Use of Bisecting Angle Techniques in Veterinary Orthopaedic Radiography

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Summary

Problems encountered in veterinary orthopaedic radiography include difficulties obtaining optimally positioned radiographs. In these situations, compromise radiographic projections are used to obtain the necessary clinical information. Results of investigations into the use of bisecting angle radiographic techniques for imaging canine long bones are presented. Comparisons are made between radiographs made using ideal positioning and using three different compromise techniques, including bisecting angle projections. The use of bisecting angle techniques in a series of ten clinical cases is also discussed.

A study into the radiographic images obtained of canine femora and humeri using an ideal projection technique (with the long axis of the bone parallel to the cassette) and using three techniques when the bone was at an angle to the cassette (beam perpendicular to cassette, beam perpendicular to bone and bisecting projection) demonstrated that the ideal radiographic technique gave the most accurate image of the bone in terms of reproduction of size and proportions. However, of the three angled techniques, the bisecting angle projection gave the most accurate reproduction of proportions at all bone-cassette angles. All angled projections created a size distortion, and at lower bone-cassette angles, this was lowest when the primary X-ray beam was perpendicular to the cassette. At higher bone-cassette angles, this projection was no more accurate at reproducing bone size than the bisecting projection. A subjective assessment demonstrated that maintenance of the radiographic appearance of the trabecular bony detail was best with the ideal projection, followed by the angled projection with the tube perpendicular to the cassette.

In 10 clinical cases, where the required information (e.g. implant placement or post-operative progression) could not be adequately obtained from standard radiographic projections, use of the bisecting angle technique allowed the area of interest to be examined more completely.

Use of bisecting angle techniques for veterinary orthopaedic investigations could be considered where optimal positioning for radiography is not possible.

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Dedication

To Mary

Declaration

I hereby declare that this thesis has been composed by myself, that the work herein is my own except where otherwise stated, and that the work presented has not been presented for any university degree before.

Acknowledgements

Martin Sullivan

Mike Farrell

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Introduction

Section 1: Historical Background

Radiology

X-rays were discovered by Wilhelm Conrad Roentgen on November 8th 1895. Holder of a chair in physics at the University of Wurzburg, he noted that something was emitted from a cathode ray tube producing fluorescence at a distance of several feet, yet was able to pass through material hitherto considered opaque. Further work established that these rays produced a shadow on striking a photographic plate, and not a photographic image. Moreover, the rays could produce a shadow of an object contained within an opaque container, such as a coin within a wooden box. Using a fluorescent screen, he established that these rays could pass through wood, rubber and thin sheets of tin foil, but were stopped by lead. Magnetism and refracting prisms had no effect on their path. Finally, he interposed his hand between the source and the fluorescent screen – and saw the shadow of his own bones. Roentgen's conclusion was that these were entirely new, unknown rays, and so he called them X-rays[1,2].

On December 22nd 1895 he obtained images of his wife's hand, with wedding ring in place, on photographic plates. This was one of the images that accompanied his preliminary report, published on 28th December 1895 in the proceedings of the Physico-Medical Society of Wurzburg, and entitled *"On a New Kind of Rays"*[3]. On release to the wider world, the paper, and especially the image of Frau Roentgen's hand, had a massive impact, and Roentgen himself quickly found celebrity, giving tours of his laboratory. However, after two more papers, published in 1896 and 1897, he moved onto other areas of research. He was awarded the first Nobel prize in physics in 1901, and early X-ray imaging referred to roentgenographs, roentgenograms and roentgenologists. Although his name is no longer remembered in such a fashion, and in spite of several disputes as to the true discoverer of X-rays, Wilhelm Roentgen should be regarded as the father of diagnostic imaging[1].

The early sensation of X-rays (where it was possible to take a radiograph of your hand for interest, or to build your own x-ray machine) was shortly followed by a recognition that some side-effects were becoming apparent (Thomas Edison, who was instrumental in developing fluoroscopy, moved to other areas of research after he developed peri-ocular erythema, and one of his chief assistants, Clarence Dally, suffered burns severe enough to warrant amputation of both of his arms, and suffered a prolonged and painful death). Early medical applications involved comparing radiographs with the results from surgery or autopsy. However, the area of medicine that embraced x-ray technology the quickest was the military hospitals. Bullets, shrapnel and fractures were easily located, and, coupled with anaesthetics and antiseptics, X-rays moved the practice of surgery to a genuine medical specialisation. Early controls on exposure levels were introduced between the wars, although initially these were loose, to say the least. As the century progressed, developments both in the technology of the x-ray machines, and in radiographic equipment and techniques (anti-scatter grids, fluorescent screens, contrast media, etc.) improved safety and image quality. After the Second World War, these improvements in radiography, coupled with the development of other imaging techniques such as ultrasonography, computed tomography, nuclear medicine and positron emission tomography (PET) and magnetic resonance imaging (MRI), allowed the development of radiology as a distinct medical speciality[1].

Orthopaedics

Although fractures have been recognised as a medical problem since the fourth to fifth century BC, orthopaedics as a speciality did not develop until the 1700s. Nicholas Andry wrote *Orthopaedia* in 1741, discussing the prevention of deformities in children. He coined the term orthopaedics from the greek terms for straight and child. Further work by Robert Chessher developed frames for the correction of deformities[2]. Percivall Pott wrote *Fractures and Dislocations* in 1768, in which he emphasised the importance of rapid reduction and muscle relaxation in gaining proper alignment of the healing fracture. John Hunter investigated the properties of bone growth and deduced the process involved both deposition and absorption of material, and is credited with the theory of sequestrum formation. William John Little was also involved in early research into developmental abnormalities (stimulated by developing a club foot, thought to be secondary to poliomyelitis, at the age of two). In 1838 he also founded what was to become the Royal National Orthopaedic Hospital[4]. However, before orthopaedics could really take off as a speciality, three further discoveries were required.

The first of these was demonstrated on 16th October 1846 in Boston, Massachusetts, where Henry Bigelow arranged the first operation under anaesthesia provided by ether. The first paper, by Bigelow, entitled "*Insensibility during surgical operations by inhalation*" was published in the Boston Surgical and Medical Journal. The term anaesthesia was suggested by Oliver Wendell Holmes. Both general and, later, local anaesthesia were rapidly accepted by the medical profession[4].

The second development was made in 1865. Joseph Lister of Glasgow, using the work of Louis Pasteur, started using a carbolic spray to clean the air around wounds. This led to the use of rubber gloves, hats and face masks by the surgeons, and the sterilisation of instruments prior to surgery. The care and attention paid to sterility produced a marked reduction in post-surgical infection[4].

The recognition of specialist orthopaedic surgeons at the end of the nineteenth century preceded the third groundbreaking discovery, that of X-rays, which has been discussed earlier[2]. During the twentieth century, orthopaedics developed significantly, helped by the discovery of vitamin D and the resulting reduction in rickets, the development of the polio vaccine by Salk and Sabin and the discovery of penicillin by Alexander Fleming. The development of the speciality was also stimulated by the two World Wars, and aided by increasing technological expertise. Orthopaedics was one of the first beneficiaries of Roentgen's discovery, and one of the early findings was that many injuries previously thought to be dislocations were in fact fractures. Other conditions that were first described after the advent of radiology include Legge-Calve-Perthe's Disease. Orthopaedics has also benefited from the development of more advanced imaging techniques such as CT and MRI[2,5,6].

Fracture management is one of the oldest medical techniques recorded, with evidence of the ancient Egyptians using wooden splints. Hippocrates' use of mechanical aids to reduce fractures, and stiffened bandages to stabilise them, remained the major management technique until the mid-1800s. The significant development in that period was the recognition of the importance of the soft tissue injuries associated with the fracture, and the concept of early mobilisation. However, during the nineteenth century, advances were made in surgical fracture management, including the development of clamping and cerclage wire, and the development of internal fixation using bone plates and intramedullary nailing. Later in the 1800s, external fixation was developed, and during the twentieth century these surgical techniques advanced further, with the introduction of Ilizarov frames and dynamic compression plates[7].

Veterinary

As the cave paintings in Lascaux, France, demonstrate, mankind has long had an interest in the animals that form part of the natural world. As society developed from hunter-gatherer to herder and farmer in the Neolithic period, initially herding sheep and goats, and later cattle, the human tribes became more organised. A further landmark in human development came with the domestication of the horse, initially in what is now southern Russia. This enabled the development of mobile military units and greater hunting ability. The increasing value of such animals led to an interest in their welfare, and the earliest recorded veterinary text is from Egypt, dated around 1900BC, and refers to diseases of cattle, dogs, fish and birds. Egypt also gives early evidence of animals kept for companionship alone. There are also records of early equine medicine from China, from about 650BC. Here, the early veterinarians were highly respected members of society. The term "veterinarian" may have developed from latin[8].

Veterinary medicine continued to develop through the Middle Ages, with some early interest in epidemiology and parasitology. Formal veterinary education arose in the eighteenth century, with the first veterinary school, at Lyon, receiving a royal charter in 1764. Further schools were founded around Europe, with the Royal Veterinary College starting in 1791. During the eighteenth and nineteenth centuries, many of the seminal medical developments, such as Lister's work into asepsis, were developed in conjunction with veterinary colleagues. Companion animal practice also started around this time, with Delabere Blaine and William Youatt early leaders in the field of canine medicine. The development of anaesthesia, in which Frederick Hobday carried out much of the early work, led to further development of veterinary capabilities[8].

Veterinarians were early acceptors of Roentgen's X-rays, with five papers on the use of x-rays in veterinary practice published within a year of Roentgen's discovery. In addition, the development of radiology allowed a great increase in the possibilities for orthopaedic treatment of small animals, and many techniques that subsequently became popular in human orthopaedics were first developed by veterinarians. Feline medicine as a separate speciality from canine medicine developed particularly in the second half of the twentieth century, reflecting the increasing popularity of cats as pets[8].

Section 2: Principles of Orthopaedic Imaging

There are some basic radiographic principles that should be applied to orthopaedic imaging in order to obtain diagnostically useful radiographs. The problems encountered when these principles are not met will be addressed in a subsequent section:

1) Maintain the area of interest parallel to the radiographic plate. In the case of a long bone, this involves maintaining the long axis of the bone parallel to the plate. For a joint, either the sagittal or dorsal plane of the joint should be parallel to the plate, depending on whether a mediolateral or craniocaudal projection is required[9,10,11].
2) The area of interest should be as close to the plate as possible. Therefore, for imaging a long bone, a mediolateral projection should be obtained as opposed to a lateromedial. Similarly, a craniocaudal projection with the patient in sternal recumbency will allow closer apposition of limb and plate than the caudocranial projection taken with the patient in dorsal recumbency[5,9,10,11].
3) The amount of overlying tissue should be minimised. This will avoid two major issues:
    a. Overlying tissue may either mask or mimic pathology in the area of interest.
    b. Increased tissue thickness will require an increase in exposure factors, increasing the patient dose[9,10].
4) Take two orthogonal views of the area of interest. A radiograph is a two-dimensional shadow of an object, and a lesion may only be visible on one projection[6,10].
5) The correct exposures and film/screen combination should be used. This will generally not be a significant problem, as most facilities will have pre-arranged exposure charts. Ideally high detail films and screens should be used, as orthopaedic problems will often present with subtle radiological changes. However, the increased dose required for higher detail combinations may limit their use (highest detail is obtained with non-screen film, but the exposure factors required to obtain a diagnostic image of a limb are unacceptably high, although non-screen film may be used for nasal or dental imaging)[9,10,11].
6) The area of interest should be adequately collimated. This will reduce scattered radiation, both reducing the radiation hazard to personnel, and also reducing the scattered radiation incident on the plate, improving image quality[9,10].

7) The x-ray beam should be directed as vertically as possible – this will increase the safety of the procedure for imaging personnel[10].

Section 3: Problems Associated with Veterinary Radiography

It is almost impossible to produce a perfect radiographic image of a biological structure such as a bone or organ. This is largely due to the irregular shape, rounded borders and *in vivo* interference by other structures[9]. The irregular shape creates alignment problems that produce distortion of the radiographic image, while the rounded margins creates edge unsharpness, as the x-ray attenuation decreases towards the extreme periphery of the structure's margin. This generates a gradation of image intensity at the edge of the radiographic shadow, giving the appearance of a blurred edge. The *in vivo* attachments to other structures (e.g. the joints of the axial skeleton) may also prevent ideal positioning, and as a result, it becomes important for radiologists to recognise distorted images of normal structures. Studies using markers have demonstrated the distortion of bone images through magnification and parallax error, and reviews of the causes of geometric distortion have been published[12,13].

There are two major difficulties with obtaining a good image of a long bone – gaining an accurate projection with minimal distortion and detecting subtle lesions such as small fissures. To deal with the second of these problems first, detecting small pathological changes may only be possible when the lesion is appropriately aligned with the x-ray beam. A fissure may only be seen when truly parallel to the axis of the beam, or a small bone chip only when skylined by the beam, and this means that repeated projections may be necessary although this increases the patient dose. An alternative is to use nuclear scintigraphy to localise areas of increased bone metabolism, and to use this as a guide to the area of bone to image. Detection of such lesions is dependent on the individual case. As can be seen in Figure 1a, when the X-ray beam is not orientated parallel to the fissure, the fissure cannot be seen on the resulting radiographic image. However, if the beam axis is orientated parallel to the fissure and centred on the area of the fissure (Figure 1b), either by rotating the tube head or the area of interest, the fissure is then visible on the resulting radiograph. The fissure is an area of lower x-ray attenuation than the surrounding bone, with resulting increased optical density on the radiograph. However, when the fissure is oblique to the x-ray beam axis, the resulting attenuation difference across the fissure is very low, and the fissure cannot be distinguished from the surrounding intact bone. However, when the fissure is parallel to the beam axis, there is an effective increase in thickness of the lower attenuating area, and the fissure may then be seen as a dark line on the radiograph. As mentioned above, detection of fissures by radiography often requires projections at multiple angles to allow detection, and alternative techniques such as nuclear scintigraphy or computed tomography may be indicated[6].

