Vol. 108, No. 4

A PHANTOM METHOD TO EVALUATE THE CLINICAL EFFECTIVENESS OF A TOMOGRAPHIC DEVICE*

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THE recent appearance of at least 8 new pluridirectional tomographic devices places the radiologist in a position of dependence when comparing different units. It seems important, therefore, to have some basis for comparing different devices and some technique for periodically checking the performance of one's chosen unit. Fortuitously, most of the physical properties of a tomographic device which affect the picture, such as its mechanical stability, the geometric form of the obscuring movement, false image formation, section thickness, etc. can be readily examined by 2 simple phantoms: a pin hole in a lead diaphragm and a composite phantom (Fig. 1, *A* and *B*).

PIN HOLE PHANTOM

Pin hole tracings of the tube-film obscuring movement can be made with a lead diaphragm in which a 3 mm. beveled hole is located in the center. If the lead diaphragm is located approximately 12.0 cm. above the plane of focus and an exposure (120 mas. at 65 kv.) is made through the full cycle of the obscuring movement, the resulting pattern will be a film record of the tomographic movement and will provide the following information:

A. *The tracing will describe the geometric form of the obscuring movement.* Figure 2 illustrates 4 basic obscuring movements: linear, elliptical, circular, and a

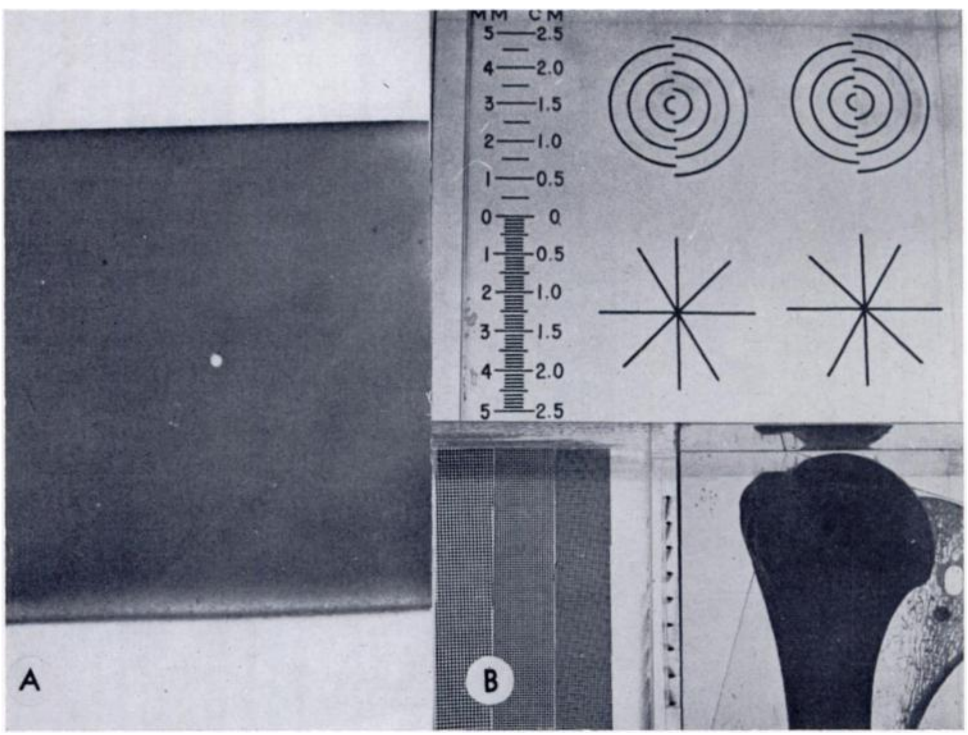

Fig. 1. Photograph of (*A*) a pin hole lead diaphragm, and (*B*) compound phantom.

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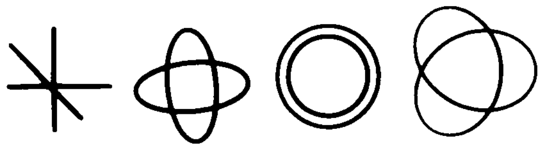

Fig. 2. Pin hole tracings of 4 basic tomographic movements.

compound movement (hypocycloid). All of the movements in these tracings show good alignment of the tomographic movement and normal mechanical stability. A properly adjusted tomographic device should not show any unwanted motion in any of the blurring movements.

B. The *mechanical stability* of the apparatus can be assessed from the pin hole picture. Figures 3, *A* and *B*; and 4, *A* and *B* are tracings of 2 different movements from 2 different tomographic devices, each of which shows significant unwanted motion developing as the speed of the tomographic movement is increased.

