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Basic Principles of Radiographic Tomography,
and Potential Application to Nuclear Medicine

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Tomography, or body section radiography, was first described in France by Bocage in 1921¹. A practical model for medical use was made in Italy in 1930 by Vallebona,² who succeeded in clearly imaging objects in a predetermined plane of interest while eliminating objects outside that plane by blurring them. This was accomplished by simultaneous motion of the x-ray tube and film in opposite directions during exposure, as illustrated in Figure 1.

Although a variety of motions are currently used in tomography, all have certain common features. The x-ray tube and the film are at opposite ends of a rigid support so that, as the tube is transported from left to right, for example, the film is transported from right to left as demonstrated in Figure 1. In all forms of radiographic tomography, the fulcrum of the motion described by the tube and the film lies in the plane of interest. Raising or lowering the patient on the table top places different planes within the patient at the fulcrum, and therefore "in focus", at any given time. Since blurring is less effective for points near the plane of focus than for points farther away from it, there is a gradation or

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progression in the degree of blurring achieved, i.e., there is a "depth of field" such that objects near the plane of focus are blurred minimally, whereas objects away from the plane are blurred maximally.

Linear tomography is the simplest form of body section radiography in use today. It has one major disadvantage, however, namely, the production of streaking linear parasite shadows which decrease the diagnostic quality of the film. The production of these streaks with linear tomography is due chiefly to the fact that maximum blurring occurs when a structure within the object to be imaged, but lying outside the focal plane, is perpendicular to the direction of the tube-film motion. A structure within the object, but outside the focal plane, which is parallel to the direction of tube-film motion is not blurred, but merely elongated. In a complex structure such as the face, linear motion is not suitable because many parts of the facial structure are parallel or almost parallel to the direction of tube-film travel and thus are incompletely blurred.

Machines with more complex motions were designed to eliminate this shortcoming of simple linear motion. Kieffer³ was the first in this country to develop and apply compound tube movements. He used circular, spiral, and sine-wave movements. The Polytome, a pluridirectional device that became available in 1951, is capable of performing linear, circular, elliptical, and hypocycloidal motions (see Fig. 2). Such motions have the distinct advantage over linear motion that all structures within a complex object outside the focal plane will at some time during the exposure be perpendicular to the axis of motion, and will consequently be blurred rather than elongated.

Ideal blurring results when the x-ray beam originates from an infinite number of points and strikes the object to be blurred from an infinite number of directions. Such a situation is closely approximated with

hypocycloidal motion, less well with circular or elliptical motion, and poorly with linear motion.

The effective focal-plane thickness (depth of field) is determined by the angle of beam motion--the larger the angle, the longer the tube travel and the thinner the section. (A thinner section can also be achieved by decreasing the target-pivot distance and increasing the pivot-film distance, but this is not practical with the average tomographic device.)

The amount of blurring achieved is also related to the angle of the motion. This angle limits the maximum distance through which the tube can travel for any type of motion. In linear tomography, the angle selected determines the length of tube travel. Although the situation is more complex for pluridirectional motions, the principle is the same, i.e., the farther the tube travels within any given angle, the greater the degree of pluridirectional motion, and hence the greater the blurring outside the focal plane. An in-depth discussion of angles, cut thickness, and distance traveled is given in references 4 and 5.

In current clinical radiographic practice, although each tomographer may have his favorite techniques, certain generalizations are applicable. At the University of Chicago, we use linear tomography when a relatively thick section is wanted, and when blurring requirements are minimal. This occurs, for example, in chest examinations. Here the main interfering structures are the overlying ribs, which are roughly perpendicular to the linear tube-film travel.

Abdominal tomography is more complex. In this instance, we frequently use zonography, which employs a very small circular motion sufficient to

blur out disturbing structures such as overlying bowel gas, but yields a sufficiently thick section to permit visualization of the organ in question. Zonography is commonly used for imaging the kidneys and the biliary duct system. Larger circles are frequently employed for long-bone tomography when very thin (1.0 mm) sections are not necessary.

For complicated structural problems in the head, e.g., visualizing the middle ear ossicles, hypocycloidal motion is essential. In this instance, maximum blurring of complex surrounding structures is required for adequate visualization. With the hypocycloidal motion, the angle is large (48°) and the tube travel long. Consequently, the effective focal plane thickness is minimal, and blurring is maximal.