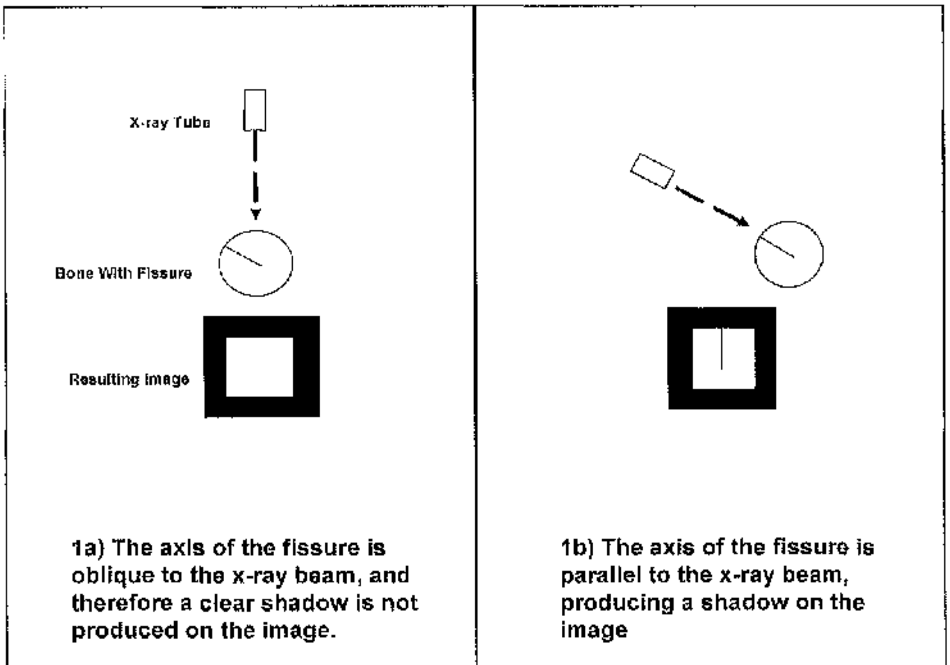


Figure 1 – Imaging Bone Fissures

In order to obtain an accurate projection of the bone, the long axis of the bone should ideally be parallel to the radiographic plate, with the axis of the x-ray beam perpendicular to the plate and centred on the mid-point of the bone. The bone should also be as close as possible to the plate. This will produce minimal distortion and magnification, and an accurate projection of the bone (Figure 2). The bone is in close apposition to the film cassette, and the long axis of the bone is parallel to the cassette. This will minimise the distortion produced by separation of the bone from the plate, as demonstrated in subsequent figures[9,10,11].

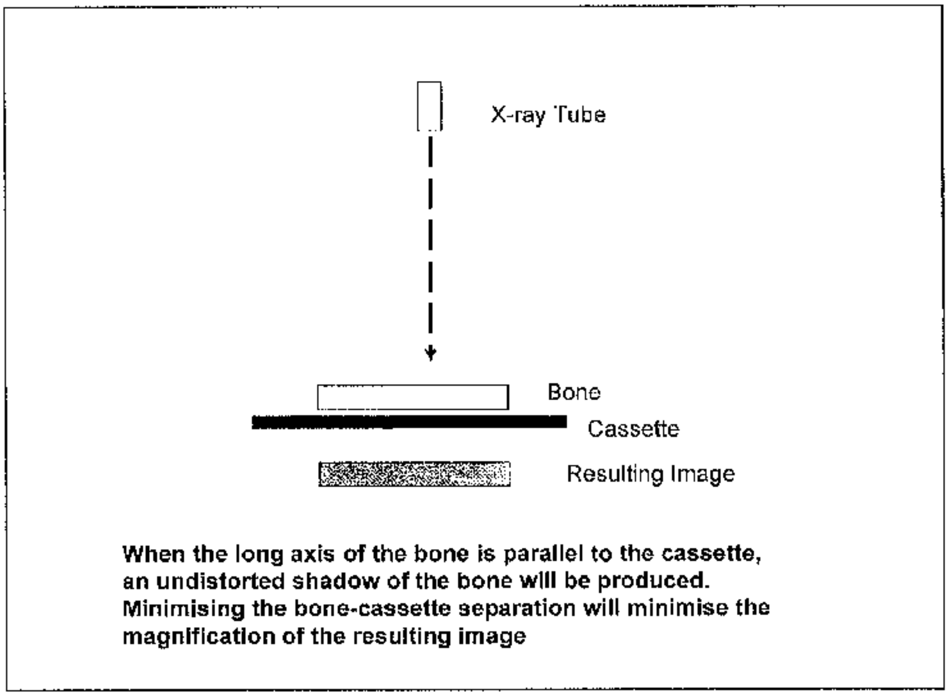


Figure 2 – Ideal Radiographic Projection of Bone

There may also be difficulties in minimising the distance between the bone and the radiographic plate. For the humerus, the compromise for obtaining a true craniocaudal or caudocranial radiograph is that there will be significant object-film separation, and this will result in both magnification of the bone, and a loss of fine detail of the bone edges, due to an increased penumbra around the bone shadow (Figure 3).

a) **Magnification.** The primary X-ray beam diverges as it leaves the X-ray tube head and passes towards the cassette. In Figure 3a, the ideal is demonstrated with the object close to the film cassette. As a result, the projection of the object onto the cassette, as demonstrated by line AB, is close to the true size of the object. There is therefore minimal magnification, and the resulting radiographic image is close to life-sized. Slight magnification is impossible to avoid, due to the divergence of the primary beam. In Figure 3b, the object has been separated from the cassette. As a result, the diverging X-ray beam creates a shadow on the cassette that is considerably larger than the true size of the object.

b) **Penumbra.** If the resulting radiographic image was purely a magnified projection of the object, this might be a desirable outcome. However, increasing the object film separation also gives rise to a penumbra[9,10,11]. X-rays are not produced from a point source within the tube, but rather from a small area of the anode (the focal spot)[9,10,11]. X-rays from either side of the focal spot will pass tangentially past one spot on the outline of an object at slightly divergent angles. As a result, they will strike the radiographic film at different locations. Because both have passed the same point on the object, this will produce a blurred image of that point. The separation between the divergent X-rays is the penumbra (Figure 3b). When this effect is considered for the entire edge of the object, an edge unsharpness effect is seen, giving a blurred image. This effect will also apply to structures within the object, and areas of fine detail, such as trabecular bone, can be masked by the resulting blurring of the image.

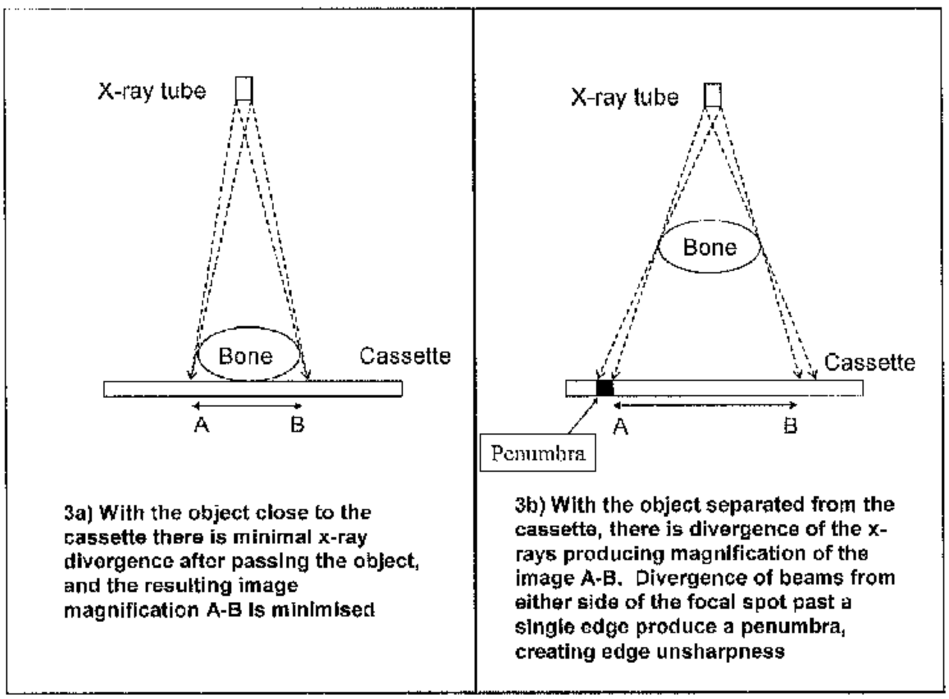


Figure 3 – Magnification and Penumbra Effects

The penumbra effect is unavoidable in diagnostic radiography. An ideal X-ray machine would produce x-rays from a point source on the anode. However, this is impossible, and the focal spot will have a measurable surface area[9,10,11]. The smaller the focal spot, the less penumbra will be formed, and the sharper the image will be[9,10,11]. However, reducing the size of the focal spot reduces the maximum current that can be used, and thus the output power of the machine. This can be partly compensated for by angling the focal spot, and, using the line-focus principle, minimise the effective focal spot. However, for general veterinary use, the focal spot will need to be above a certain size. Specialist low-output machines, such as dental or mammography units, can use smaller focal spots[14]. Some larger machines will have a dual focal spot system, where at lower currents a smaller focal spot can be used.

However, in many cases, and especially with the canine and feline humerus/femur, the long axis of the bone cannot be aligned parallel to the plate. This is generally for anatomical reasons – either the hip or the shoulder cannot be extended sufficiently, or the surrounding anatomic structures prevent the plate from being positioned parallel to the bone. However, pathological causes include hip dysplasia and degenerative joint disease or soft tissue swelling. In addition, the soft tissues may show stiffness after prolonged surgery, and other iatrogenic factors, such as surgical implants may reduce the mobility of joints. Whatever the reason, this inability to position the long axis of the bone parallel to the radiographic plate will produce geometric distortion of the bone. The end of the bone that is further from the plate will have increased magnification, and also decreased detail due to an increased penumbra[9,10,11]. As can be seen in Figure 4, when the bone is at an angle to the cassette, the resulting image is distorted. The end of the bone that has a greater separation from the cassette has a greater magnification, with a resulting greater penumbra and loss of fine detail (e.g. trabecular pattern). This gives geometric distortion of the radiographic image, which may either mimic or mask pathological changes.

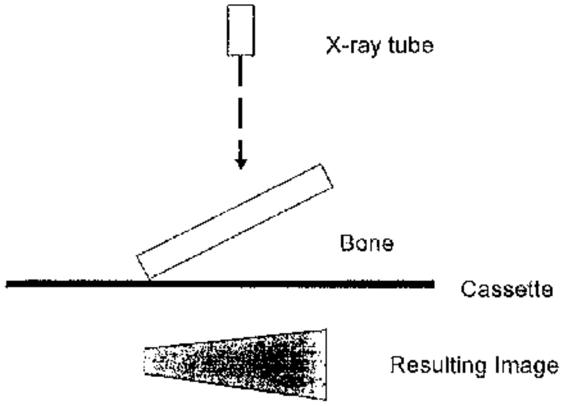


Figure 4 – Distortion due to Obliquity

It is also possible to produce a penumbra, with resulting edge unsharpness and blurring of fine detail, by having too short a film-focal distance (the distance between the X-ray tube and the cassette)[9,10,11]. When the film-focal distance is decreased, the divergence of X-rays from opposite sides of the focal spot after they pass through the same point of the object increases. This produces an increased penumbra, with resulting loss of edge sharpness and masking of fine detail. This is demonstrated in Figure 5. In theory, increasing the film-focal distance to the maximum possible would give the sharpest possible image. However, increasing the film-focal distance requires an increase in the exposure factors in order to achieve a radiograph of diagnostic quality[9,10,11]. This is due to the divergence of the primary X-ray beam. As the distance from the X-ray tube increases, the intensity of the X-ray beam decreases in accordance with the inverse square law. Therefore, for each doubling of the film-focal distance, the primary beam intensity (determined by the filament current and exposure time) must be quadrupled to maintain the beam intensity per unit area at the cassette. The maximum possible exposure factor is limited by the capabilities of the X-ray machine, and also by the necessity to minimise exposure to personnel from scattered radiation, which will increase as the exposure factors are raised. As a result, the film-focal distance is generally a compromise between the need to obtain a sharp radiographic image, and the need to minimise exposure factors as far as possible, in accordance with the ALARA

(As Low As Reasonably Achievable) principle[9,10,11,15]. Most veterinary radiographic units use a film-focal distance of 75-100cm.

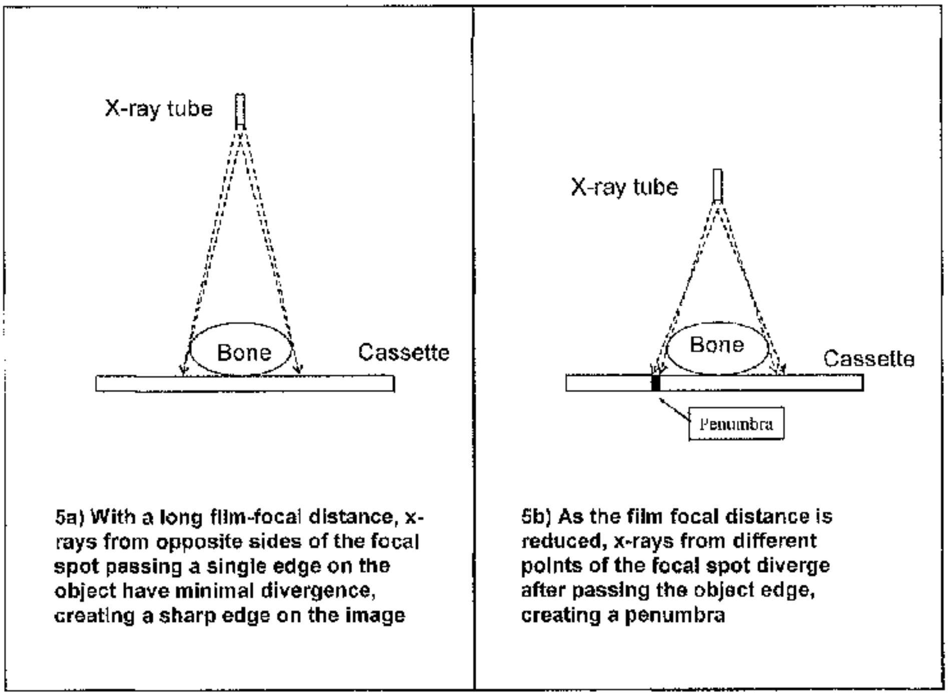


Figure 5 – Effect of Reducing Film-Focal Distance

Personnel safety is also an important consideration when use of a beam away from the vertical orientation is planned. The primary beam is most easily controlled when it is directed into the floor, or an appropriate attenuating material (e.g. a lead rubber mat)[10,15]. A significant amount of the scattered radiation produced will be absorbed by the patient and table. In this orientation, the majority of the unabsorbed scattered radiation is directed back towards the tube head. The controlled environment around a vertically-directed primary beam is easily demarcated, minimising exposure to the scattered radiation. As the beam is angled away from the vertical, the horizontal components of both the primary beam and the scattered radiation increase. There are two major safety implications. The horizontally-moving X-radiation is harder to control, and may present an increased personnel risk. Secondly, the primary beam is now likely to be directed towards the walls or doors. Often these structures have insufficient attenuation to completely stop the primary beam, and therefore there is a radiation risk to people on the other side of these structures. Therefore it is best to have the primary beam aligned as close as possible to the vertical position. In order to obtain a true craniocaudal radiograph, the radiographer may consider angling the x-ray tube head. However this will result in an increased horizontal component of the primary x-ray beam, and this will have safety implications for personnel[10,15]. This is demonstrated in Figure 6.

