at least, be able to provide information within consistent confines which one can describe when reporting one's work. Furthermore, even when one is totally unable to make statements about absolute sizes, one may still be able to make comparative statements.

Although I have emphasised the problem of magnification and ways in which one can limit its effects, I want to finish by pointing out something which is perhaps so obvious that it is often overlooked, which is that the relationships between structures seen on a radiograph are the same as occur in the object itself, irrespective of the degree of magnification. If this were not so, there would be no X-ray departments as radiographs would have no clinical value! The magnification on an image applies, to all intents and purposes, equally to all dimensions one may care to measure. Therefore, ratios and other proportions which relate one dimension to another are unaffected. For example, one will always be able to determine an index of the type where one dimension on the image is divided by another, as both of these will have been magnified to the same degree. (Not only that, but when calculating an index such as this the units of measurement are lost in the division.) Likewise, angles between bony landmarks, at least those in the plane perpendicular to the X-ray beam, are also unaltered by the image-making process. (A note of caution should always be sounded when angles are mentioned as they require special statistical treatment.)

A radiograph can be a valuable data source, and store, but it is one that takes a visual, or perhaps one might say analogue, form. It is necessary, therefore, to extract its data and to do so in the right way for it to be useful as accurate and meaningful data.

Further reading

Wilks, R. and Graham, D. T. 1996 *Principles of Radiological Physics*. Churchill Livingstone Edinburgh, 3rd edition.

Box 1 – Determining the degree of magnification

Image length ÷ known length = magnification

To obtain true sizes, divide image sizes by the magnification factor.

Example:

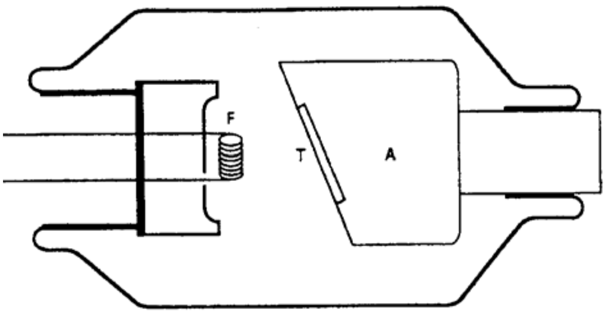
Image length = 27.5mm
Known length = 25.0mm

Magnification = 27.5 ÷ 25.0 = 1.1 times

Given an image length of 38.5mm, the true length will be:

38.5mm ÷ 1.1 = 35.0mm

Figure 1 – A stationary Anode X-Ray tube



F – Filament
T – Tungsten target
A – Anode block (copper)

Figure 2 – An X-ray circuit

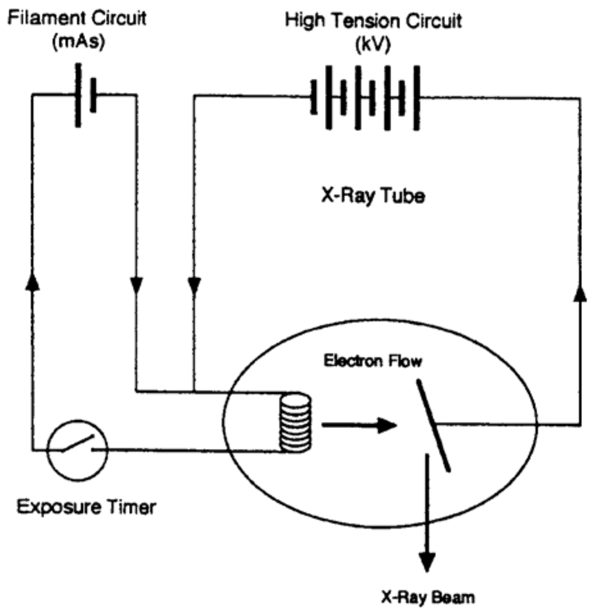


Figure 3 – Anode geometry (the line focus principle)