C. The *completeness of the exposure* will appear as an open section in the tracing. Figure 3*A* indicates that the exposure is not complete through an elliptical blurring movement. Skip areas of greater magnitude can adversely affect the tomogram. Figure 5, *A* and *B*, is a tracing of a tomographic device which should have provided a half circle obscuring movement. The tracing (Fig. 5*B*) indicates that the tube is energized only during a small arc of the sweep and hence the effective blurring movement is a small angle linear sweep rather than a half circle. Overriding of the exposure will also be detected

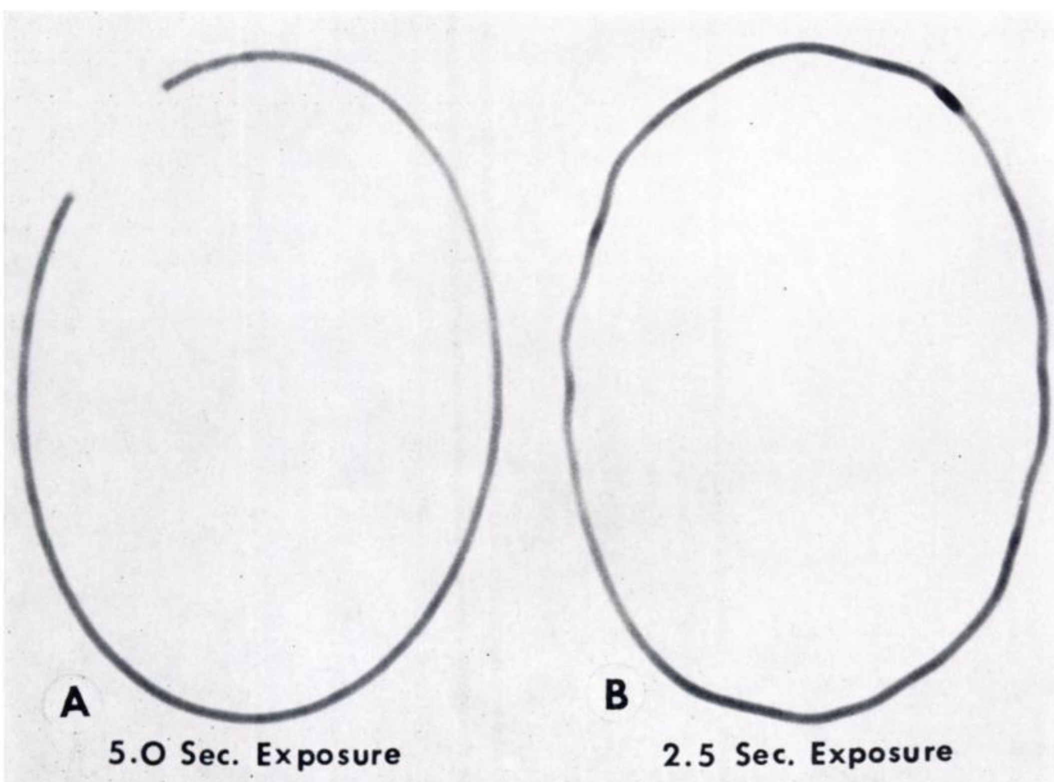

Fig. 3. (*A*) Tracing of elliptical tomographic movement. Note incomplete exposure. (*B*) Significant unwanted motion develops in this device as speed of the tomographic movement is increased from 5 to 2.5 seconds. The unwanted motion is recognized as a wavy pattern in the tracing.

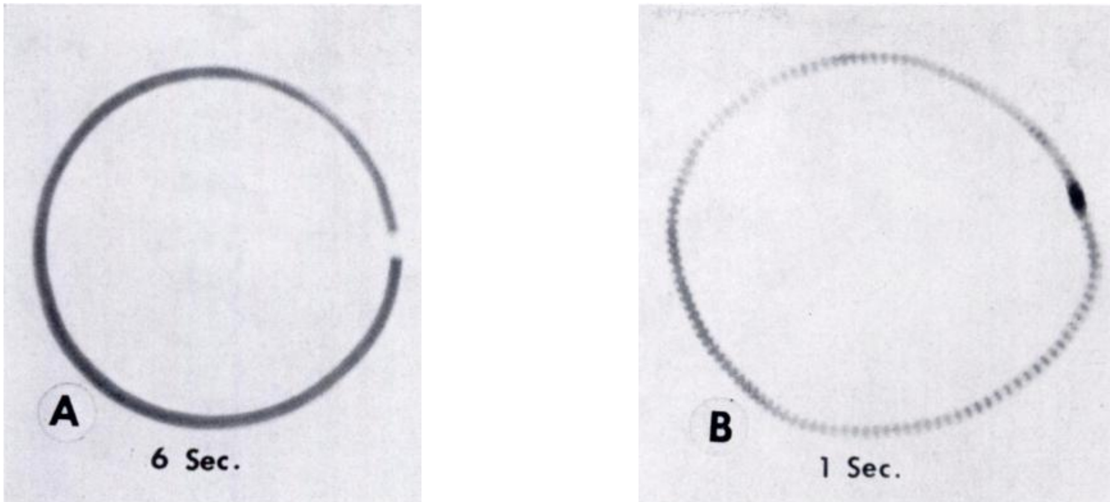

Fig. 4. (*A*) Pin hole tracing of a 30° circular movement showing good stability of the unit, although the tracing is not exactly a circle. (*B*) This same movement at high speed exhibits significant unwanted motion together with accentuation of the loss of the circular pattern.

by this method. Figure 6*A* is a tracing of an experimental spiral movement which was produced by selective timing to eliminate a circular portion of the movement in the center of the spiral. The first attempt failed to eliminate the circle and was easily detected in the pin hole tracing.

D. *Variation in intensity of exposure* may be a factor of tube speed and will be noted as a change in the density of the tracing. Figure 7, *A* and *B*, illustrates 2 spiral movements, both of which demonstrate a decrease in tube speed with increasing intensity of exposure as the movement approaches the center of the spiral. Variations in intensity of this magnitude reduce the effectiveness of the spiral movement, for in this instance the major portion of the exposure is occurring during an arc of less than 360° and hence the blurring characteristics of this movement will approach that of a circle rather than a spiral.