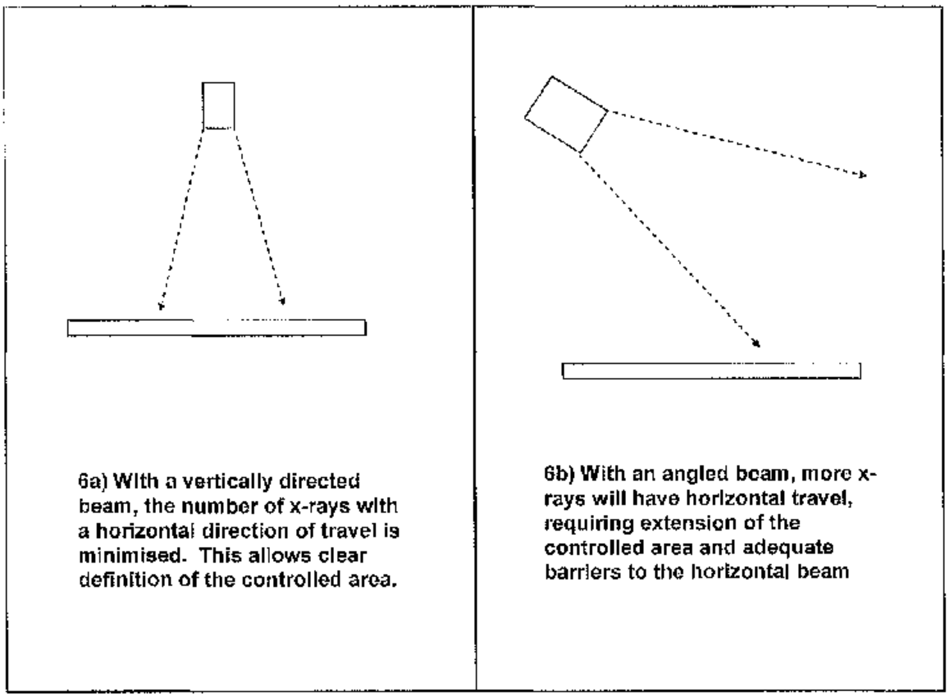


Figure 6 – Angulation of Primary Beam

If the x-ray beam cannot be angled, and the bone axis is tilted from the horizontal, then this will result in foreshortening of the bone, and over-riding of areas of bone. This may mask pathological changes. For post-operative radiographs, this could result in overlying shadows of implants and fracture fragments, causing difficulties in assessing the reduction and apposition of the fracture, and the placement of the implants. In Figure 7a, with the long axis of the bone parallel to the cassette, the two points marked by the black dots will be spatially separated on the radiographic image. However, when the long axis of the bone is at an angle to the cassette, as shown in figure 7b, the two dots will now be superimposed on each other on the radiographic image. These foreshortening and overriding effects may mask pathology such as fissures. They may also mimic the effect of an over-riding fracture, although this should be confirmed by an orthogonal radiograph[6]. Problems are also caused when assessing the placement of orthopaedic implants – the superimposed shadows of screws, for example, makes assessment of placement and alignment especially difficult.

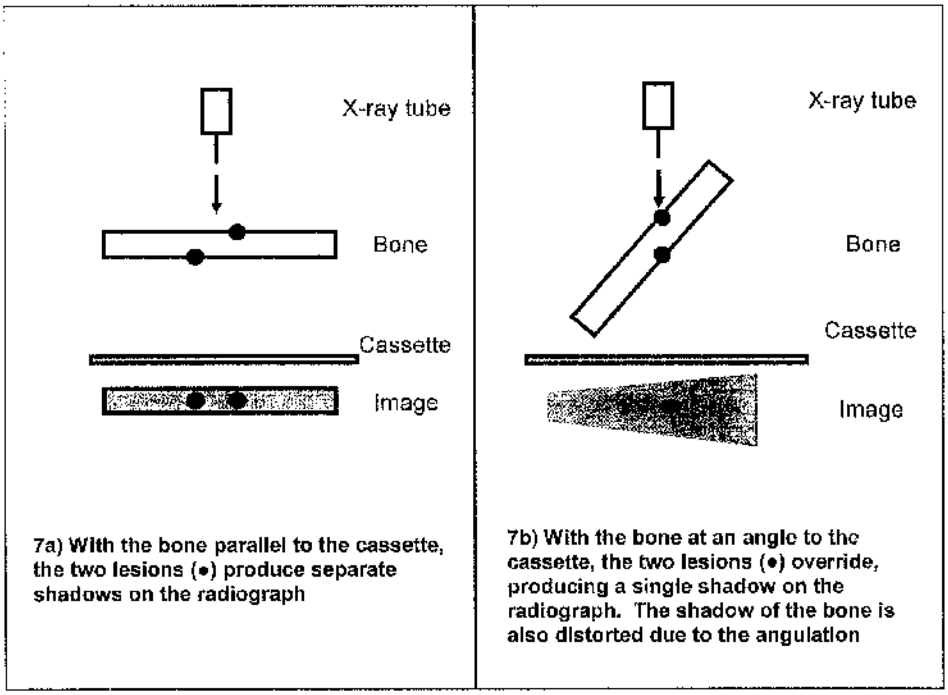


Figure 7 – Superimposition and Foreshortening

Veterinary orthopaedic radiography has numerous technical problems, some of which are associated with general radiography of bone, and some of which are specific to the field of veterinary medicine. If we consider the problems that are specific to veterinary radiography initially, they are:

1) **Restraint.** This is one of the major considerations in veterinary radiography. For human patients, cooperation can be increased by use of communication techniques, interviews and videotapes prior to introduction to entry to the radiology department[16]. To maximise the safety of personnel involved in radiography, given the use of ionising radiation, veterinary patients require non-manual restraint that is adequate for the necessary examination. With a placid or well trained animal, it may be possible to use physical restraint, such as sandbags or rope ties alone. However, this is rarely adequate, especially for orthopaedic examinations, where the positioning of both the area of interest and the contralateral limb can be physically awkward for the patient.

Generally, some form of chemical restraint is used. This may involve sedation, often using a combination of drugs, or general anaesthesia. The choice of sedation versus anaesthesia is often down to individual preference, but care needs to be taken for both regarding any other systemic problems, which may raise the risks associated with drug administration[10].

2) **Positioning.** Cursorial specialisation has led to companion animals developing a conformation that is exceptionally well developed for fast locomotion. However, this conformation poses problems when coming to obtain radiographs. In particular, the muscular girdle attaching the forelimb to the thoracic wall creates difficulties when trying to obtain true craniocaudal or caudocranial radiographs of the humerus. Similarly, the conformation of the hindquarters poses problems when trying to obtain true craniocaudal or caudocranial radiographs of the femur.

3) **Breed Variation (canine).** Although the general anatomy of all breeds of dog is similar, there is marked variation in the conformation between the breeds, and this can affect the possible projections. For example, markedly chondrodystrophic breeds such as the bassett hound have proportionally short, curved long bones, and this makes aligning the projection and radiographic plate with the bone axis problematic.

4) **Facilities available.** Because many veterinary practices have limited space, and are often sited in buildings that were originally designed for another purpose, the room containing radiographic equipment is frequently somewhat small. In addition, the lack of a purpose-built facility commonly requires that radiographs are taken with a vertically oriented beam only. This can create further problems in obtaining a diagnostic radiograph. To conveniently take horizontal beam radiographs often requires a fixed X-ray unit, and these are generally only found in larger veterinary practices or referral hospitals, or practices that carry out a significant amount of equine work, where horizontal beam radiography is a necessity[15].

There have been previous studies looking into ways of improving the ease and quality of orthopaedic radiography. One investigated the use of a horizontal beam caudo-cranial projection for imaging femoral fractures or osteotomies[17]. This study found that fissures were more easily detected on the horizontal beam caudocranial projection than on the traditional craniocaudal projection obtained with a vertically directed beam. In addition, the positioning was easier, and was subjectively more comfortable for the patients. However, as discussed earlier, the use of a horizontal beam does increase the radiation hazard of the procedure. The technique may not be possible with the available equipment in smaller veterinary practices.

Section 4: Bisecting Angle Techniques

There is significant use of radiography in dentistry as it allows imaging of the tooth root and periapical tissues[14]. This gives excellent information about periapical diseases. Radiographs are also extremely useful for ascertaining the extent of dental caries. The development of dedicated dental X-ray machines, and intra-oral high-detail films (often in disposable envelopes) allows early detection and intervention in dental disease.

However, if we consider the main principles of radiographic positioning – long axis of object parallel to plate, minimal object-film distance – then problems become apparent. The shape of the oral cavity is such that it is impossible to align an adequately-sized dental film parallel to the axis of a tooth, especially a molar. As a result, it is extremely difficult to obtain diagnostic quality radiographs[14].

A solution to this was first proposed in 1904 by W. A. Price, based on the principle of isometry[18]. The principle of isometry states that two triangles are equal if they have two equal angles and share a common side. Therefore, if angles x and y are the same, and line AD is perpendicular to CB, then the triangles ABD and ACD are identical. More importantly, the lines AB and AC are of equal length (Figure 8).

If we consider AC to be the object being radiographed, and AB to be the orientation of the radiographic plate, then aligning the primary X-ray beam perpendicular to either AC or AB would result in a distorted image on the radiograph. However, if the beam were aligned perpendicular to the plane of bisection, AD, then the principle of isometry states that AC and AB are equal. Thus, the image of AC projected onto the plate aligned with AB will be of the same length as AC itself. This is the basis for bisecting angle radiography.

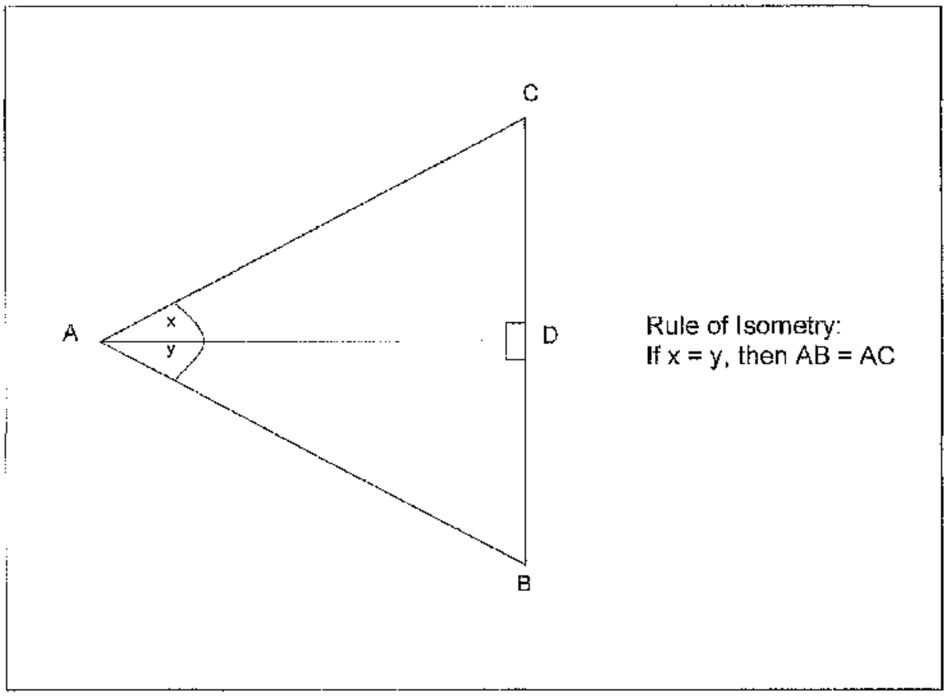


Figure 8 – Principle of Isometry

Although the technique was developed at the turn of the twentieth century, it was not until 1967 that Ennis advocated the use of these techniques for general dental radiographic practice[19]. They remain in use to this day, and investigations have been performed into increasing patient comfort, reliability of technique and diagnostic accuracy[20,21,22]. Another study has demonstrated that the bisecting angle technique produces the least difference between radiographic image length and actual tooth length for maxillary molars[23]. A more recent development in dentistry is panoramic radiography, which, using tomography and slit-beam radiography, produces an image of the entire dentition on a single film. This allows a reduction in the patient dose compared to imaging each tooth individually, but the image quality is lower due to magnification and distortion[24].

Unfortunately, the technique has shortcomings when applied to three-dimensional structures that have height, breadth and depth[14]. With such objects, any deviation from the bisecting rule will result in some distortion of the resulting image. However, this distortion will be less than if the beam is aligned perpendicular to either the tooth axis or the plate, with the plate at an angle to the tooth axis.

Section 5: Basis for Study and Hypothesis.

Obtaining diagnostic post-operative radiographs of patients undergoing orthopaedic procedures on the humerus or femur (especially fracture repairs) was noted to be difficult in a referral veterinary clinic. In particular, accurate assessment of the placement and positioning of the implants was problematic, due to superimposition. It was suggested that use of an angled beam may improve the visualisation of the orthopaedic implants. This was beneficial for examining the implants, but the resulting distortion of the bone was unacceptable. As a result, it was postulated that use of a bisecting angle technique may provide an adequate compromise, maintaining bone geometry whilst allowing full visualisation of the implants. It was decided to study this in more detail to ascertain the practicality of this technique for general use.

Hypothesis

Use of bisecting angle techniques will allow adequate imaging of canine long bones and orthopaedic implants while minimising geometric distortion.

Materials &Methods

Section 1: Feasibility

A cadaver study was performed as an initial investigation to test whether the proposed technique would be feasible in a clinical situation. Five canine cadavers that had been euthanatised for reasons unconnected to the musculoskeletal system were selected. All were weighing 20-30kg, and had been previously frozen and thoroughly thawed.

For each femur (10), pre-radiographic preparation was as follows. The mid-diaphyseal region of the femur was exposed using a lateral approach through the skin and soft tissues. Each femur was then fractured in one of three ways.

1) Four were fractured in the transverse plain, using a osteotome and hammer. An initial guide was created in the lateral cortex using a hacksaw, and then the osteotome was placed and used to create a complete transverse mid-diaphyseal fracture.

2) Three were fractured in an oblique plain, again using a chisel and hammer, but with the initial guide created at an angle of about 45^{0} to the transverse plane.

3) The final three were fractured in a comminuted fashion, using a hammer alone. The leg was supported underneath at the level of the stifle, and struck repeatedly at the level of the mid-diaphysis. This produced a comminuted fracture.

After each bone had been fractured, the soft tissues were closed using a single layer continuous suture pattern, to prevent contamination of the radiography room.

The cadavers were initially radiographed using standard mediolateral and craniocaudal projections. A bisecting angle projection was also attempted for the pre-repair long bones of the first cadaver. All radiographs were taken using a standard X-ray unit*, with exposure factors determined from a pre-existing chart appropriate to the machine. This X-ray machine had a fully-adjustable tube head, with an inbuilt angle guide, allowing accurate determination of the beam angle. Radiographs were obtained

* Systemi Villa Medicali, Italy

on standard double emulsion radiographic film[†], using intensifying screens[‡], and were developed using a automatic processor[§]. From these initial radiographs, a basic repair plan for the fracture was devised. Fractures were repaired using an intramedullary pin and cerclage wires, or an interlocking nail and screws. The intra-medullary pins were introduced in a retrograde fashion into the proximal fragment, and then drilled into the distal fragment. The interlocking nail was introduced in a normograde fashion, with a dedicated guide allowing placement of the screws once the nail was in place. The aim of the repair was only to achieve good alignment and apposition, but not necessarily to provide the stability required in a clinical case.