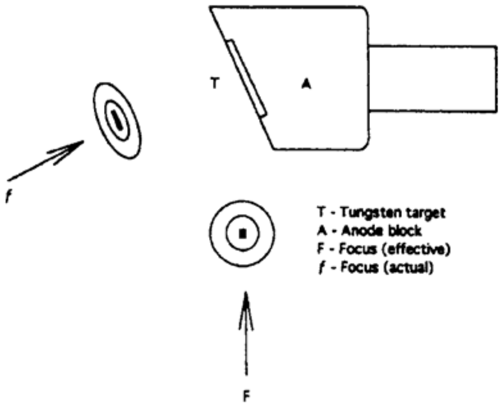


Figure 4 – Unsharpness

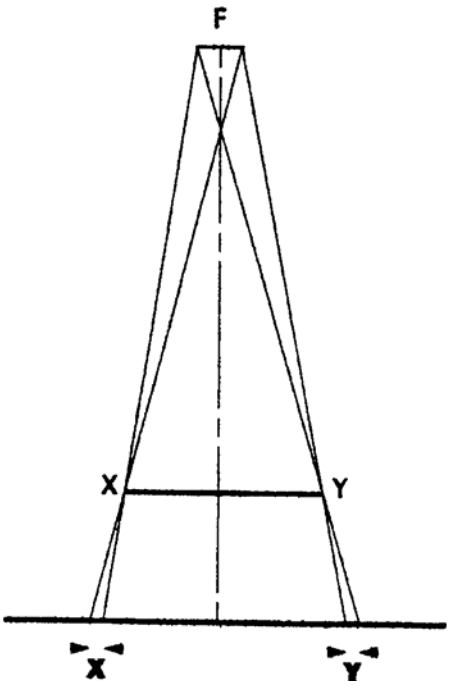
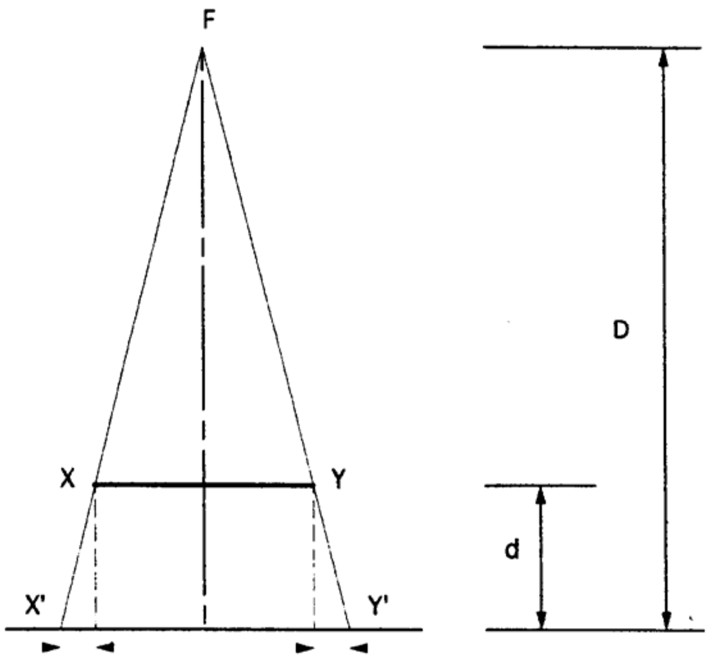


Figure 5 – Magnification



Magnification = D (D-d)

Figure 6 – Off-centre projection

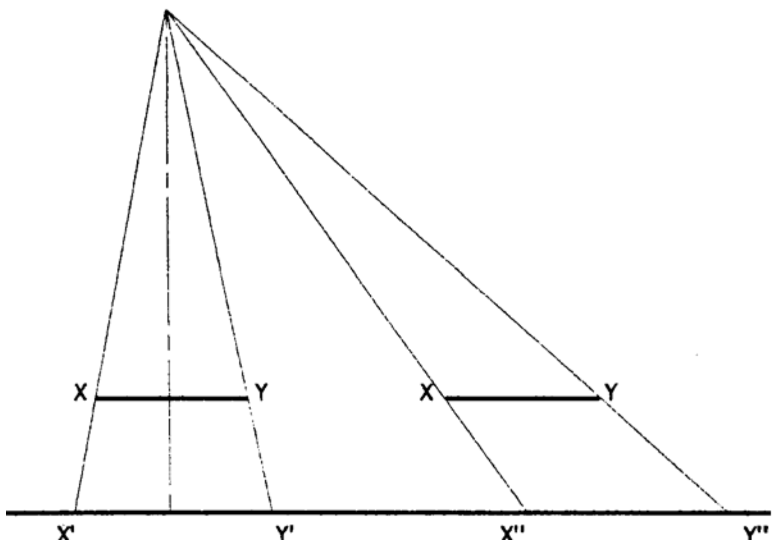


Figure 7 – Foreshortening