E. *The pendular angle* can be measured

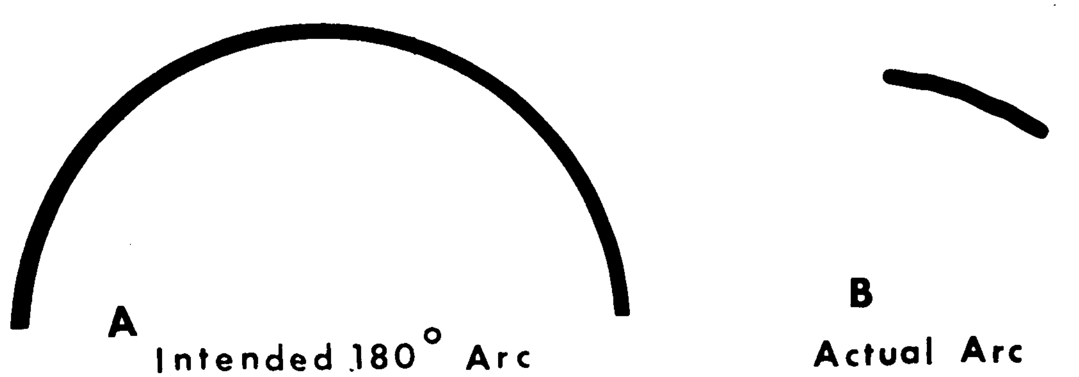

Fig. 5. (*A* and *B*) A gross example of incomplete exposure during the tomographic movement. The actual arc at *B* represents only approximately 20 per cent of the intended 180° arc shown at *A*. The quality of the blur, therefore, will resemble a linear movement rather than a semicircle.

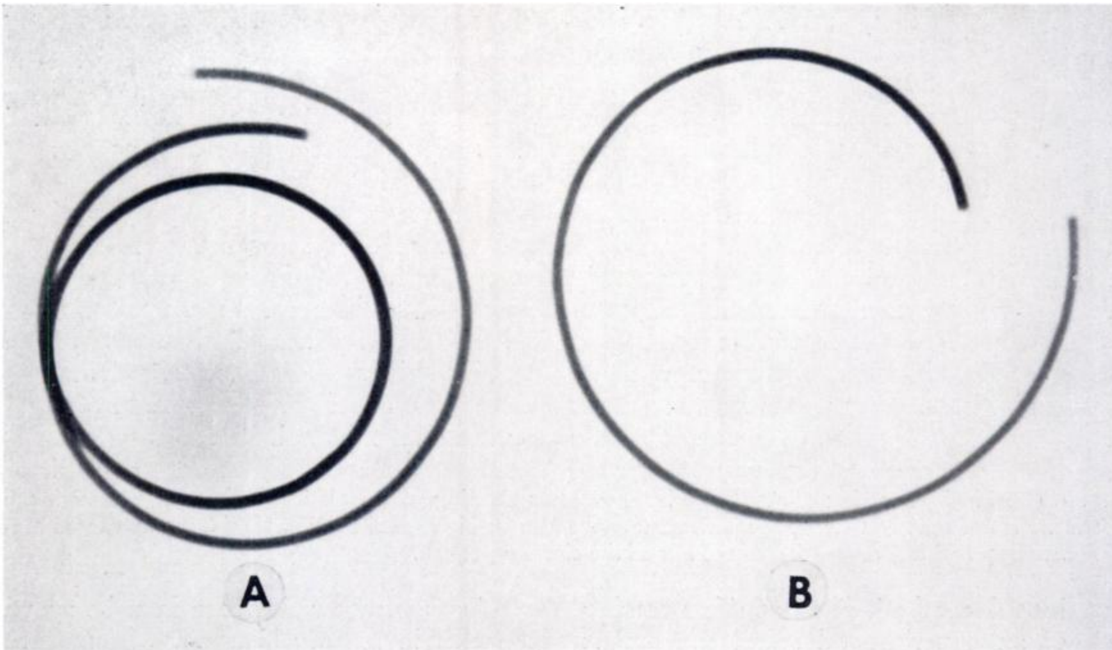

Fig. 6. (*A* and *B*) Pin hole tracings of an experimental spiral movement produced from a circular movement. The spiral (*B*) was created by selectively timing the exposure to eliminate the parent circular movement. The first attempt (*A*) failed to eliminate the circle and for practical purposes this blurring movement would then still resemble a circle more closely than a spiral.