After repair each cadaver was again radiographed using mediolateral and optimised craniocaudal projections. The optimised craniocaudal projection was positioned to give as undistorted a radiographic image as possible. Where it was not possible to extend the hip so that the femur was parallel to the cassette/table-top, the cassette was angled such that it was parallel to the long axis of the femur, using foam wedges or sandbags as support underneath the cassette. In the majority of cases, the optimised craniocaudal position was used. In addition, a bisecting angle craniocaudal was taken in each case. The bisecting angle radiograph was taken with the same exposure factors as the standard craniocaudal. The film-focal distance was maintained at 90cm for all radiographs. The angle between the long axis of the femur and the cassette/table top was measured using a commercial goniometer. The long axis of the femur was defined as a line between the greater trochanter and a point about 1cm cranial to the lateral femoral epicondyle. The tube head was then angled away from the vertical by an angle of half that between the femur and the cassette. This aligned the primary beam so that it was perpendicular to the plane of bisection between the leg and cassette. All radiographic procedures were performed by a single radiographer. The ease of performing each projection was subjectively assessed using a 0-3 scale (0 = Easier than standard craniocaudal projection; 1 = Same ease as standard cranio-caudal projection; 2 = More difficult than standard craniocaudal projection; 3 = impossible to achieve), as was the clarity and distortion of the image of the fracture reduction and implants allowed by each projection (0 = Same Appearance; 1 = Mild decrease in image quality; 2 = Moderate decrease in image quality; 3 = Severe decrease in image quality).

[†] AGFA Cronex 10T

[‡] Quanta Fast Detail

[§] Dupont Cronex CX 130

Both bisecting angle and optimised craniocaudal projections were more difficult to position than the standard craniocaudal projection due to the need to angle either the tube head or cassette.

Section 2: Mensuration

Once the feasibility study had been completed, a test of the accuracy of reproduction of bone size was devised. This was designed to allow assessment of the degree of magnification and distortion produced by each of three projection techniques.

Preparation: Five canine humeri and five canine femurs were selected from retained anatomical specimens. All were from skeletally mature animals, and were from a range of breed sizes. Each bone was then marked using small lengths of 1.5mm solder wire and micropore surgical tape. One piece was taped at the level of the proximal metaphyseal region and one at the level of the distal metaphyseal region. Two further markers were placed 25mm apart and on opposite sides (one cranial, one caudal) of the bone in the mid-diaphyseal region. The purpose of these was to give radio-opaque markers that would allow consistent measurement points. In addition, the diaphyseal markers on opposite sides of the bone would allow an assessment of the degree of superimposition. Each bone was given an identification number from one to ten, which was written on the tape. One bone of average size for the group was radiographed to obtain appropriate exposure factors. For all radiographs, a film-focal distance of 90cm was checked using an integral tape measure housed in the tube head. All radiographs were taken using the same X-ray machine, cassettes and film as for the feasibility study.

Radiography: Each bone was imaged in a craniocaudal projection using four projection techniques. For each radiograph, the x-ray beam was centred on the mid-diaphyseal region of the bone and collimated close to the bone margins. Radiographs were labelled using radio-opaque marker tape[**], identifying the bone, angulation and technique. The first projection taken was a true craniocaudal, with the long axis of the bone parallel to the plate – this represented the ideal radiographic projection, and would produce minimal distortion (Figure 9).

[**] X-Rite Tape

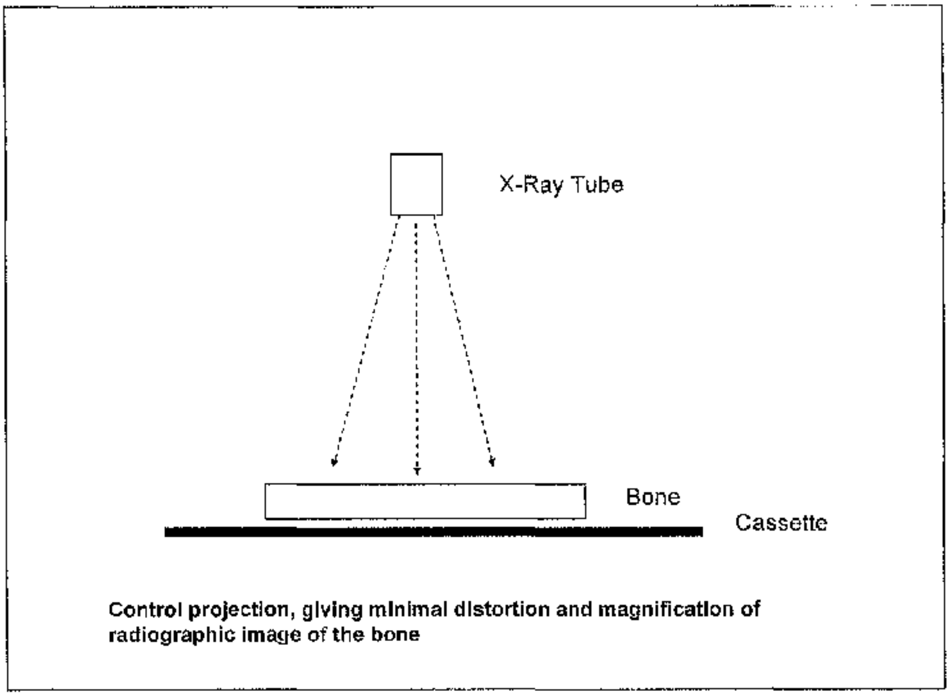


Figure 9 – Ideal Bone Projection

Bones were then positioned so that the long axis was at an angle (15, 30 or 45 degrees) to the plate, measured using a goniometer[††]. Positioning was achieved with the use of radiolucent foam wedges. The plate was maintained resting on the table top. In this position, the bone was radiographed using three further projection techniques:

1) The x-ray beam was maintained perpendicular to the cassette. This was expected to give foreshortening of the projected image. This was called the Tube-Plate projection (Figure 10).

[††] WHSmith Ltd

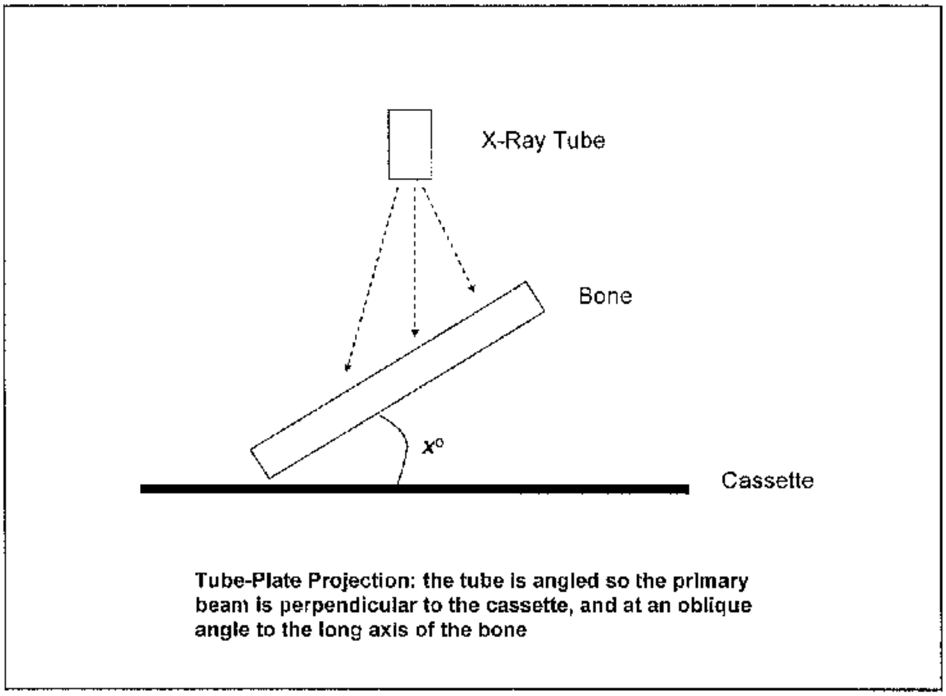


Figure 10 – Tube-Plate Projection

2) The beam was angled so that it was perpendicular to the long axis of the bone. This was expected to give lengthening of the projected image, and was called the Tube-Bone projection (Figure 11).

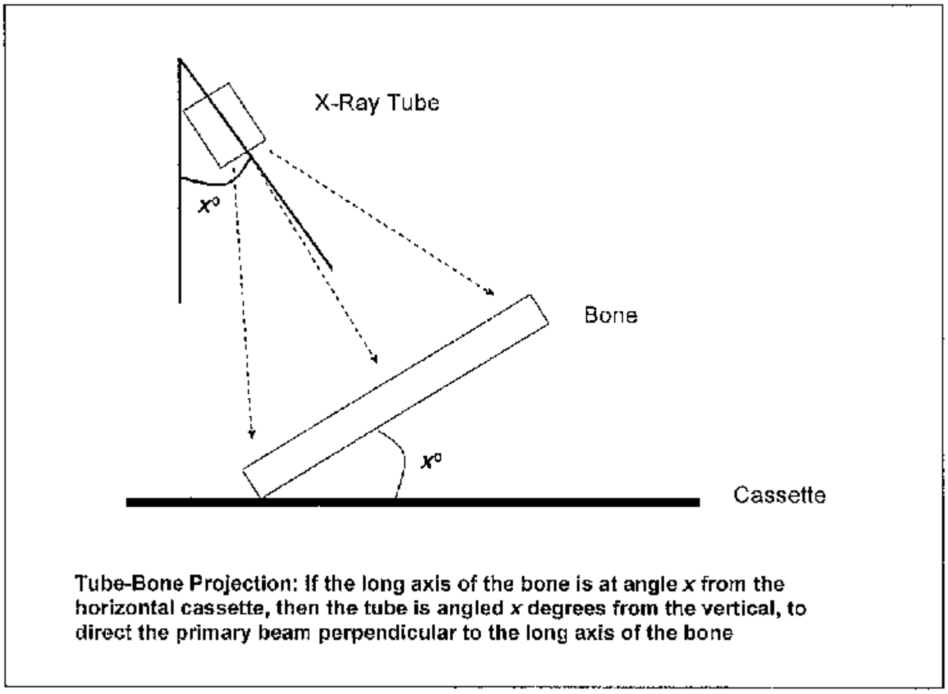
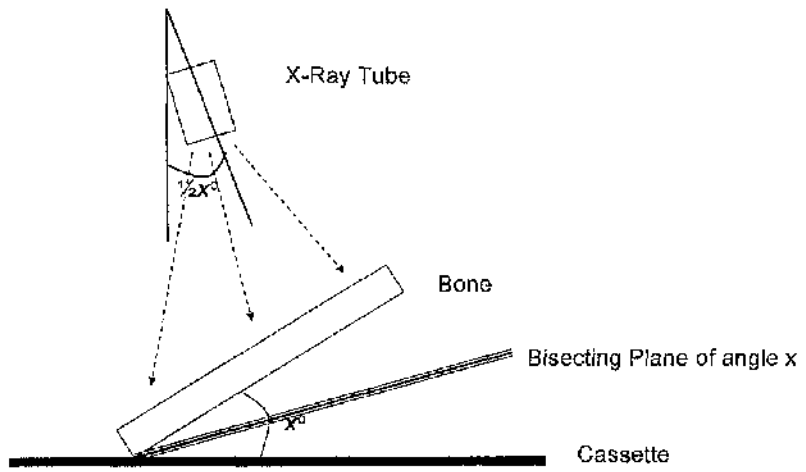


Figure 11 – Tube-Bone Projection

3) The beam was angled so that it was perpendicular to the plane of bisection. This was labelled the Bisecting projection (Figure 12).



Bisecting Projection: If the long axis of the bone is at angle *x* to the horizontal cassette, then the tube is angled at ½*x* to the vertical, such that the primary beam is perpendicular to the bisecting plane of the bone-cassette angle *x*.

Figure 12 – Bisecting Projection

Each bone was radiographed using all three techniques in each of three angles (15, 30 and 45 degrees) to the horizontal. The radiographs were assessed for quality and adequate labelling, and were then separated into groups based on the angulation of the long axis of the bone.

Measurement: Once all radiographs had been taken, measurements were made. All measurements were made on a single occasion by a single observer. The cortex-cortex width was taken at the mid-point of the radio-opaque markers at the proximal and distal metaphyseal regions, and also at the mid-point of the more proximal of the mid-diaphyseal markers. The length of the bone was measured from the middle of the humeral head to the intercondylar groove for the humeri, and from the femoral neck to the intercondylar groove for the femora. The separation between the mid-points of the diaphyseal markers was also measured. The same measurements were also obtained directly from each bone using callipers and a ruler. The results of all measurements were entered into spreadsheets, with a separate sheet for each bone angle. Spreadsheets were developed using a widely-available software programme[‡‡].

Analysis

The measurements obtained from the bone and from each relevant image were compared to ascertain which projection (control, tube-plate, tube-bone and bisecting) gave the most accurate reproduction of the actual dimensions of the bone. For each radiographic image, the difference between each measurement and that from the bone was calculated. This difference was then calculated as a percentage from the relevant measurement from the bone. The means of each group of measurements were calculated. The projection producing the percentage change closest to 0 was determined to be the most accurate reproduction.

The degree of distortion was also assessed by calculating bone proportions. For all measurements (bones and all projections) the bone proportions were calculated using ratios. Bone length was divided by each of proximal width, middle width, distal width and medial separation. The ratios obtained from each projection at each angle were then compared to those for the bone, allowing an assessment of loss of normal proportions. Analysis was with a two-way analysis of variance, using data analysis software[§§].

The main aim of this study was to compare the bisecting angle projection to other radiographic projections, including the ideal projection, to assess accuracy of image reproduction. Therefore, for each radiographic measurement from the angled projections, the difference between that measurement and that obtained from the control or ideal radiographic projection was calculated by subtraction. These differences were then compared using a two-way analysis of variance to determine which of the angled projection techniques gave the closest image to the ideal radiograph.

The trabecular pattern in the metaphyseal regions was determined using a subjective 4-point scale comparing the general trabecular pattern of the bone image to that obtained on the ideal projection of each set of radiographs. Each image was graded as: 0 = Same trabecular pattern as control projection; 1= Slight loss of clarity of trabecular pattern; 2 = Marked loss of clarity of trabecular pattern; 3 = Severe loss of clarity of trabecular pattern. In each case, the score was given according to the most

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[‡‡] Microsoft Excel

[§§] Minitab 14

severely affected area of trabecular pattern.

Section 3: Clinical Cases

The bisecting technique was used on a series of cases that had been referred to the orthopaedic service at the Small Animal Hospital of the University of Glasgow Faculty of Veterinary Medicine. In all cases, further clinical information than could be adequately obtained from standard radiographic projections was required by the clinician in charge, giving clinical justification for repeating the radiographic procedure using a bisecting angle technique. Clinical justification was decided on by a single radiologist after review of the initial radiographs in conjunction with the orthopaedic surgeon in charge of the case. For some of the clinical cases, an alternative x-ray machine[***] was used as dictated by availability. This machine also has a moveable tube head with an angle indicator, but was not used for the experimental study as it was felt subjectively to be more awkward to position. The cases, including the clinical reason for the radiographic procedure are listed in Table 1.