Compared to nuclear tomography with current techniques, radiographic tomography has the obvious advantages of vastly superior resolution and a high photon flux. We used radiographic tomography in an experimental setup designed to emulate the conditions of a nuclide scan, to determine whether it is necessary to use a complex motion pattern in order to obtain the type of resolution ultimately desired for nuclear examinations. One of the major current problems in nuclear medicine is the inability to visualize small lesions in the liver; it is widely hoped that nuclear tomographic techniques applied to the liver may help correct this shortcoming.

To investigate the problem, and to determine how complicated the tomographic motion needs to be so that the hepatic duct system can be seen, we performed the following experiment: a dog liver, freshly removed from a sacrificed animal, was obtained. The sphincter of Oddi was cannulated, and air was injected into the biliary duct system. In this way, the soft tissue

of the liver would appear dense ("hot"), while the ducts themselves (filled with the lower-density air) would appear lucent ("cold"). This situation is similar to that in colloidal liver scanning where the hepatic parenchyma contains the tracer, but the ducts and vessels do not. With this experimental preparation, we made 30° linear tomographic cuts of the dog liver. The result, shown in Figure 3A, indicates that the duct system is readily visualized in significant detail with the simple linear motion.

In a second experiment, designed to assess the effect of respiratory motion on high-resolution tomographic images, the dog liver was moved slightly (8 mm perpendicular to the axis of tube travel) during the course of a linear tomographic cut. This is illustrated in Figure 3B. It is evident that visualization of the smaller branches of the duct system is almost entirely lost by organ motion during the tomographic examination.

Conclusion

Radiographic tomography can be performed with a variety of motions, each of which has a specific usefulness in the practice of current clinical diagnostic radiology. If tomography is used as a model of a high-resolution, high-photon-flux system, it appears that a simple linear tomographic motion will be entirely adequate for detailed visualization of small structures such as the minor hepatic ducts. If the object to be imaged moves during the course of examination, however, fine detail is almost completely lost. It seems prudent, therefore, to couple investigative work in nuclear tomography with simultaneous efforts to control the respiratory-motion artifact on scans, so that the potential benefits of greater resolution with the tomographic technique will be realized.

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Figure Legends

Figure 1. Principles of Tomography

Figure 1A demonstrates the principle of production of tomographic blurring which depends on simultaneous motion of the x-ray tube and radiographic film in opposite directions, depicted diagrammatically as motion from position 1 to position 2. Tube and film are fixed at opposite ends of a rigid support so motion through any angle (T_1 , X , T_2) occurs about a fulcrum (X). Any point on plane X is projected onto a single position on the film throughout tube-film motion and is always in focus.

All other points (A , B , C) on all planes above or below the focal plane (X) are blurred across the film during tube-film motion and are not in focus.

Figure 1B demonstrates that points A and B , on planes equidistant above and below the focal plane X are blurred equally across the film, but in opposite directions, during tube-film motion from position 1 to position 2. Blurring is progressive and increases as the distance from the fulcrum or focal plane increases, so that the image of point C , further away from the focal plane than points A and B is blurred more than points A and B and at times during the exposure may even be projected completely off the film.

Because the focal plane is infinitely thin and because blurring above or below this plane is progressive, tomographic images are inherently unsharp. The human eye, however, perceives a plane of some effective thickness which appears to be "in focus". The thickness of this plane depends on the angle of tube-film motion in an inverse relationship, i.e., the larger the angle, the thinner the effective focal plane.

Figure 2. Types of Motion in Common Use in Radiographic Tomography

- A. Linear Motion
- B. Elliptical Motion
- C. Circular Motion
- D. Hypocycloidal Motion

Figure 3. 30° Linear Tomography of an Isolated Dog Liver Preparation

3A Air has been injected into the biliary tree. The simple linear tomographic motion adequately demonstrates the minor hepatic ducts in great detail.

3B In this case, the liver has been moved 8 millimeters perpendicular to the direction of tube-film travel during the course of the exposure. It is clear that the motion virtually obliterates most of the detail. It would seem that respiratory motion during any high resolution high photon flux tomographic examination is sufficient to negate all of the potential benefit the technique has to offer.

FIGURE 1

PRINCIPLES OF TOMOGRAPHY

1:A) TUBE - FILM MOTION, FOCAL PLANE, AND PRODUCTION OF BLUR

1:B) PROJECTION OF POINTS ONTO FILM DURING TUBE FILM MOTION FROM POSITION (1) TO POSITION (2)