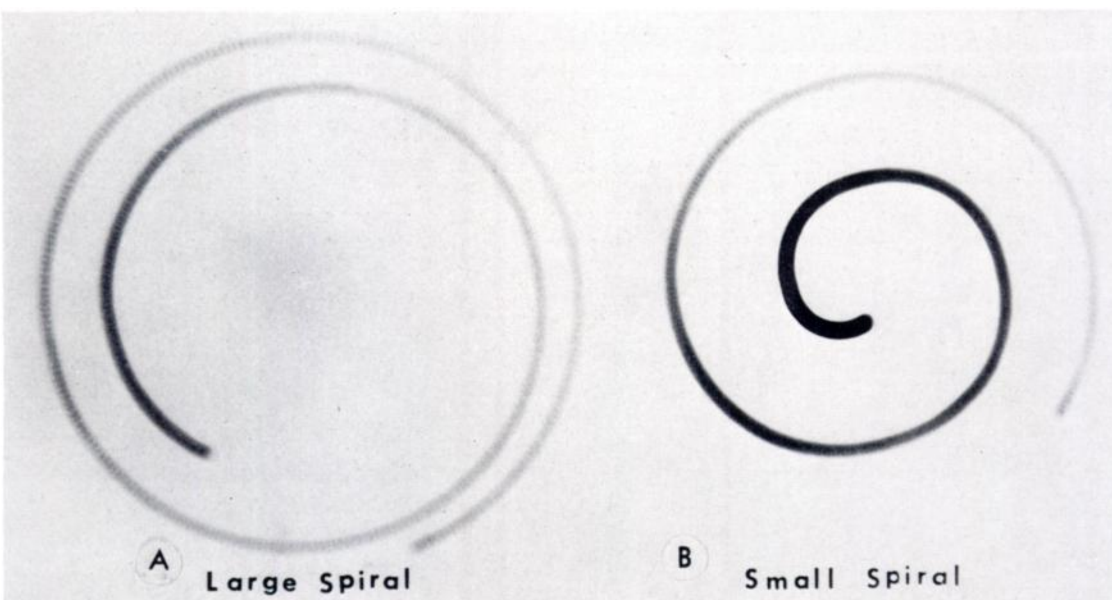

Fig. 7. (*A* and *B*) Tracings of 2 spiral movements illustrating the change in intensity of exposure with decreasing speed of the tube as it approaches the center of the spiral.

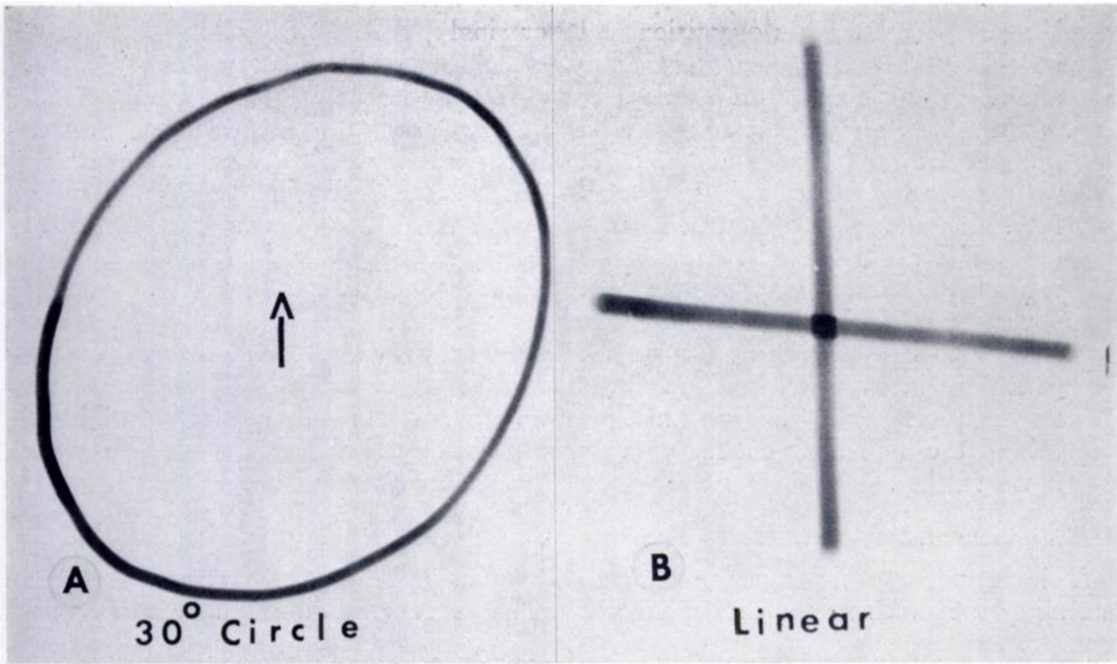

Fig. 8. (*A*) An intended circular tomographic movement is seen to be an ellipse, oblique to the long axis of the table. (*B*) Two linear movements were intended to be perpendicular to each other but the tracing shows the transverse movement to be oblique to the long axis of the table rather than perpendicular.