[***] Galaxy 15HF unit, SMR Medical Imaging

Case	Breed	Age	Sex	History	Reason for Radiography
1	Cocker Spaniel	1y6m	S	Femoral Fracture	Immediate postoperative assessment of repair
2	Old English Sheepdog	6y	C	Total Hip Replacement	Immediate postoperative assessment of prosthesis
3	Greyhound	1y8m	F	Humeral Fracture	Immediate postoperative assessment of repair
4	Great Dane	10m	M	Stifle Deformity	Accurate bone images for surgical planning
5	Collie	2y6m	M	Humeral Fracture	Postoperative assessment of progression of healing
6	English Springer Spaniel	4m	M	Humeral Condylar Fracture	Immediate postoperative assessment of repair
7	Whippet	5y	M	Humeral Supracondylar Fracture	Immediate postoperative assessment of repair
8	Springer Spaniel	3y5m	M	Humeral Condylar Fracture	Postoperative assessment of progression of healing
9	Cocker Spaniel	6y	M	Humeral "Y" Fracture	Postoperative assessment of progression of healing
10	Springer Spaniel	6y1m	M	Humeral "Y" Fracture	Postoperative assessment of progression of healing

Table 1 – Presenting history and clinical indication for cases undergoing bisecting angle radiography (y=years, m=months).

Results

Section 1: Feasibility

The results of the feasibility study using canine cadavers were assessed subjectively.

Practicality of bisecting angle projection:

The bisecting angle projection was only attempted pre-repair on the first cadaver before being abandoned. This was due to the impossibility of determining the long axis of the bone when a fracture was present, and as a result, the bisecting angle could not be accurately calculated.

For the post-repair radiographs of all ten femora the bisecting angle projection was easier to position than the optimised craniocaudal projection, where the plate was positioned such that it was parallel to the long axis of the bone, and hence all bisecting projections were given a subjective ease score of 0. Because the hindlimbs of the cadavers could not be extended parallel to the table top, for the ideal radiographic projection, it was necessary to angle the cassette using foam wedges and sandbags. This was not necessary for the bisecting angle projection, where the cassette was simply rested flat on the table.

The inconveniences of the bisecting angle projection were firstly determining the long axis of the bone and measuring the angle from the horizontal, and secondly repositioning the x-ray machine tube to the necessary angle and film-focus separation. Repositioning the tube was probably easier with the machine used for this study than it would be with many others due to the flexibility of its design. The widely-available goniometer was found to be a quick and convenient method for determining bone-cassette angle. All angle measurement were repeated twice in succession by the same observer, with little variation in recorded angle between the two measurements. The ease of obtaining a bisecting angle projection compared to that for obtaining a cranio-caudal projection with the primary beam angled vertically and the cassette resting on the table-top was not assessed, as it was assumed that this method of obtaining a cranio-caudal projection, where no angling of the cassette or primary beam was necessary, would always be easier to perform.

The second area of subjective assessment for the feasibility study was the evaluation of the image obtained of the orthopaedic implants using the bisecting projection in comparison to that obtained using the idealised cranio-caudal projection. For all radiographs, the image quality for the bisecting projection was graded as the same as the idealised projection (grade 0, n=3) or slightly worse than the idealised projection (grade 1, n=7). In all cases, the decrease in image quality was due to loss of clarity of the fine detail of the orthopaedic implants (e.g. the threads of the screws). The reduction and apposition of the fracture was easily assessed on all radiographs.

Section 2: Mensuration

Individual measurements were compared between the bone and the various images to determine which of the radiographic projections (control, tube-bone, tube-plate and bisecting) gave the most accurate reproduction of bone dimensions. Results of the differences in length measurements across the control projection and three different angled projections at different bone-cassette angles are presented below in tables 2, 3 and 4.

15^0	**Difference in length of projected image from bone**							
Bone	**Control**		**Tube-Plate**		**Tube-Bone**		**Bisecting**	
	Length	**%**	**Length**	**%**	**Length**	**%**	**Length**	**%**
1	1	**0.6**	-1.5	**-0.9**	9	**5.7**	4	**2.5**
2	5	**2.3**	4	**1.9**	14	**6.5**	11	**5.1**
3	2.5	**1.7**	-2.5	**-1.7**	17.5	**12.2**	8.5	**5.9**
4	3.5	**2.4**	-3	**-2.1**	16.5	**11.4**	8.5	**5.9**
5	0	**0**	-0.5	**-0.3**	6	**3.9**	2.5	**1.6**
6	1.5	**1.2**	-6	**-4.6**	14	**10.8**	4.5	**3.5**
7	2	**1.5**	-1	**-0.7**	14	**10.5**	6.5	**4.9**
8	5	**2.6**	3.5	**1.8**	12	**6.2**	7.5	**3.9**
9	1	**0.5**	-4.5	**-2.1**	19.5	**9.1**	9.5	**4.4**
10	8	**3.5**	7.5	**-3.3**	20	**8.7**	5.5	**2.4**
Mean magnitude of change		**1.6**		**1.9**		**8.5**		**4.0**

Table 2 – Changes from actual bone length (mm) produced by different projection techniques at bone-cassette angle of 15^0.

30°	Difference in length of projected image from bone							
Bone	Control		Tube-Plate		Tube-Bone		Bisecting	
	Length	%	Length	%	Length	%	Length	%
1	1	**0.6**	-6	**-3.8**	39.5	**24.8**	15.5	**9.7**
2	5	**2.3**	-2.5	**-1.2**	58.5	**27.2**	19.5	**9.1**
3	2.5	**1.7**	-11.5	**-8.0**	46.5	**32.5**	12.5	**8.7**
4	3.5	**2.4**	-20.5	**-14.2**	42.5	**29.4**	10.5	**7.3**
5	-0.5	**-0.3**	-6.5	**-4.2**	37	**24.0**	14	**9.1**
6	1	**0.8**	-18	**-13.8**	43	**33.1**	8	**6.2**
7	2	**1.5**	-15	**-11.2**	44	**33.0**	10.5	**7.9**
8	4	**2.1**	-3.5	**-1.8**	47.5	**24.5**	18	**9.3**
9	0	**0**	-27.5	**-12.9**	70	**32.7**	18	**8.4**
10	8.5	**3.7**	-1.5	**-0.7**	62.5	**27.3**	26.5	**11.6**
Mean magnitude of change		**1.5**		7.2		**28.9**		**8.7**

Table 3 – Changes from actual bone length (mm) produced by different projection techniques at bone-cassette angle of 30°.

45°	Difference in length of projected image from bone							
Bone Number	**Control**		**Tube-Plate**		**Tube-Bone**		**Bisecting**	
	Length	**%**	**Length**	**%**	**Length**	**%**	**Length**	**%**
1	0	**0**	-22.5	**-14.2**	94	**59.1**	28	**17.6**
2	4	**1.9**	-24	**-11.2**	152	**71.0**	45	**20.9**
3	1.5	**1.0**	-34.5	**-24.1**	101.5	**71.0**	15.5	**10.8**
4	3.5	**2.4**	-33.5	**-23.2**	112	**77.5**	14.5	**10.0**
5	0	**0**	-24	**-15.6**	104.5	**67.9**	23	**14.9**
6	1	**0.8**	-36.5	**-28.1**	96.5	**74.2**	13	**10.0**
7	2.5	**1.9**	-32.5	**-24.3**	95.5	**71.5**	18.5	**13.9**
8	5	**2.6**	-24	**-12.4**	143.5	**74.0**	38	**19.6**
9	0.5	**0.2**	-38.5	**-18.0**	169	**79.0**	32.5	**15.2**
10	8.5	**3.7**	-23.5	**-10.3**	183	**79.9**	51	**22.3**
Mean magnitude of change		**1.5**		**18.1**		**72.5**		**15.5**

Table 4 – Changes from actual bone length (mm) produced by different projection techniques at bone-cassette angle of 45°.

The percentage changes from actual bone measurements for each of the three angled projection techniques were then compared to those obtained from the idealised control projection, with p=0.01. Measurements of length, proximal width, middle width, distal width and medial marker separation were compared at each of the three bone-plate angles. Results are presented in tables 5, 6 and 7.

15°	**Mean % Length Change**	**Mean % Prox Width Change**	**Mean % Middle Width Change**	**Mean % Distal Width Change**	**Mean % medial separation change**
Control Projections	1.63	6.74	10.81	3.76	2.08
Tube-Plate Projections	-0.50	14.76	9.64	1.66	-16.78
Significantly different from control projection?	No	Yes	No	No	Yes
Tube-Bone Projections	8.56	5.67	12.38	8.57	17.80
Significantly different from control projection?	Yes	No	No	No	Yes
Bisecting Projections	4.42	9.00	11.69	2.89	1.73
Significantly different from control projection?	Yes	No	No	No	No

Table 5 – Comparison of length magnification created by angled projections to length magnification produced by control projection at bone-cassette angle of 15° ($p = <0.01$).

30^0	**Mean % Length Change**	**Mean % Prox Width Change**	**Mean % Middle Width Change**	**Mean % Distal Width Change**	**Mean % medial separation change**
Control Projections	1.48	9.54	9.57	3.26	0.74
Tube-Plate Projections	-7.05	2.67	6.62	2.15	-40.37
Significantly different from control projection?	Yes	No	No	No	Yes
Tube-Bone Projections	29.68	5.18	15.94	13.76	40.14
Significantly different from control projection??	Yes	No	No	Yes	Yes
Bisecting Projections	9.78	19.14	12.00	5.31	-2.94
Significantly different from control projection??	Yes	No	No	No	No

Table 6 – Comparison of length magnification created by angled projections to length magnification produced by control projection at bone-cassette angle of 30^0 ($p = <0.01$).

45^{0}	Mean % Length Change	Mean % Prox Width Change	Mean % Middle Width Change	Mean % Distal Width Change	Mean % medial separation change
Control Projections	1.45	7.43	8.18	2.39	-0.10
Tube-Plate Projections	-18.13	2.90	9.38	-0.20	-64.09
Significantly different from control projection??	Yes	No	No	No	Yes
Tube-Bone Projections	72.89	9.64	24.04	24.03	87.98
Significant lee different from control projection??	Yes	No	Yes	Yes	Yes
Bisecting Projections	15.97	17.97	13.82	7.23	-5.69
Significantly different from control projection??	Yes	No	No	No	No

Table 7 – Comparison of length magnification created by angled projections to length magnification produced by control projection at bone-cassette angle of 45^{0} ($p = <0.01$).

The effect on increasing bone-plate angle on the percentage changes from actual bone measurements for each angled projection technique was also determined with p=0.01. The control values were not compared as this did not involve adjusting the bone angle. Results for the three different projection techniques (Tube-Plate, Tube-

Bone and Bisecting) are presented in tables 8, 9 and 10.

Tube-Plate	15° Mean % Changes	30° Mean % Changes	45° Mean % Changes	Significant difference between bone cassette angles?
Length	-0.50	-7.05	-18.13	Yes
Proximal Width	14.76	2.67	2.90	No
Middle Width	9.64	6.62	9.38	No
Distal Width	1.66	2.15	-0.20	No
Medial Marker Separation	-16.78	-40.37	-64.09	Yes

Table 8 – Changes in length, proximal, middle and distal widths and medial marker separation between measurements taken from projected image and from bone for Tube-Plate projections at bone-cassette angles of 15°, 30° and 45° ($p = <0.01$).

Tube-Bone	15° Mean % Changes	30° Mean % Changes	45° Mean % Changes	Significant difference between bone cassette angles?
Length	8.56	29.68	72.89	Yes
Proximal Width	5.67	5.18	9.64	No
Middle Width	12.38	15.94	24.04	Yes
Distal Width	8.57	13.76	24.03	Yes
Medial Marker Separation	17.80	40.14	87.98	Yes

Table 9 – Changes in length, proximal, middle and distal widths and medial marker separation between measurements taken from projected image and from bone for Tube-Bone projections at bone-cassette angles of 15°, 30° and 45° ($p = <0.01$).

Bisecting	15^0 Mean % Changes	30^0 Mean % Changes	45^0 Mean % Changes	Significant difference between bone cassette angles?
Length	4.42	9.78	15.97	Yes
Proximal Width	9.00	19.14	17.97	No
Middle Width	11.69	12.00	13.82	No
Distal Width	2.89	5.31	7.23	No
Medial Marker Separation	1.73	-2.94	-5.69	Yes

Table 10 – Changes in length, proximal, middle and distal widths and medial marker separation between measurements taken from projected image and from bone for Bisecting projections at bone-cassette angles of 15^0, 30^0 and 45^0 ($p = <0.01$).

The maintenance of bone proportionality by the different projection techniques compared to the direct measurement of the bone was assessed, and results are presented in table 11.

	Bone	Control	Tube-Plate	Tube-Bone	Bisecting
15^0 L/Prox Width	6.54	6.28	5.74*	6.75	6.33
15^0 L/Mid Width	12.30	11.48*	11.36*	12.13	11.76
15^0 L/Dist Width	8.58	8.43	8.41	8.69	8.84
15^0 L/Med Separation	6.77	6.74	8.18*	6.23*	6.95
30^0 L/Prox Width	6.54	6.08	6.02	8.10*	6.17
30^0 L/Mid Width	12.30	11.67	10.86*	14.04*	12.33
30^0 L/Dist Width	8.58	8.46	7.82	9.94*	8.96
30^0 L/Med Separation	6.77	6.81	10.84*	6.26	7.70
45^0 L/Prox Width	6.54	6.23	5.34	10.40*	6.53
45^0 L/Mid Width	12.30	11.73	9.31*	17.54*	12.73
45^0 L/Dist Width	8.58	8.54	7.03*	12.26*	9.30
45^0 L/Med Separation	6.77	6.88	17.98*	6.23	8.46

Table 11 – Bone proportions calculated as length/width and length/marker separation ratios for bone, control and angled projections (* = $p<0.01$).

The variations in proportion ratios with increasing bone-plate angle was also calculated for each angled projection technique. Results are presented in tables 12, 13 and 14.

Tube-Plate	**15° Mean % Changes**	**30° Mean % Changes**	**45° Mean % Changes**	**Significant difference between bone-cassette angles?**
L/Prox Width	5.74	6.02	5.34	No
L/Mid Width	11.36	10.86	9.31	Yes
L/Dist Width	8.41	7.83	7.03	Yes
L/Med Separation	8.18	10.84	17.98	Yes

Table 12 – Changes in bone image proportions produced by Tube-Plate projection techniques at bone cassette angles of 15°, 30° and 45° ($p = <0.01$).

Tube-Bone	**15° Mean % Changes**	**30° Mean % Changes**	**45° Mean % Changes**	**Significant difference between bone-cassette angles?**
L/Prox Width	6.75	8.10	10.40	Yes
L/Mid Width	12.13	14.04	17.54	Yes
L/Dist Width	8.67	9.94	12.26	Yes
L/Med Separation	6.23	6.26	6.24	No

Table 13 – Changes in bone image proportions produced by Tube-Bone projection techniques at bone cassette angles of 15°, 30° and 45° ($p = <0.01$).

