Appreciating X-ray Beam Geometry And Clinical Applications for Using Tube Angulation

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X-ray beam geometry related to radiograph magnification and distortion, and image sharpness due to penumbra is understood by most radiographers. Although these concepts are well documented in radiography textbooks, they are not reviewed thoroughly in the literature. In addition, many radiographers do not have knowledge of x-ray beam geometry outside of the image effects previously listed.[1-4] Many clinical radiographers recognize that angling the x-ray tube can introduce distortion of the anatomy being imaged. However, a solid understanding of x-ray beam geometry can enhance image quality as well as help technologists demonstrate anatomy in ways commonly thought unachievable.

X-ray Beam Geometry

X-rays are electromagnetic waves, much like light, and travel along a straight path from their origin, the focal spot. They are emitted from the focal spot in all directions. Clinical radiography, however, only uses a small percentage of these photons, collimating required x-rays to a field through a small aperture in the x-ray tube housing (see **Figure 1**).

The central ray refers to the x-ray photon path in the exact middle of the field and is therefore the only x-ray that does not travel in a divergent path from the focal spot.[1-3] The perpendicular ray is the x-ray path that projects perpendicularly to the detector. When centering perpendicularly to the detector, the central ray and perpendicular ray are the same.

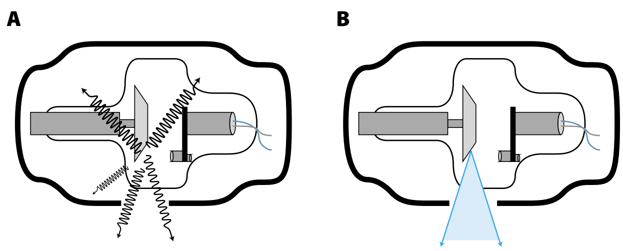

Figure 1. *A. X-rays are produced in all directions from the focal spot. B. Only a small number are used through an aperture in the tube housing. Images courtesy of the authors.*

Of the x-rays that are used for clinical radiography, the x-ray beam diverges from the focal spot into a pyramid shape that often is simplified to a 2-D triangular diagram in literature (see **Figure 2**). This 2-D representation is useful because in clinical radiography, the tube mostly is set to rotate along 1 axis (longitudinal) of the pyramid with effectively no movement along the corresponding axis (transverse). As such, angulation of the x-ray field typically only occurs in 1 plane.

Clinical radiography attempts to acquire images of the body with relatively little distortion. Distortion occurs when the body part or the x-ray beam is not aligned appropriately to the detector. The body part must be placed so that the long axis is parallel to the detector, and the central ray is perpendicular to the detector. Distortion occurs when either of these 2 considerations are not met.[1,2,4,5]

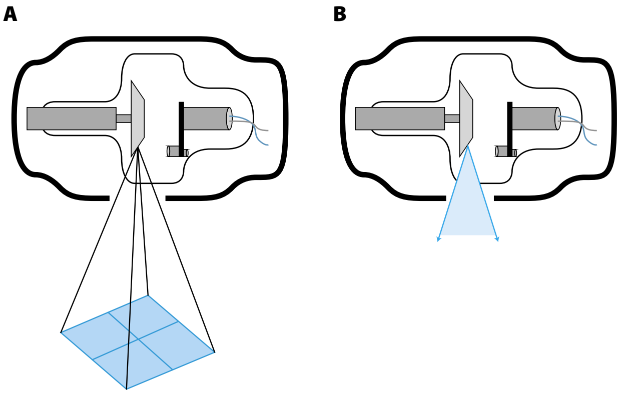

Figure 2. *A. The x-ray field is pyramidal in shape. B. The x-ray field commonly is depicted in literature as a 2-dimensional diagram. Images courtesy of the authors.*

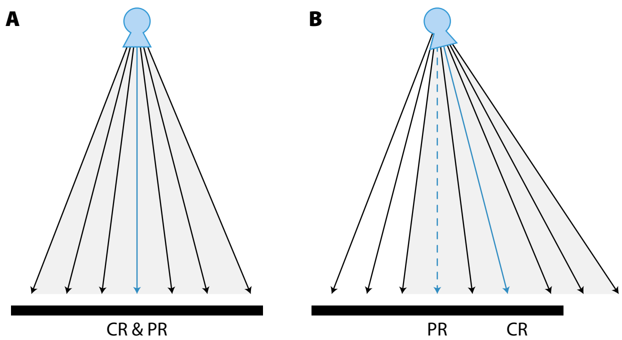

Figure 3. *When rotating the x-ray tube in isolation of all other movements, the perpendicular ray (PR) remains consistent, while the central ray (CR) and x-ray field is angled to the detector. Images courtesy of the authors.*

Conventionally, any angulation of the central ray from perpendicular to the detector creates some form of shape distortion.[2-4] Likewise, given that all x-rays in the field outside of the central ray are divergent and increase in divergence the further they exist from it, the central ray typically is directed to the location required for imaging. In the case of joint space imaging, the central ray is directed through the joint space; for long bones, it is directed to the middle of the bone.