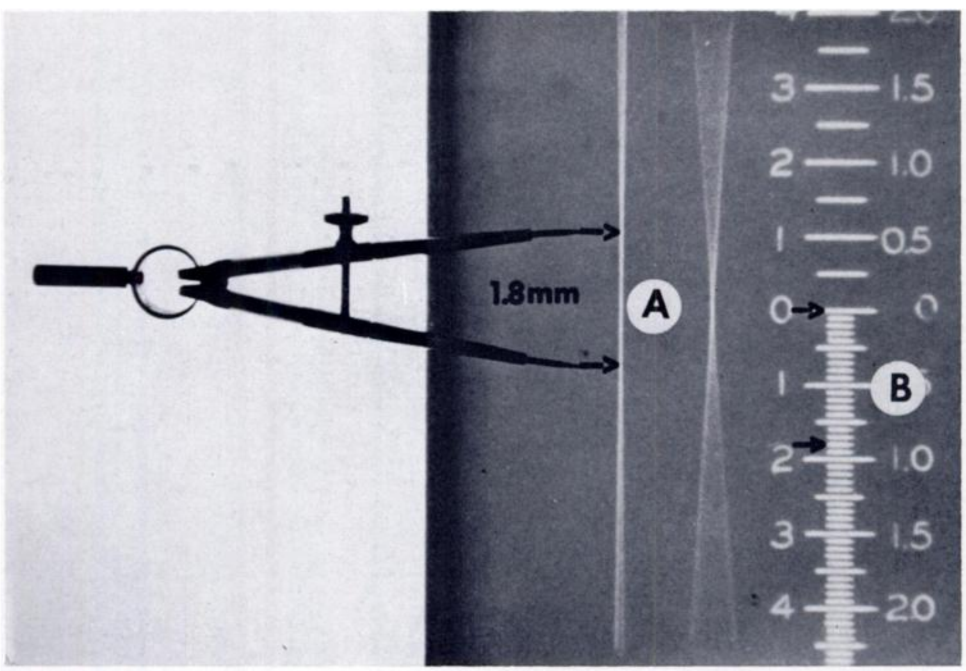

Fig. 9. (*A* and *B*) Interval thickness can be measured directly as the amount of wire in focus at *A*, as compared to a millimeter scale at *B*.

with a pin hole tracing. A spot exposure is made with a tube in 0 position and its relationship to the entire tracing allows one to check the half angles.

F. *Orientation of the movement* with reference to the long axis of the table will be apparent in the pin hole tracings. Figure 8*A* shows the tracing of a unit set for a 30° circle. The device is actually describing an ellipse which is oblique to the long axis of the table. Figure 8*B* is a tracing from a device which was intended to provide 2 linear movements perpendicular to each other; the malalignment is obvious in the tracing.

COMPOSITE PHANTOM

A single tomographic exposure through the midplane of the composite phantom brings into focus 5 test patterns on one film or singly, if desired, by blocking out the other patterns with lead shields (Fig. 1, *A* and *B*). The first pattern is designed to measure section thickness (Fig. 1*A*). It has been previously described in detail[1] and consists only of 2 inclined copper wires, one inclined through a depth of 1.0 cm. to measure millimeter increments and the other through a depth of 5.0 cm. to measure 1.0 cm. increments. The inclined wires are adjacent to x-ray rulers, measuring in millimeters and centimeters. This pattern permits the direct reading of section thickness, allows one to examine the accuracy of the level indicator, and the exactitude of the section intervals. The magnification factor and the constancy of the geometry can also be examined from this pattern. Focal plane thickness is read directly as the amount of

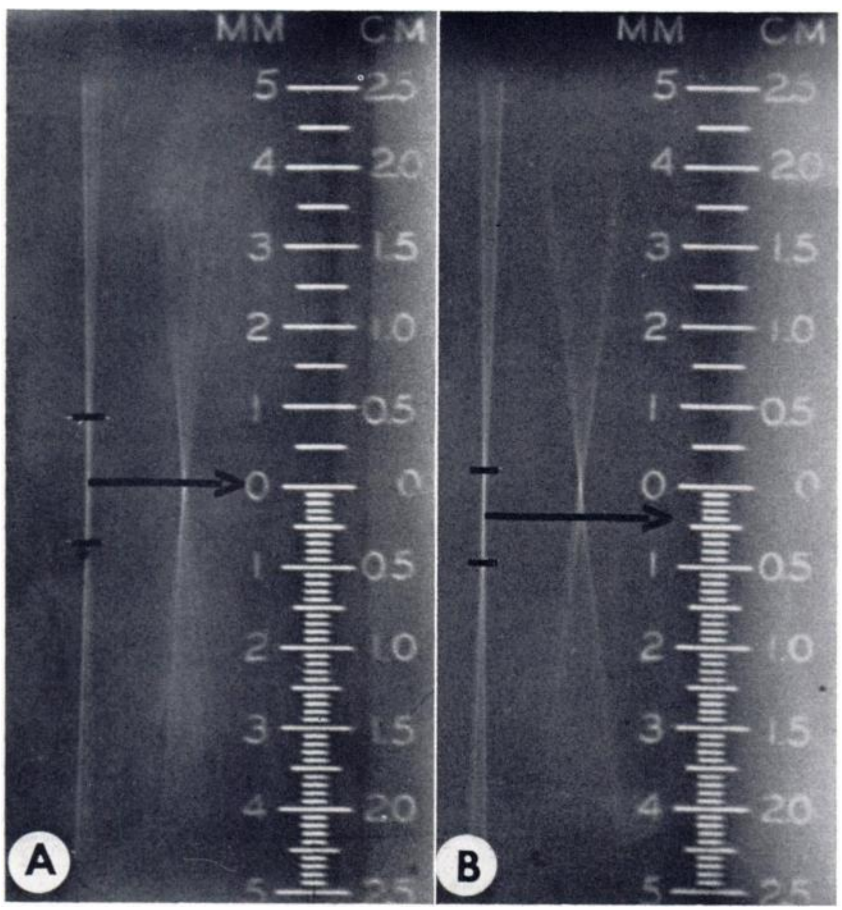

Fig. 10. (*A* and *B*) Interval thickness test pattern illustrates a change in the center of the focal plane when switching from a large spiral movement (*A*) to a small spiral (*B*).

wire that is in focus during the tomographic exposure. For example, in Figure 9, *A* and *B*, the wire in focus at *A* is measured with calipers and compared to the millimeter scale at *B* to indicate a section thickness of 1.8 mm. This same test pattern will allow one to detect a changing focal plane between 2 different tomographic movements. For example, in Figure 10, *A* and *B*, the focal plane level is seen to change almost 0.5 mm. between a small spiral movement (Fig. 10*A*) and a large spiral tomographic movement (Fig. 10*B*). Geometric distortion of the focal plane image will also become apparent in this test pattern. Figure 11*A* represents an exposure made with a 30° circular tomographic movement. When this angle is increased to 60° (Fig. 11*B*) the geometric distortion becomes so great that no image is formed in the focal plane. Notice that the wire is not clearly in focus anywhere through the intended focal plane; hence, this device at this circular movement could never produce a clear tomographic picture.