Bisecting	15° Mean % Changes	30° Mean % Changes	45° Mean % Changes	Significant difference between bone-cassette angles?
L/Prox Width	6.33	6.17	6.53	No
L/Mid Width	11.76	12.33	12.73	Yes
L/Dist Width	8.74	8.96	9.30	Yes
L/Med Separation	6.95	7.70	8.46	Yes

Table 14 – Changes in bone image proportions produced by Bisecting projection techniques at bone cassette angles of 15°, 30° and 45° ($p = <0.01$).

The maintenance of trabecular pattern was assessed using a subjective scale, comparing each oblique projection to the corresponding control image for each bone-cassette angle. Results are presented in table 15.

	Bone	15°	30°	45°
Tube-plate	1	0	1	1
	2	0	1	1
	3	0	1	1
	4	0	1	1
	5	0	1	1
	6	0	1	1
	7	0	1	2
	8	0	1	1
	9	1	1	1
	10	0	1	1
Tube-bone	1	1	3	3
	2	2	3	3
	3	2	2	3
	4	2	2	3
	5	2	2	3
	6	1	2	3
	7	2	2	3
	8	2	2	3
	9	2	3	3
	10	2	3	3
Bisecting	1	0	1	1
	2	0	1	1
	3	1	2	1
	4	1	1	1
	5	1	1	1
	6	0	1	2
	7	1	1	2
	8	1	1	1
	9	1	1	2
	10	1	2	2

Table 15 – Subjective scoring of trabecular pattern compared to control projection for tube-plate, tube-bone and bisecting projections at bone-cassette angles of 15°, 30° and 45°. 0 = Same trabecular pattern as control image; 1= Slight loss of clarity of trabecular pattern; 2 = Marked loss of clarity of trabecular pattern; 3 = Severe loss of clarity of trabecular pattern.

Examples of the images produced during the mensuration phase of the study are demonstrated in figures 13, 14 and 15.

a)

b)

c)

d)

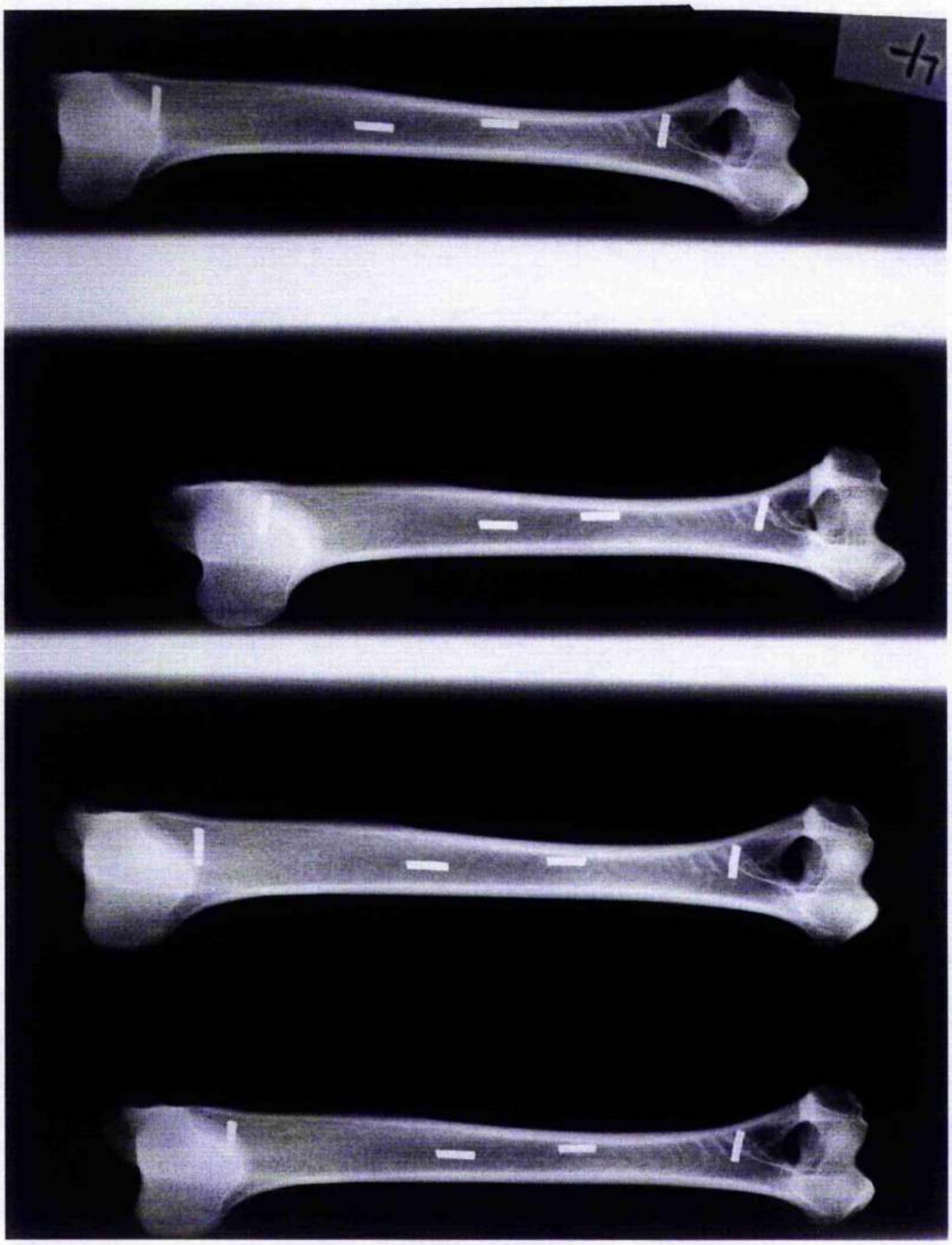

Figure 13 - Images of single bone obtained using control projection (a) with long axis parallel to cassette, and using angled projections (tube-plate (b), tube-bone (c) and bisecting (d)) at bone-cassette angle of 15°.

a)

b)

c)

d)

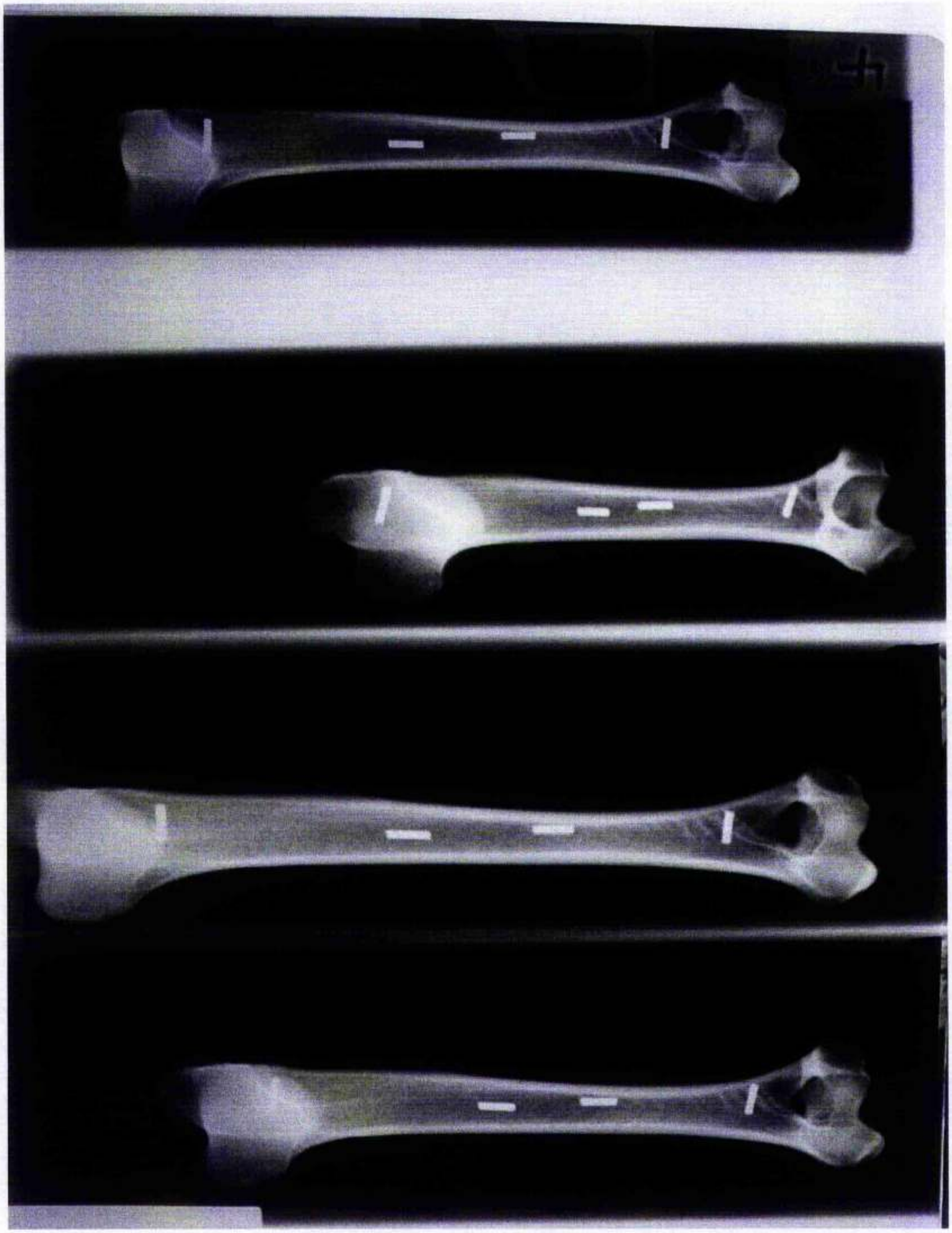

Figure 14 - Images of single bone obtained using control projection (a) with long axis parallel to cassette, and using angled projections (tube-plate (b), tube-bone (c) and bisecting (d)) at bone-cassette angle of 30°.

a)

b)

c)

d)

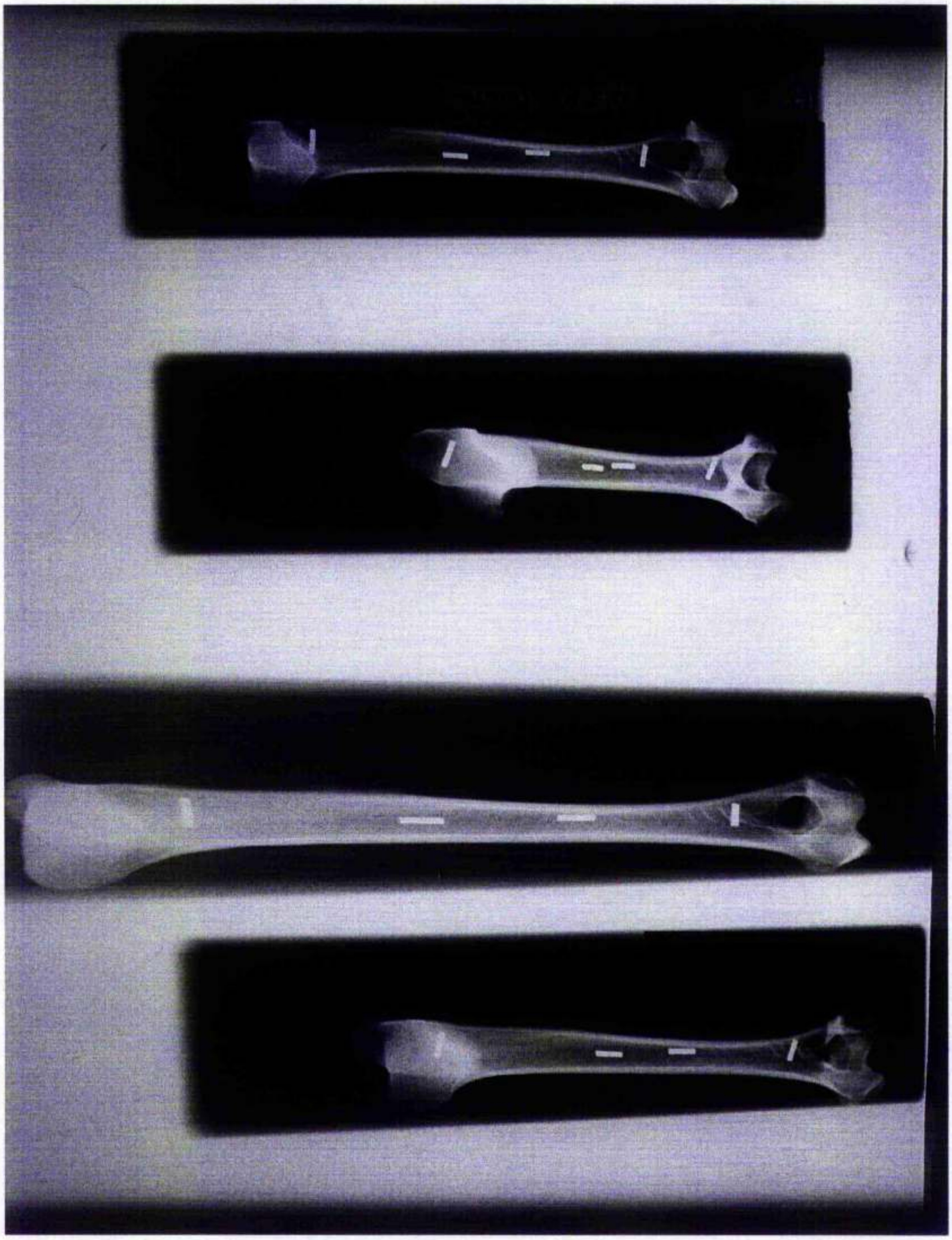

Figure 15 - Images of single bone obtained using control projection (a) with long axis parallel to cassette, and using angled projections (tube-plate (b), tube-bone (c) and bisecting (d)) at bone-cassette angle of 45°.

Section 3: Clinical Cases

For all cases, the amount of useful clinical information was increased over that provided by the standard radiographic views by using the bisecting angle technique. The results are presented in table 16, with a paragraph on each case following.

Case Number	Clinical Justification for bisecting projection	Quality satisfactory?	Bisecting projection useful?
1	Unable to fully extend limbs after surgery	Yes	Yes
2	Avoid stress on prosthesis immediately post surgery	Yes	Yes
3	Unable to align humerus to cassette	Yes	Yes
4	Unable to align femur to cassette	Yes	Yes
5	Unable to align humerus to cassette	Yes	Yes
6	Unable to align humerus to cassette due to elbow stiffness	Yes	Yes
7	Unable to align humerus to cassette	Yes	Yes
8	Unable to align humerus to cassette	Yes	Yes
9	Unable to align humerus to cassette due to elbow stiffness	Yes	Yes
10	Unable to align humerus to cassette	Yes	Yes

Table 16 – Clinical justification and assessment of quality and benefits of bisecting angle projections in clinical cases.

Case 1: The placement of a lateral external fixator to reduce the femoral fracture created difficulties in positioning the patient for both standard craniocaudal and mediolateral postoperative radiographs. The standard craniocaudal radiograph that was obtained produced superimposition of the proximal external fixator pins. The use of a bisecting angle technique gave a craniocaudal projection without superimposition of the implants, allowing greater assessment of the placement of the fixator pins.