Understanding the Geometry

Although much of the previously described x-ray beam geometry is common knowledge in conventional radiography, some clinical radiographers might misunderstand that the x-ray beam is an electromagnetic photon field, and x-rays act much like light in that they will travel in straight lines. Notably, for conventional radiographic tubes, the x-ray tube rotates around the focal spot. Therefore, when rotating the x-ray field, the focal spot, the perpendicular ray, and the incident point of the perpendicular ray on the detector are fixed, and the field moves around these points. This concept first was raised by Gleeson and presented at the Australian Annual Scientific Meeting for Medical Imaging and Radiation Therapy in Hobart in 2013.[6] In the absence of any other movements, when the central ray is angled, it separates from the perpendicular ray while the ray remains perpendicular to the detector. When this occurs and the x-ray field is rotated in isolation from other movements on the field, the original divergence of the entire field remains the same (see **Figure 3**).

This concept is useful because it infers that provided the x-ray tube is not moved in any other direction, the field can be rotated to include anatomy in 1 direction without compromising the projection of the perpendicular ray to the region of interest. Lacey and his colleagues were the first to provide clinical examples that used this concept in a presentation at the Australian Annual Scientific Meeting for Medical Imaging and Radiation Therapy in Hobart in 2013.[7]

Notably, this concept only applies to the rotation of the x-ray tube, given that this will ensure no movement of the focal spot. The swiveling of the x-ray tube to move in a transverse manner, such as that which occurs when performing imaging in the horizontal beam lateral hip position, for example, entails a movement of the focal spot and as such, the concept described herein would no longer apply.

Demonstrating X-ray Beam Geometry

To demonstrate that the x-ray tube rotates around the focal spot, the authors performed a simple experiment using metallic balls and rings and acquired images on 4 different radiographic units. The setup for the experiment is demonstrated in **Figure 4**. Two metallic rings were fixed 4-cm apart to the underside of a 5-cm thick radiolucent immobilization sponge. On the upper side of the sponge, the first metal ball was fixed at a

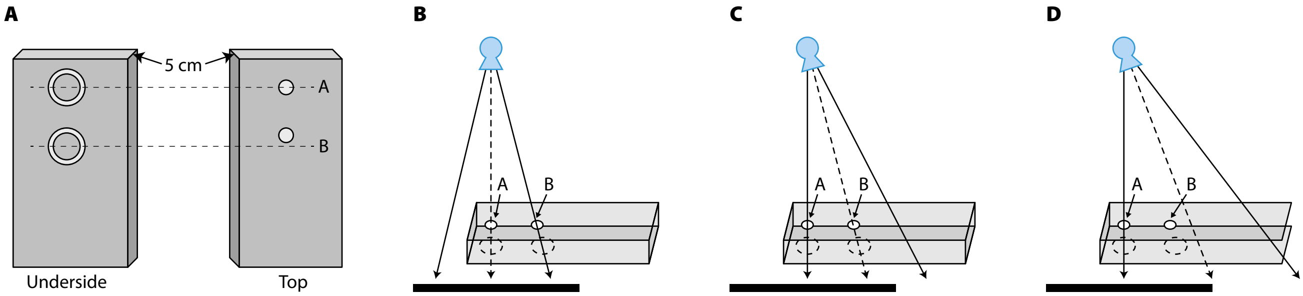

Figure 4. *A. Two rings were placed on the underside of a radiopaque sponge that was 5-cm thick. The rings were set 5-cm apart in the midline of the sponges. Two metallic balls were placed on the top of the sponge and set so that they were centered to the rings when imaged. B. A control image was taken with the central ray and perpendicular ray centered to ring A. Ball B was offset slightly so that when imaged, it was projected to the center of ring B. C. Image in 5° of angulation. A movement of degrees toward ball B was performed and images taken. D. Image in 10° of angulation. A movement of 10° toward ball B was performed. Images courtesy of the authors.*

point directly over the center of the metal ring nearest to the edge of the sponge. The sponge then was placed such that the central ray was placed directly to the center of the metallic ball. The second ball then was placed such that it was fixed to project within the second metal ring when imaged.