The second portion of the phantom consists of 2 identical patterns of 10/1,000 inch copper wire arranged in arcs and radii (Fig. 1*B*). This phantom is also described in numerous previous communications.[2-4] One of the 2 identical patterns is located in the plane of focus and the other 5 mm. above the focal plane. The first pattern represents a picture of the focal plane and the second represents the blur from any element layer outside the focal plane. The picture and the blur are, therefore, separated for purposes of examination. From this test pattern one can examine the form of the blur and predict its effectiveness (Fig. 12, *A–E*) as well as to visualize the sharpness of the focal plane image. Figure 13, *A* and *B*, illustrates the blur pattern produced by an 18° open circle which was provided by the manufacturer to simulate a linear movement at high speed. The blur

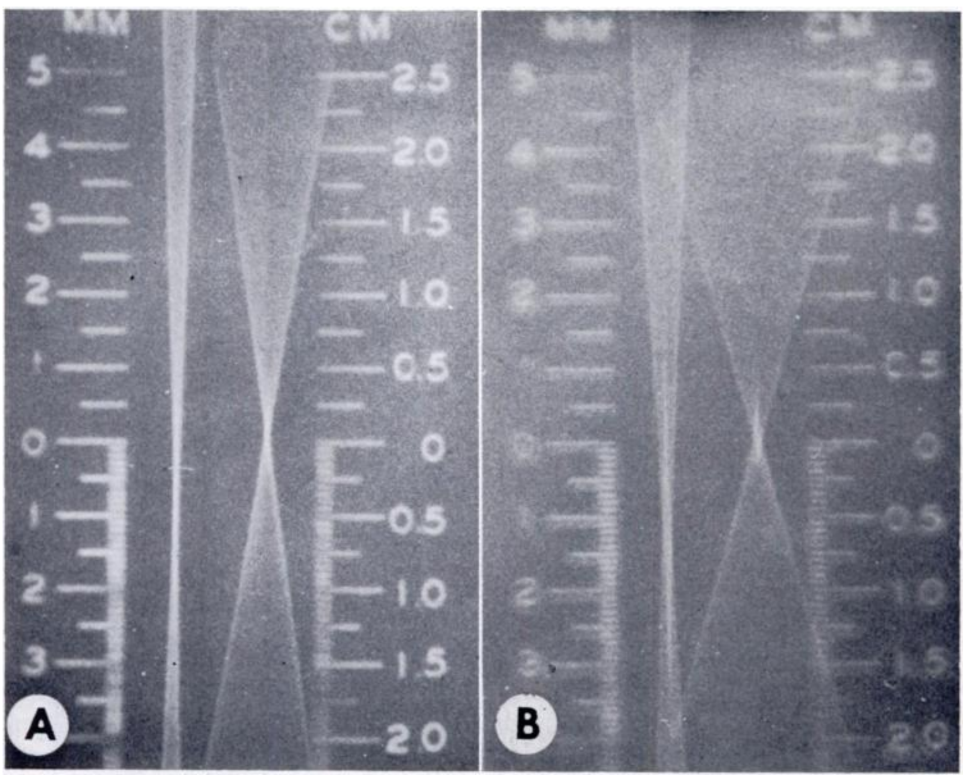

FIG. 11. (*A*) Interval thickness test pattern with a 30° circular blurring movement. Increasing the angle to 60° (*B*) produces sufficient geometric distortion to blur the entire focal plane. No clear focal plane image can be identified.