Case 2: Full assessment of the placement of the femoral prosthesis following total hip replacement was required. However, minimal extension of the prosthesis was requested by the surgeon in charge of the case. The standard craniocaudal projection gave a foreshortened projection of the femoral implant, and did not allow full assessment of the location of the implant within the femoral medullary cavity. The bisecting projection centred on the proximal femur allowed this information to be obtained.

Case 3: A postoperative craniocaudal projection of the humerus following repair of a diaphyseal fracture with an external fixator was required, but that obtained using the standard technique resulted in superimposition of the implants preventing full assessment. The bisecting angle craniocaudal projection allowed full assessment of the implants by preventing this superimposition.

Case 4: Radiographs were obtained to allow full assessment of the femur prior to planning surgical correction of a rotational stifle deformity. It was not possible to align the femur parallel to the cassette to obtain a standard craniocaudal projection, but as accurate a depiction of true femoral size and proportions as possible was required. A bisecting angle craniocaudal projection was obtained as the projection that would give the most accurate depiction of size and proportions (the standard craniocaudal produced foreshortening of the bone).

Case 5: A six-week postoperative assessment of the healing of a humeral fracture repaired with a bone plate and intramedullary pin was required. However it was not possible to obtain a standard craniocaudal projection allowing full assessment of the implants and fracture site. A bisecting angle craniocaudal allowed assessment of both the fracture site and implants to the surgeon's satisfaction.

Case 6: Immediate postoperative assessment of implant placement following reduction of a humeral condylar fracture was required. However, due to soft tissue swelling and joint stiffness, it was not possible to obtain a standard craniocaudal projection of the distal humerus allowing full assessment of the implants (supracondylar wire and transcondylar lag screw). A bisecting angle craniocaudal projection allowed full assessment of the implants and fracture reduction.

Case 7: Immediate postoperative assessment of implant placement following reduction of a humeral supracondylar fracture reduced with a bone plate was required. However, a standard craniocaudal projection allowing full assessment of fracture reduction and implant placement was not possible, whereas a bisecting angle craniocaudal projection allowed the necessary information to be obtained.

Cases 8, 9 and 10: In all of these cases, previous humeral condylar (case 8) or "Y" (cases 9 and 10) fractures were being assessed six weeks postoperatively. In all cases, it was not possible to obtain a standard craniocaudal projection of the elbow and distal humerus that gave the necessary information about implants and fracture healing. In all cases, this information was obtained from a bisecting angle craniocaudal projection.

Examples of radiographs obtained from case 8 using a standard craniocaudal projection (figure 16a) and a bisecting projection technique (figure 16b) are shown below.

Figure 16a

Figure 16b

Figure 16 – Radiographs of the elbow of a dog presenting for follow-up assessment of reduction of a lateral humeral condylar fracture. Figure 16a shows the image obtained using a standard craniocaudal projection. Figure 16b shows the image obtained using a bisecting angle technique, with the elbow in the same position as that used for the craniocaudal projection.

As is demonstrated in figure 16, the bisecting projection gave a clearer image of the area of interest than the standard craniocaudal projection. For all cases, the amount of useful clinical information obtained from the bisecting projection was deemed to be greater than that obtained from the standard projection by both the radiologist and the orthopaedic surgeon in charge of the case.

Discussion

The problems in obtaining good quality veterinary orthopaedic radiographs have already been discussed. The purpose of this study was to assess the use of bisecting angle techniques for obtaining diagnostic quality radiographs of long bones in situations where standard radiographic projections cannot be obtained.

The first major consideration in using the bisecting angle projection involves the principle of isometry. This principle, where two triangles are identical if they share a common side and have two identical angles, is only truly accurate in two dimensions. In other words, the introduction of a third dimension (in the case of radiography, the thickness of the structure being radiographed) creates a situation where a true image is no longer possible. In addition, the principle also requires a linear structure. Most long bones have a slight curve that prevents them from having a true long axis. However, both of these factors are also considerations for dental radiography, where teeth are curved, three-dimensional structures, yet bisecting techniques are used successfully. It was therefore felt that, based on the long history of bisecting angle use in dentistry, that these techniques might be adequately applied to veterinary orthopaedic radiography.

The feasibility study demonstrated several factors. The first, and most significant, was that it was possible to use bisecting techniques in a clinical small animal radiographic setting. This was shown by the ability to obtain a radiograph using a bisecting projection from an entire canine cadaver. In clinical veterinary radiography, chemical restraint with either sedation or general anaesthesia is generally recommended. This improves radiation safety, as the need for physical restraint is lessened, and also the patient is less likely to struggle or move during radiography, reducing the number of repeat radiographic exams necessary. For veterinary orthopaedic radiography gives two further indications for the use of chemical restraint: firstly, that the discomfort of some of the positions required, and the degree of muscular relaxation necessary to obtain that position, is such that it will rarely be tolerated by a fully conscious animal, especially if pathology is present; and secondly that complete immobility is required. The latter is important in all radiography, as far as possible, but is particularly important for imaging bony structures, as even a slight tremor will result in blurring of the fine trabecular pattern. In addition, some x-ray machines have a fine-focus system, allowing the use of a smaller focal spot. This will produce a sharper image, but the maximum tube current is lower, and so the exposure time must be extended (although for most small animal veterinary radiography, with the relatively low exposures used, this time will still be short (in the region of 10msec)).

In comparison to the optimised craniocaudal projection, the bisecting angle was consistently easier to perform. This was felt to be predominately due to increased ease of positioning the radiographic cassette beneath the cadaver. For the idealised projection, aligning the plate parallel to the long bone presented two major obstacles. The first was determining the long axis of the bone. This was found by identifying palpable landmarks at either end of the bone (e.g. the greater trochanter and condyles of the femur) and connecting a theoretical line between them. The obvious drawbacks of this technique are twofold: the initial identification of the landmarks, and the designation of the long axis. The latter is largely dependent on operator assessment, but can also be complicated by variations within the shape of the bone between patients. In addition, severe soft tissue swelling (such as that associated with fractures, infection or neoplasia) may prevent identification of the landmarks. Of course, these drawbacks also apply to the bisecting technique. For this study, all determination of long axes was performed by a single observer, and so there was a consistent identification of the landmarks and thus determination of the bony axis. However, in a clinic, this process might require some education of the radiographer, before they were comfortable with the technique. For the bisecting projection, there was also less need to extend the associated joints as far as possible. While this was not a problem with the cadavers, this may influence the decision making process about use of the bisecting technique in clinical cases, especially when only sedated.

The bisecting projection, although easier to arrange, presented some problems of its own. It relies on identification of the long axis of the bone, with the difficulties alluded to above. However, once the long axis was determined, measuring the angle between the bone and the cassette was relatively simple to perform, using a cheap, widely-available goniometer. Calculation of the angle of the bisecting plane was then straightforward (halving the angle between the bone and cassette). Aligning the tube head to the bisecting plane was also simple, although this was undoubtedly aided by the equipment available for the project. The x-ray machine had a rotating tube head that could be locked at any angle, determined from an integral protractor. An integral tape measure allowed maintenance of a consistent film-focal distance. It cannot be denied that the availability of this equipment was of considerable benefit, and indeed it was noted that for the clinical cases radiographed using the second x-ray machine in the clinic, the slightly more restricted movement of the tube head did increase the technical challenge of obtaining the bisecting projection, although not enough to outweigh the benefits of the resulting radiograph. However, in many veterinary clinics, the x-ray facilities available will be more basic, with the result that tube positioning will be more difficult or restricted, and the lack of integral measurement devices may lead to assessment of tube angle in particular being largely subjective. As obtaining the best possible bisecting angle radiograph requires accurate measurement of tube angle, this lack of an objective method of determining tube angle could reduce the diagnostic accuracy of any radiographs produced using this technique. The restricted tube movement would probably be less of an obstacle than the lack of accurate measurement, as positioning aids such as troughs and wedges might be used to reduce the angle between the bisecting plane and the table-top cassette. However, in a facility where the tube is permanently fixed in a vertical orientation, use of bisecting angle techniques will most likely be impossible. In particular, for small veterinary practices performing a limited number of radiographic examinations (defined as a workload <240mAs/week, not more than 100kV), a controlled area may be designated within a radius of 2 metres from the primary beam. However, one criterion of this approval is that the primary beam is only ever orientated vertically. As a result, in such a facility, bisecting angle techniques could not be used.

As mentioned earlier, if the bisecting angle technique is to be used, then the premises must be of an appropriate type. In particular, the increased horizontal vector to the primary beam means that the walls of the radiography room should be of an appropriate thickness (preferably 2mm lead equivalent or double brick, and at least single brick/0.5mm lead equivalent), and it must be possible to control the area beyond the boundary of the radiography room (preferably a little-used area).

Canine cadavers were used as there could be no clinical justification for using a live animal as a test specimen for this technique. A benefit of using cadavers was the option of creating and repairing fractures to give an early assessment of the clinical use of the bisecting angle technique. It had been hypothesised that, should the bisecting angle projection have a clinical use, it would likely include the postoperative imaging of fracture repairs, and thus an early opportunity to test the benefits of this projection in these situations was welcome.

One further consideration of the feasibility study performed for this project was the economics of the study. For the ten femora fractured and stabilised, all were repaired to achieve alignment and apposition only, and not to a level that would allow ambulation. This was satisfactory for this study, as all that was being investigated was the imaging of the implants and assessment of the accuracy of repair. Reduction and alignment of the fracture fragments were the major criteria in assessing the accuracy of the procedure. The apparatus was not assessed in detail, and this rudimentary repair was driven by both time and financial considerations. Using intramedullary pins and interlocking nails allowed the same implants to be used for several cadavers, markedly reducing the financial cost of the study. Placing these implants was also considerably more efficient than contouring a plate and screws, and allowed a more rapid reduction. However, as a result, the feasibility study did not investigate the imaging of bone plates and screws using the bisecting angle technique (although the clinical case series subsequently showed this to be possible). In addition, in a clinical case, it is likely that more implants would be used, and therefore create more overlying objects obscuring the fracture site. However, this would affect all post-operative radiographs irrespective of radiographic technique used. Only one cadaver had the femoral fracture apposed using a basic unilateral external fixator. It cannot therefore be said that bisecting angle techniques are appropriate for all cases where an external fixator has been used. The cost of the additional radiographs for the bisecting projections was not significant. Therefore, although the feasibility study demonstrated that bisecting angle techniques were possible in the dog, it did not demonstrate the suitability of the technique for a wide range of conditions. It was anticipated that use of the technique would be determined by the individual case, and would therefore be demonstrated across a wider range of presentations by the clinical case series. This part of the study therefore achieved its aim of demonstrating that bisecting angle techniques could be applied to veterinary radiography.

Bone Measurements

Before the bisecting angle technique could be used in clinical cases with any confidence, it was felt that a demonstration of the distortion of the image produced by the radiographic technique should be assessed, and compared to that produced by the alternative projections that might be considered in situations where the bisecting projection could be applied. This was important, as any excessive distortion in either bone proportions or actual bone size would limit the use of the bisecting technique in situations where it was necessary to have a fair idea of the actual bone size from the radiographs (e.g. pre-operative assessment of implant size). All radiographic projections, including those that are theoretically ideal, will produce some magnification compared to the actual size of the bone, although as long as the film-focal distance is maintained at a suitable separation, and the object-film distance is kept to a minimum, any magnification should be insignificant. Obviously, for the study using the canine long bones, the object-film distance could be reduced further than in clinical cases due to the lack of soft tissues. In addition, it was feasible to position the bones exactly as desired as no other anatomical structures were present to affect the positioning of the bone. However, as this reduction in object-film distance was consistent for all the projection techniques, it was still possible to directly compare the measurements taken from the various images produced, although the magnifications and distortions could not be directly applied to radiographs taken from live animals. It was thought more important that the film-focal distance be maintained at a fixed distance for all projections to minimise another possible source of magnification and distortion. This was measured using the integral tape measure in the tube head, and could thus be kept at consistent distance from the plate, no matter what angle the tube was directed at.

Radio-opaque markers constructed from lengths of solder wire were attached to each bone to allow consistent measurement points. In addition, markers were attached on opposite cortices of the mid-diaphyseal region of each bone to allow assessment of both distortion but also superimposition of this area. This was included since, as well as an assessment of the bony distortion produced by the various techniques, there was also interest in the amount of masking of bony change that could be produced by superimposition of opposite sides of the bone. It is also possible to mask cortical fissures by imaging the bone at an oblique angle, such that the fissure is not parallel to the primary beam (although conversely a fissure not visible on the initial projection may be revealed by the oblique radiograph). Superimposition of orthopaedic implants in long bones that cannot be orientated parallel to the cassette appears to be a common problem, and was one of the factors behind the development of this project.

All other available techniques for maximising bony detail were employed. The x-ray machine was used on a fine focus setting, with high detail intensifying screens. The same exposure settings were used for all bones (the range of bone sizes used was not great enough to require alteration of the settings, particularly with the absence of soft tissues). The lack of other tissues meant that bony detail achieved during this part of the study was superior to that possible in live patients.

Therefore, using the equipment and techniques described above, the radiography of the bones was easier, and likely to produce higher quality images than would be possible in a clinical situation. It was decided to image each bone at three different angles to the plate (15, 30 and 45 degrees) in order to assess whether the degree of angulation had any effect on which projection technique produced the most accurate image. From personal experience, while it is usually almost impossible to align the femur or humerus parallel to the table-top, in a fully relaxed (i.e. anaesthetised) animal, it is often possible to reduce the angle of separation to 15-20 degrees. However, where there remains muscle tone, or where pathology restricts the range of motion of the associated joints, it is often difficult to achieve an angle of much less than 45 degrees. The angles described above were therefore selected as representative of the leg-table angles encountered in veterinary radiography.

Bone Measurement Results

As an initial, fairly crude assessment of the distortion of the bone produced by the varying image techniques, the percentage change in the length of the bone from the actual bone measurement was calculated for each image at each of the three angles. As can be seen from the results, the control or idealised projection produces a lower percentage change in separation than any other projection. This is to be expected, as there should be minimal magnification or distortion with this view. However, if we compare the results for the three oblique projections (tube-plate, tube-bone and bisecting) we notice a variation in the optimal technique as bone angle increases. At 15 degree angulation, the average percentage change produced by the tube-plate projection is considerably lower than that produced by the other angle projections, and indeed is only slightly higher than that of the control. The average percentage change from the bisecting projection is half that of the tube-bone projection.

At 30 degrees, the average percentage change in length for all angled projections has increased. However the change produced by the bisecting and tube-plate projections is similar, with the change from the bisecting projection slightly worse. At 45 degrees, the situation has reversed, with the bisecting angle projection producing the lowest average percentage change in length, although again the change has increased for all projections with the increase in angle.

These initial results show several point of interest:

1) The bisecting angle projection does not produce a true image of the bone at any angle. This is probably due to the three dimensional nature of the bone affecting the rule of isometry, as discussed earlier.

2) At lower angles, the simplest projection technique (tube-bone) produces the lowest amount of distortion. This may be expected, as at such a low angle, the apparent difference in length from the horizontal alignment will be extremely low.

3) As the angle increases, the change produced by all projections increases, but in particular, the change produced by the tube-plate projection increases more than that produced by the bisecting projection, indicating that at higher angles (e.g. less flexible legs), the bisecting angle projection produces less distortion of length than the other projection techniques.