With the x-ray tube vertical, therefore placing the central ray perpendicular to the detector, an image was acquired demonstrating the balls located within the rings. At this point, the central ray and the perpendicular ray are the same. From this position, the tube was angled 5° and then 10° to the rings, and the collimators opened to include both rings. Images were obtained with both angles. An angle greater than 10° did not allow for inclusion of the rings, and so the experiment was limited to this amount of angulation. This is like the process undertaken by Fuller and Pierce, which was presented at the Australian Society for Medical Imaging and Radiation Therapy Scientific Meeting in Canberra in 2018.[8]

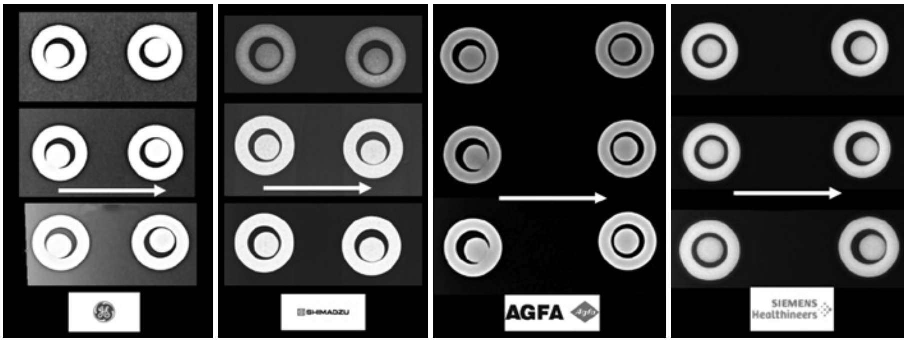

Figure 5. *Images procured of balls and rings under varying angulation. In all images the ball is situated in the same location in the ring, regardless of the tube tilt, proving that the tube rotates around the focal spot. Images courtesy of the authors.*

The images were obtained on a General Electric Optima XR656 Direct Digital radiographic unit with Flash-Pad Flat-Panel Wireless Digital Detectors (GE Healthcare), a Shimadzu RADspeed Pro Automatic unit with a Canon CXDI 70C detector (Shimadzu Corporation), an AXIOM Luminos dRF Max (Siemens Healthineers), and a DX-D 500 (Agfa-Gevaert Corporation). The images for these units are shown in **Figure 5**. The ball position in the metal rings remain unchanged as the beam is progressively angled through 5° and then 10° of angulation.

This experiment demonstrates that the x-ray tube rotates around the focal spot on 4 different radiographic units. It is reasonable to assume then, that this is the case for most, if not all, radiographic units. The clinical importance of this concept is that it gives radiographers the ability to center the x-ray field to 1 region of interest and then angle the tube to extend the field in 1 direction without compromising the projection of the perpendicular ray to the region of interest. There are several clinical applications for this concept that are useful to radiographers and might optimize imaging.

Clinical Radiography Applications

Imaging of the ankle, like the imaging of any joint, requires centering through the joint space and including at least the distal third of the tibia and fibula.[5,9,10] However, this position leads to the inclusion of the full foot and often a considerable amount of space inferior to the foot (see **Figure 6**). To acquire a more appropriate image and ensure the collimated field is more appropriate, this principle can be used to center the joint space and angle the central ray (and collimated field) superiorly. This technique also is useful for imaging any joint where the anatomy of 1 bone should be emphasized or when a long bone must be imaged with specific demonstration of 1 of the articular ends.

Bone Deformity Correction

The aim of bone deformity correction is to improve alignment and length discrepancies.[11] Typically, an osteotomy is performed, and the bone then is placed in external fixation. Correct alignment and control of the proximal and distal bone fragments is crucial in effective deformity correction. It also is important for the projection of the beam to be orthogonal to the reference ring of the external fixator and by extension through the osteotomy site.[12-14]

The osteotomy typically does not occur in the center of the bone. Therefore, imaging the entirety of the bone while aligning the beam to pass through the reference ring or osteotomy site is challenging. Using the concept described here, the central ray can be directed to the osteotomy site and angled to include both bone ends on the image. In this case, the perpendicular ray would still be projected through the osteotomy site (see **Figure 7**).