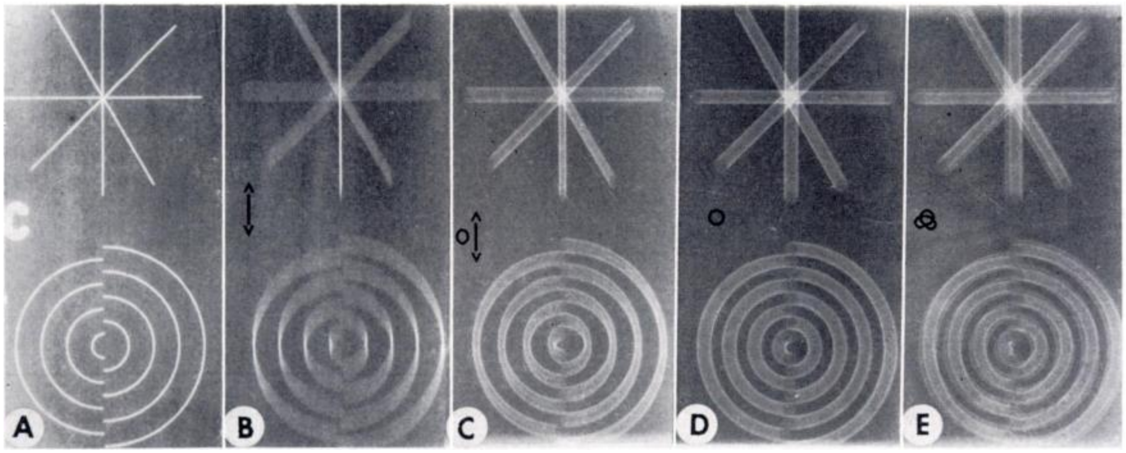

Fig. 12. (*A–E*) Wire pattern to illustrate a clear focal plane image at *A* and the blurring characteristics of 4 tomographic movements: (*B*) linear, (*C*) elliptical, (*D*) circular, and (*E*) hypocycloid.

pattern, however, is that of an ellipse rather than a linear movement. The blur pattern of a large spiral movement such as we noted in Figure 6*A* will resemble a circle more closely than a true spiral movement, so that we may expect the blurring characteristics of the circle rather than a spiral.

The next test pattern consists of 3 strips of wire mesh having 20, 30 and 50 lines per inch respectively (Fig. 14, *A–C*); each strip is inclined at an angle of 7°. The focal plane image through the center of the strips permits an evaluation of resolution. A good device should resolve 50 lines per inch (Fig. 14*C*). In addition, false image formation can be detected by the recurrence of the screen pattern above and below the focal plane.

The completeness of the marginal occurrences of the beam and, therefore, the accuracy of the roentgen record of the focal plane image can be assessed from the next test pattern (Fig. 15, *A* and *B*) which represents one radius of a phantom previously described by Stieve.[5] Nine small copper wires (4 on either side) are inclined from a center wire, which is perpendicular to the x-ray beam, at 5° increments to a total of 20° inclination for the peripheral wire. Tomograms through the midsection of each wire should, therefore, produce a circular pattern for the central wire and an oval pattern for the inclined wires. A linear section, Figure 15*B* for example, would not produce a complete picture of this wire, inasmuch as there is not a great enough direction change of the obscuring movement to provide marginal occurrences of the x-ray beam with the entire periphery of the wire. A compound movement would produce a better picture, as shown in Figure 15*A*.

Although I am certain that plastic and wire test patterns allow one to reliably predict the effectiveness of a tomographic device and its obscuring movement, the radiologist is primarily concerned with the quality of the tomograms of human tissue. For this reason, the final test pattern in this phantom consists of the head and proximal shaft of a human humerus, the midplane of which is removable and contains a simulated lesion in the spongiosa of the bone (Fig. 1*B*). The tomogram can, therefore, be compared with a conventional roentgenogram of the simulated lytic lesion and the quality and accuracy of the tomogram compared with the actual appearance of the lesion.

DISCUSSION

The radiologist in his search for a new tomographic device needs some standard of comparison when reviewing different units produced by different manufacturers. He needs to be concerned about the geo-

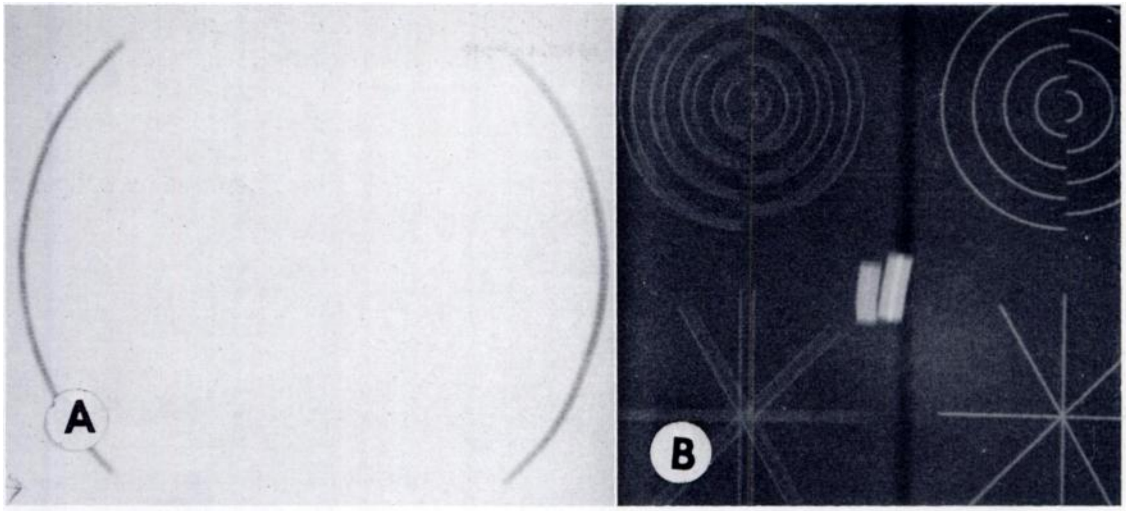

Fig. 13. (*A*) Tracing of 18° "open-circle" designed to simulate a linear movement. Blurring characteristics (*B*), however, resemble an ellipse.

metric form of the obscuring movements provided, the effectiveness of the blur produced by these movements, the mechanical stability of the unit, the size of the focal spot and all of the other factors which affect the sharpness of the focal plane image. Tomograms of the skull made by a distinguished colleague using a particular apparatus does not provide sufficient information to permit an intelligent comparison. Clinical tomograms can be compared only with tomograms that any radiologist might