4) The tube-bone projection produces consistently more length distortion than the other angled techniques.

These preliminary results suggest that if the long bone can be extended to within 15-20 degrees of the table top, the most accurate image is probably obtained using the tube-plate projection, and thus the bisecting projection is unnecessary. This is useful to know, as this is the simplest of the angled projection techniques, and does not require any movement of the tube head. However, with increasing angle, the bisecting technique starts to produce the most accurate reproduction of bone, and these results suggest this should be considered for bone-table angles of greater than 30 degrees. The tube-bone projection is consistently the least accurate in terms of length distortion, and as this projection technique will also produce the greatest horizontal component to the primary beam, this should not be considered as a radiographic technique.

To quantify the changes produced by the projection techniques further, the percentage changes in length, proximal, middle and distal width and separation of the diaphyseal markers from the actual bone measurements were calculated, and the changes for each angled projection were compared to those produced by the idealised control projection, with the results grouped by the bone-table angle. At 15 degrees, the tube-plate projection produced significant changes in proximal width and medial marker separation, while both the tube-bone and bisecting angle views produced a significant difference in length, with the tube-bone also producing a significant difference in medial marker separation. Therefore, for the lowest bone-cassette angle, the tube-plate projection gave the best reproduction of bone length in comparison to the idealised projection, but the bisecting angle projection resulted in the least distortion and over-riding of the mid-diaphyseal region.

At 30 degrees, the length changes significantly for all projections, but the medial separation changes significantly for the tube-plate and tube-bone projections, and the distal width for the tube-bone. Again, the bisecting projection produces the lowest distortion of the mid-diaphyseal area. At 45 degrees, the results are similar to those at 30 degrees, although the middle width is also significantly different for the tube-bone projection.

The points of interest for these comparisons are:

1) The bisecting technique is consistently the best projection for minimising distortion of the mid-diaphyseal area.
2) At lower angles, the tube-plate projection produces less distortion of external bone measurements.
3) At higher angles, all projections produce significant distortion of bone length in comparison to the control projection.
4) At higher angles, the bisecting angle technique produces a significant change in fewer parameters than the other techniques investigated.

However, one factor not taken into consideration when this part of the study was designed was that the proximal and distal wire markers would vary in their position relative to the metaphyses and epiphyses of the bone depending on the degree of rotation. What was noticed when the measurements were taken from the radiographs was that, depending on the degree of rotation, the cortex-cortex width at the level of the proximal or distal marker varied significantly more than expected. This was noted particularly over the proximal humeri, where a slight change in angle could significantly change the amount of humeral head measured at the level of the marker. Similarly, for the proximal femora, rotation altered the amount of the greater trochanter included at the level of the marker. The sometimes marked variation in percentage change of length between different bones when comparing similar angles and projections was felt to arise from inherent variation within the bones selected for the study. There was a range of bone sizes and types, from the long relatively straight bones typical of large breeds to the smaller more curved bones (especially humeri) from chondrodystrophic species. As the bone angle increased, the change in length from these more curved specimens was greater than that from the straighter specimens.

As a result of these findings, the actual significance of the measurements taken from proximal and distal markers has to be questioned. However, even ignoring these results, the bisecting angle still appears superior to tube-plate and tube-bone projections at higher angles due to the lack of significant change in mid-diaphyseal width and middle marker separation.

A further comparison was then made, using the same measurements, but instead comparing the effects of increasing bone-cassette angle on the radiographic images produced by each projection technique. Thus, the measurements taken from the tube-plate projections at 15, 30 and 45 degrees were compared, as were those from the other projection techniques. Again, the percentage changes from the idealised projection were calculated. Given the discussion above about the accuracy of the proximal and distal measurements, these can be discounted. It can be seen that all three projection techniques produced significant differences in overall length and middle marker separation as bone-cassette angle is increased. In addition, the tube-bone projection produces a significant increase in mid-diaphyseal width as the angle of separation increases. This demonstrates that none of the techniques compared are capable of producing a radiographic image of equal accuracy to the ideal projection when the bone-cassette angle is increased. However, if we look at the actual values calculated, it can be seen that the range of calculated percentage length changes is smaller for the bisecting projection than for the others. For example, the percentage change in length produced for the bisecting angle between 15 and 45 degree angulation is from 4.42-15.97. The equivalent ranges for tube-plate and tube-bone projections are 17.63 and 64.33 respectively. A similar pattern can be seen with the middle marker separation. Therefore, this analysis suggests that, although significant differences in length are produced by the bisecting projection, this technique produces less variation than that produced by the other projection techniques analysed. The tube-bone projection produces the most overall magnification change, as can be seen by the significant increases in mid-diaphyseal width.

However, for the bisecting projection at higher angles, although the mid-diaphyseal marked separation did not significantly change compared to the idealised projection, the overall bone length did still significantly increase compared to the idealised projection. It was therefore concluded that the bone proportions were going to be altered from the true measurements by this projection. The results were therefore re-analysed to assess alterations in bone proportions, by calculating ratios of bone length to proximal, mid-diaphyseal and distal width, and to middle marker separation. These ratios were calculated for all projections, as well as for measurements taken direct from the bone. Again, although the ratios of length to proximal and distal width were calculated, these results had to be taken in the context of the measurement uncertainties described previously.

Table 11 shows that for the control projection, there was a small degree of magnification, and there was a resulting slight loss of proportionality due to an increased magnification of the width in comparison to the length, as indicated by the marginal decrease in all the ratios compared to those taken direct from the bone. However, only one of these ratios (15^0 Length/Middle Width) was significantly different to the others. This may have been accounted for by a slight rotation of one or more of the bones when positioned for the control projection, resulting in a slight increase of the average apparent middle width and thus a decreased ratio. However, overall it can be said that the idealised projection produces an image of the bone that does not significantly alter the appearance of the bone proportions.

If we turn our attention to the tube-plate projections, it can be seen that for all bone-cassette angles, the ratios of length to middle width and length to middle marker separation are significantly different to those for the bone. As discussed earlier, this projection would be expected to create shortening of the bone image, and this is demonstrated by the decreased length to middle width ratios (i.e. the bone appears much wider in proportion to its length). The ratio of length to middle marker separation increases significantly at all angles, indicating that the marker separation is foreshortened to a greater degree than the overall bone length. This demonstrates that not only is the image of the bone produced by this technique markedly distorted in terms of proportion, but that there is also considerable superimposition of the mid-diaphyseal area. The significance of this would be masking of subtle bony lesions or superimposition of implants, making assessment difficult.

The tube-bone projection also produces significant changes in the calculated ratios. These are less marked at 15 degrees than those produced by the tube-plate projection, although at 30 and 45 degrees, the differences are generally greater for the tube-bone projection. However, the length-middle marker separation is only significantly different to the bone at 15 degrees. This indicates that the tube-bone projection does not produce a significant distortion of the mid-diaphyseal area in comparison to the rest of the bone (compare this to the tube-plate projection). Therefore, the tube-bone projection maintains reasonable bone proportions, although as discussed previously, there is significant magnification.

The bisecting projection shows no significant variation in length to width or length to middle marker separation at any bone-cassette angle in comparison to the measurements taken from the bone. It can therefore be confirmed that the bisecting projections maintain bone proportions as well as the idealised projection, and do so at a range of angles. In this regard, the bisecting projection is undeniably superior to either the tube-plate or tube-bone projections. However, what these results do not show, and which has been seen previously, is that the bisecting angle produces magnification of the image, and therefore is generally inferior to the ideal projection technique.

In order to investigate the changes in length/width ratios with increasing bone-cassette angle for each separate projection technique, the results were compared. All three projection techniques showed statistically significant variation in most of the ratios calculated as the bone-cassette angle increased. The most interesting of these results is that the length-middle marker separation ratio does not significantly change for the tube-bone projection as the bone-cassette angle increases, whereas there is significant increase for both the tube-plate and bisecting projections. This indicates that there is less effect of increasing angle on this aspect of the tube-bone projection than on others. However, although significant, the range of values for the bisecting projection is lower than those for the tube-bone and tube-plate, and so the combination of the increased maintenance of accurate bone proportion, and the reduced variation with increasing bone angle indicates that the bisecting angle is consistently the most accurate way of depicting bone shape and proportion.

As well as maintaining bone proportion, it is also important that the projection technique used does not compromise the assessment of fine bony detail, such as the trabecular pattern. The detection of subtle bone disease, such as fissure fractures or early neoplasia requires high detail radiographs. Therefore, it was felt important to assess the maintenance of the trabecular pattern by the various projections. This was most conveniently assessed with a subjective scoring scale. The various angled projections were compared to the relevant image produced using the control projection, with a visualisation of the trabecular pattern compared. The first note about this scoring system is that the lack of soft tissues in this model will increase the sharpness of the trabecular pattern due to reduced scatter. As a result, the results of the comparison could not be directly correlated to a clinical situation. However, given the same conditions for all radiographic projection techniques, a comparison between the images was still possible, to give an indication of which technique best maintained the definition of the trabecular pattern.

The results of this subjective scoring show that, in comparison to the idealised control projection, the trabecular pattern is best maintained by the tube-plate projection at all bone-cassette angles. Although this is at first slightly surprising, given that it has already been demonstrated that the bisecting projection maintains the bone proportions to a greater degree than the tube-plate projection, a re-appraisal of the geometry of each projection explains this result. Although for both projections at a given bone-cassette angle the separation between the elevated end of the bone and the cassette is identical, the separation as projected by the x-ray beam is not. For the tube-plate projection with a vertically oriented beam, the separation as projected is the vertical distance between bone and cassette (i.e. the minimal possible given the bone arrangement). However, for the bisecting projection, an angled x-ray beam is used, and this results in the image being projected at an angle to the vertical, resulting in a greater effective bone-cassette distance. This could be calculated using the cosine of the tube angle and the vertical bone-cassette separation. Increasing the object film distance not only increases magnification of the object, but also induces a degree of "edge-unsharpness" (lack of definition of the edge of the bone) due to the penumbra effect. This unsharpness results in loss of definition of the fine trabecular pattern. The same argument explains the consistent decrease in clarity of the trabecular pattern seen with the tube-bone projection compared to the bisecting. Again, the increased angle of the tube to the vertical results in a decrease in the cosine of the angle, and a resulting increase in the projected bone-cassette distance (effectively the hypotenuse of a right-angled triangle with the vertical bone-cassette distance as the adjacent side).

These changes in the clarity of the trabecular pattern may affect the amount of clinical information obtained from the radiograph. However, the significance of this effect will depend on the clinical problem being investigated and the required information to be obtained from the radiograph. If there is concern for a fissure extending from a fracture site, or for neoplasia (where an early bone tumour causing cortical destruction may appear initially as a coarsening of the trabecular pattern), then it is important to obtain the optimal clarity of detail, and therefore in such circumstances it may be appropriate to use a tube-plate projection technique. However, when it is more important to assess bone shape, to have as accurate a representation of bone size or to prevent superimposition of structures such as orthopaedic implants, but where fine bony detail is likely to be of lesser significance, then it may be more appropriate to use a bisecting angle technique. As with many aspects of veterinary medicine, there is a "trade-off" in terms of optimal information as provided by each technique, and therefore clinical judgement must be used for each individual case.

Clinical Cases:

The ten clinical cases on which the bisecting technique was used were selected on clinical judgement that the bisecting projection might add useful clinical information to the standard projections already acquired. As can be seen from the case list, seven of the ten cases were being radiographed for post-operative checks after surgical repair of distal humeral and humeral condylar fractures (Figure 16). In these cases, restricted elbow movement often reduced the ability to position the humerus parallel to the table-top (difficult in any case). The alternative cranio-caudal projection of the humerus, with the dog in dorsal recumbency and the shoulder flexed, was also deemed to be unsatisfactory in these cases, due to an inability to minimise the film-object distance. These factors combined to produce significant foreshortening of the humeral image, and also superimposition of the surgical implants. Therefore, the bisecting projection was used. In all cases, this gave improved imaging of the surgical implants and distal humerus compared to the other projections that had been attempted. The proximal humerus was relatively poorly imaged using this technique (creating both magnification and underexposure due to separation from the plate and the exposure factors being set for the thinner distal end of the proximal forelimb), but this was not considered to be any worse than that produced in the other views. In particular, the tapering nature of the canine proximal forelimb generally requires variation in exposure between the proximal and distal ends.

The other cases had the bisecting projection performed for various reasons. For the postoperative check on the total hip replacement , it was necessary to check the placement of the femoral prosthesis within the proximal diaphysis, but without unduly stressing the joint (i.e. without excessive extension). In this case, the bisecting projection gave an adequate image to assess placement of the implant. Implants and muscular stiffness prevented proper craniocaudal imaging of the femur immediately post fracture reduction. The bisecting projection allowed this. For the stifle deformity, the size of the dog (a great dane) and some hip stiffness prevented a true cranio-caudal of the femur being obtained. A reasonably accurate idea of femoral size was necessary, as corrective osteotomies were planned, and measurements of size were necessary. In this case, the bisecting projection was the easiest to obtain the required information.

There were many cases seen in the hospital where the bisecting technique might have been appropriate, but adequate information was obtained from the standard views. In these cases, the benefits of the additional view were outweighed by the potential drawbacks (increased radiation dose, increased use of consumables, etc), and therefore the use of the bisecting projection could not be justified. As the study progressed, the conclusion was reached that the bisecting projection was a technique that would not be required in a majority of cases, but could provide valuable clinical information where appropriate. Whilst no firm conclusions could be reached on the basis of such a modest group of clinical cases, a more controlled study, comparing several projections from the same patient could not be clinically justified, due to the increased cost patient radiation dose that would entail. Study using both a greater number and wider range of cases would be required to fully assess the potential benefits and pitfalls of using bisecting angle projections.

Conclusions for use of bisecting angle techniques in veterinary orthopaedic radiography.

1) The radiograph produced by a bisecting angle projection is an inferior image in terms of detail and accuracy of reproduction in comparison to the image produced using an optimal radiographic projection (with the bone parallel to the cassette and perpendicular to the x-ray beam). Therefore, where possible, the proper radiographic technique should be used, as the bisecting angle is not an adequate substitute.
2) Overall, the image produced using a bisecting technique is superior in reproduction of bone proportions and size to those produced where the primary beam is perpendicular to either the cassette or the bone, and where it is not possible to position the bone parallel to the cassette. Therefore, in these circumstances, the bisecting angle technique should be considered as that likely to produce an image with the most clinical use. The exception to this is where the prime clinical interest is in the fine detail of the bone, but where the overall bone shape and proportion are less important. In these conditions, the best technique is to maintain the x-ray beam perpendicular to the cassette, thereby minimising the object-film distance and the resulting loss of fine detail due to penumbra.
3) Bisecting angle projections are relatively easy to set up, but this may well be dependent on the available radiographic equipment. The necessity to move the primary beam away from the vertical also has implications for safety, and may be restricted by the local rules governing the radiographic facility.
4) The bisecting angle technique may be of use in a wide range of orthopaedic presentations, but appears to be of particular benefit in imaging the distal humerus, especially in cases of distal humeral trauma.

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