Digital Image Stitching

With the advent of digital radiography systems and automated x-ray tube, it is now possible to perform examinations of extensive anatomical regions that can be stitched and represented as 1 image. One substantial issue that arises with this technology is the parallax error that occurs due to the movement of the focal spot.

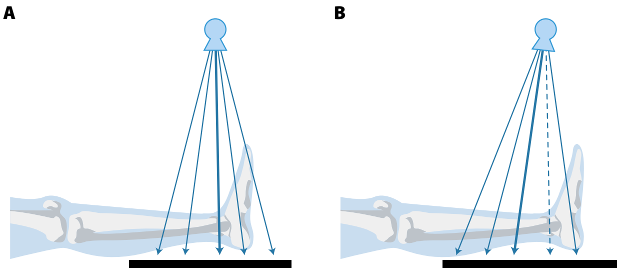

Figure 6. *A. The central ray is centered to the joint space. B. The tube is rotated to include more of the tibia and fibula, which is relevant and less of the under-foot which is not. Images courtesy of the authors.*

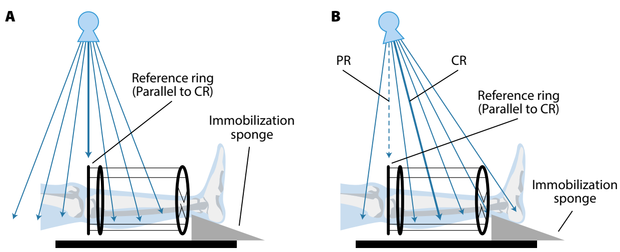

Figure 7. *A. Immobilization sponges support the tibia to be positioned so that the reference ring is vertical, and the central ray is centered to the ring. This will ensure that the ring will be projected as a straight line and the nearby osteotomy will be projected free of distortion. B. By angling the tube from that established in panel A, the PR will remain projected to the reference ring and osteotomy while the CR and x-ray field will angle to include the distal tibia and fibula. Images courtesy of the authors.*

Many digital radiography units now use the concepts of beam geometry described here to acquire images free from parallax error and to reduce geometric distortions.[15] This is the case for full-length imaging of the legs and scoliotic spinal imaging.

In the case of full spine imaging, if separate images were performed of the cervical spine, the thoracic spine, and the lumbar spine, and the images were accurately stitched together, the process would introduce a parallax error in the final product (see **Figure 8**). This error is because the focal spot moves, and, therefore, the position of anatomy will be projected to different areas of the image. When stitching occurs, the anatomy does not truly match. A few digital radiography systems will counter this by applying a rotational movement to

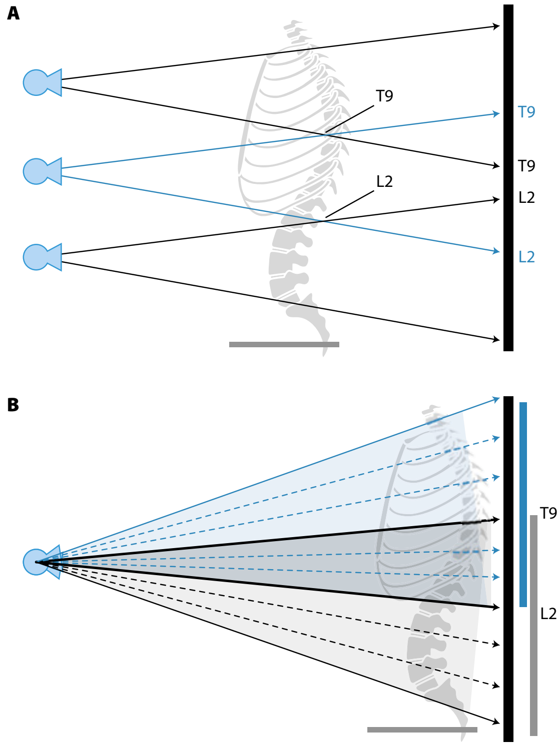

Figure 8. *A. Linear movement of the tube to perform image stitching. The movement of the tube also renders a movement of the focal spot and by extension creates a parallax error. Using the projection of T9 and L2 as an example, they are projected to different points on the detector, due to the movement of the focal spot. B. Rotational movement of the tube when stitching maintains the position of the focal spot. This ensures that the projection of body parts such as T9 and L2 are projected to the same point on the detector, reducing any parallax error. Images courtesy of the authors.*

image stitching. This involves the rotation of the x-ray tube and movement of the detector to allow for stitching that extends the field to include anatomy at a certain distance from the detector to be projected in much the same position. This ensures no movement of the focal spot, dramatically reducing the parallax error and providing more accurately stitched images.