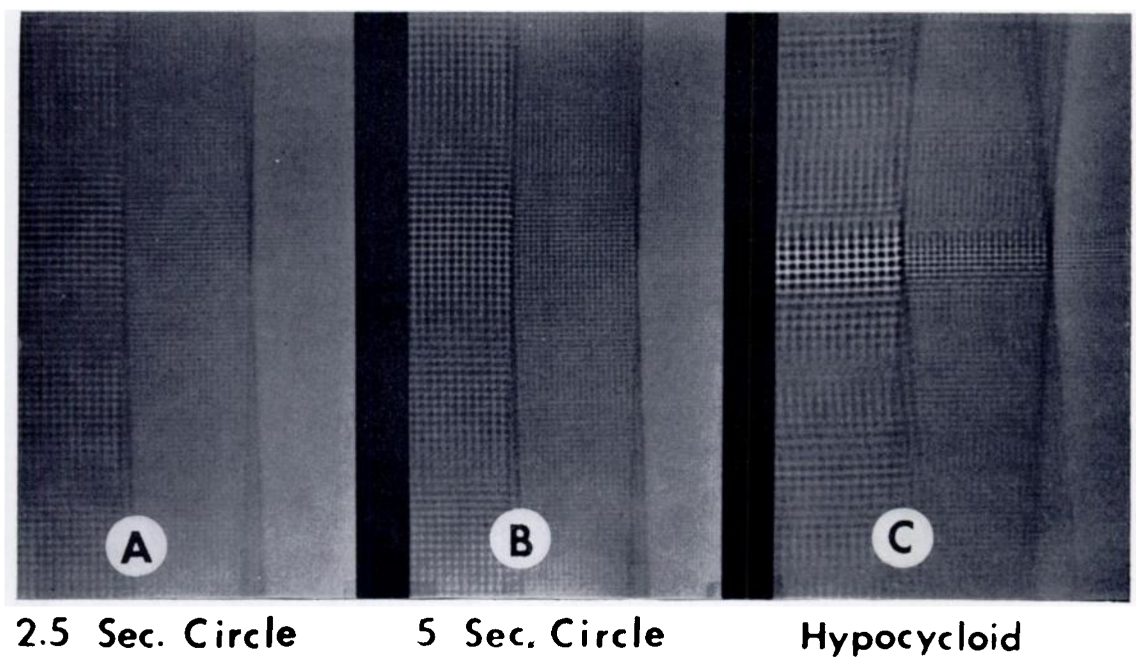

Fig. 14. (*A–C*) Wire mesh pattern to examine the resolution of a tomographic movement. (*A*) High speed circular movement with significant unwanted motion. No clear focal plane image is seen. (*B*) Same movement at slower speed with improved resolution. (*C*) Compound movement showing excellent resolution to 50 lines per inch.

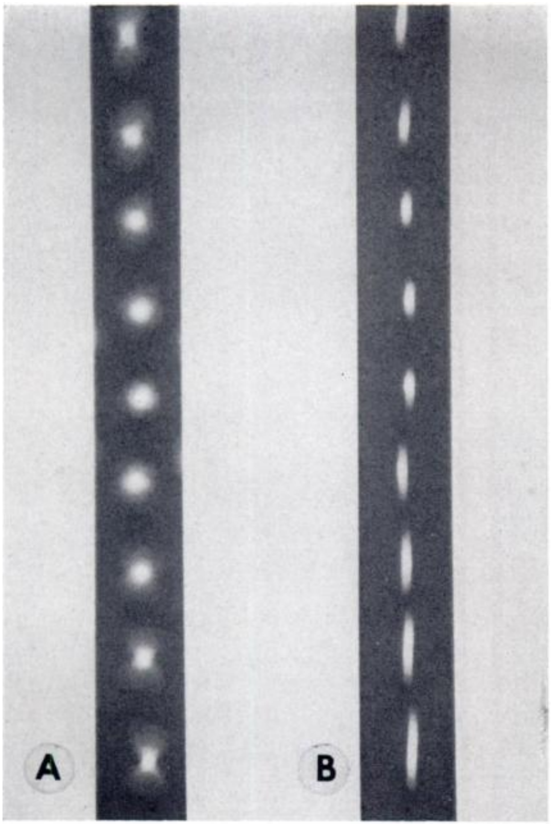

Fig. 15. (*A* and *B*) Stieve test pattern showing incomplete marginal occurrences of x-ray beam with hypocycloid movement (*A*) and incomplete tangential occurrences with linear movement (*B*).

have seen in the past. Perhaps this radiologist has never seen a good one. A standard series of tomograms on a standard phantom, however, does provide a precise and exact method of comparison between different devices. Experience gained from testing 5 different units by 5 different manufacturers indicates that this phantom technique does provide a reliable estimate of the quality of the clinical tomogram. In addition, once the radiologist has chosen his tomographic device he needs some way of monitoring its performance during its useful life. A phantom technique lends itself very readily for this purpose.

SUMMARY

The physical properties of a tomographic device which affect the clinical tomogram can be readily examined and evaluated with phantom techniques consisting of a lead diaphragm with a 3 mm. pin hole and a compound phantom containing 5 test objects.

The technique for using these phantoms and their effectiveness are described.

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