The Lateral Cervical Spine Projection

One problem that exists when imaging the cervical spine for a lateral projection is demonstrating the C7/T1 junction without superimposition by the shoulders. In this case, an understanding of beam geometry can be used to achieve such an image.

Using typical positioning, the central ray is directed to the level of C3/C4. This introduces the diverging beam that will project the shoulder closer to the detector over the lower aspects of the cervical spine (see **Figure 9**). Considering the geometry of the beam as described in this article, a technologist imaging C7/T1 and the lower cervical vertebrae can center the central ray to the level of C7/T1 and angle the tube to include the full cervical spine. In this case, the perpendicular ray will be projected above the shoulders, which should allow for the greatest reduction of superimposition of the shoulders as possible.

Conclusion

X-rays travel in straight lines in a diverging path from the focal spot. The x-ray tube rotates around this focal spot, and when rotating the field along the longitudinal plane, in the absence of any other movement, the

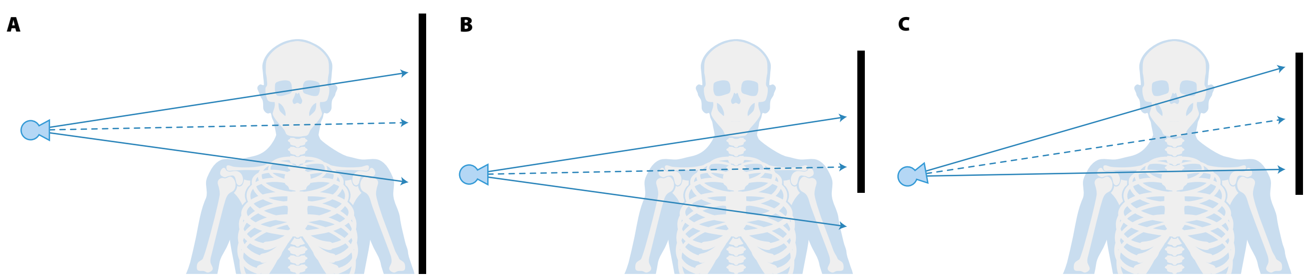

Figure 9. *A. The cervical spine projection. The conventional projection centers the field to the level of C4, which renders the beam projecting through C7 to be superimposed by the shoulder closest to the detector. B and C. Proposed method to better demonstrate C7/T1. By centering to C7 and angling to include the cervical spine, the C7/T1 junction will be imaged relatively free of superimposition from the shoulders. Images courtesy of the authors.*

central ray and field will move in the direction of the rotation. The perpendicular ray and the focal spot, however, will not move, and it is this principle that can be used to produce an image that is centered to a specific location but angled to include more anatomy in 1 direction without compromising the projection through the region of interest. This principle can be demonstrated through a simple experiment: imaging metal balls and rings to confirm that no misalignment will occur due to the angulation of the beam in absence of any other movement. The applications of this technique in clinical radiography are numerous. Although this article describes the advantage of using the principles of beam geometry to imaging the ankle, bone deformity correction, digital stitching, and imaging the spine, the concept can be applied to many imaging situations.

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Read the preceding article and choose the answer that is ***most correct*** based on the article.

1. To prevent distortion, the body part must be placed so that the long axis is _______ to the detector, and the central ray is _______ to the detector.
   a. parallel; parallel
   b. parallel; perpendicular
   c. perpendicular; perpendicular
   d. perpendicular; parallel

2. According to the article, when rotating the x-ray tube in isolation of all other movements, the perpendicular ray remains consistent, while the _______ is angled to the detector.
   1. central ray
   2. x-ray field
   3. focal spot

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

3. An understanding of the beam geometry principles discussed in this article can be applied to all of the following clinical radiography situations, ***except***:
   a. ankle imaging.
   b. bone deformity correction.
   c. a lateral cervical spine projection.
   d. a horizontal beam lateral hip projection.

4. Parallax error can occur in digital image stitching technology due to the movement of the:
   a. central ray.
   b. focal spot.
   c. detector.
   d. x-ray field.