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Quantification of the Respiratory Motion Artifact in Radioisotope Scanning with the Rectilinear Focused Collimator Scanner and the Gamma Scintillation Camera[1,2,3]

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Although liver scanning has gained world-wide acceptance as a useful clinical technique in the past decade, and although almost every viewer of liver scans—from technician to physician—recognizes the edge distortion caused by respiration, this motion artifact has been almost universally ignored. The present communication re-emphasizes the distortion caused by respiratory motion and points out that if the problem is not solved, much of the advantage gained by sophisticated imaging and improved count rates will be lost when moving organs are examined.

MATERIALS AND METHODS

In order to simulate respiration, a special platform was constructed to hold the radioactive target. The essential feature of this device consisted of a variable-speed motor driving a rotating arm attached to a handle on a moving platform. The arm-handle combination could be adjusted to various lengths, thus controlling the excursion of the platform.

The phanton was imaged by three different instruments:

1) A conventional Picker Magnascanner: NaI crystal 3″ × 2″; collimator 19 holes, 3″ long, focal length 3½″, diameter of field of view in focal plane 1.17″.

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[3]Presented at the 12th Annual Meeting of the Society of Nuclear Medicine, Bal Harbour, Florida, June, 1965.

2) A custom-built, rectilinear scanner with electronics by Beck and Charleston (1): scanning speeds up to 400 cm/min; NaI crystal 2″ × ¼″ collimator designed for high resolution at 140 keV, 253 holes, 1.375″ long, focal length 2½″, diameter of field of view in focal plane 0.44″.

3) A Nuclear-Chicago gamma-scintillation camera: NaI crystal 11″ × ½″; multi-aperture collimator 3″ long, 1039 round, parallel holes 0.24″ D. in a hexagonal array inscribed in the 11″ circle.

All studies were done with technetium-99m. The count rates and scan speeds were adjusted so that total counts accumulated for comparable areas imaged were kept constant. The counts accumulated for all studies were normalized to those obtained from the phantom under conventional scanning conditions using the 19-hole collimator (about 175,000 counts). Even though the phantom has rays ten inches long, the scans included only the *tip* (*i.e.* the high frequency end) and adjacent six to seven inches. This was done so that the same area could be used with the scintillation camera without introducing the edge distortion artifacts seen when the useful eight-to-nine inch field of view of the camera is exceeded. A two inch layer of scattering material (unit density Prestwood) was placed over the phantom for all studies. All rectilinear scans were made at the *focal point* of the collimator used.

The experiment was designed to simulate clinical rectilinear scanning conditions and thus was not optimal for the gamma camera. Specifically, the total counts accumulated were low, the collimator-to-phantom distance, over two inches, was somewhat long, and the collimator used, the three inch multiaperture collimator, was designed for higher energies than 140 keV. It should be pointed out that the exposure time needed to obtain 175,000 counts with the camera was 1/60th of the time necessary for the high resolution scans when the phantom contained an equal dose of isotope.

The Siemens sine-wave phantom used, shaped like a slice of pie, has a central angle of 90°. Accordingly, for each situation studied, two scans were made— one with the central axis of the phantom, *i.e.*, the central ray running from the pointed tip to the curved edge, parallel with the direction of simulated respirations, and the other with the central axis perpendicular to the direction of motion. By placing these two scans adjacent to each other, a composite 180° figure was formed that included the maximum and minimum distortion caused by motion.

Only normal resting respiratory motion was investigated, since the studies were made with a simulated respiration rate of 16 breaths per minute and with a respiration depth of 1.5 cm. This is comparable to a patient lying quietly in the supine position, breathing easily.

Evaluation of the scans is admittedly subjective, but every study was viewed by several observers and the agreement between them was good. Each observer was asked to find the end-point resolution, which was defined as that point on the scan at which the sunburst pattern was obliterated, *i.e.*, the point at which the distinction between active and inactive areas was no longer possible. The end point resolution was recorded in two ways: First, in terms of lines per centimeter—a manifestation of the *frequency* of the isotope containing rays. This frequency increases as the central point of the phantom is approached, and second, as the inverse of the end point resolution frequency, that is, the *distance between*

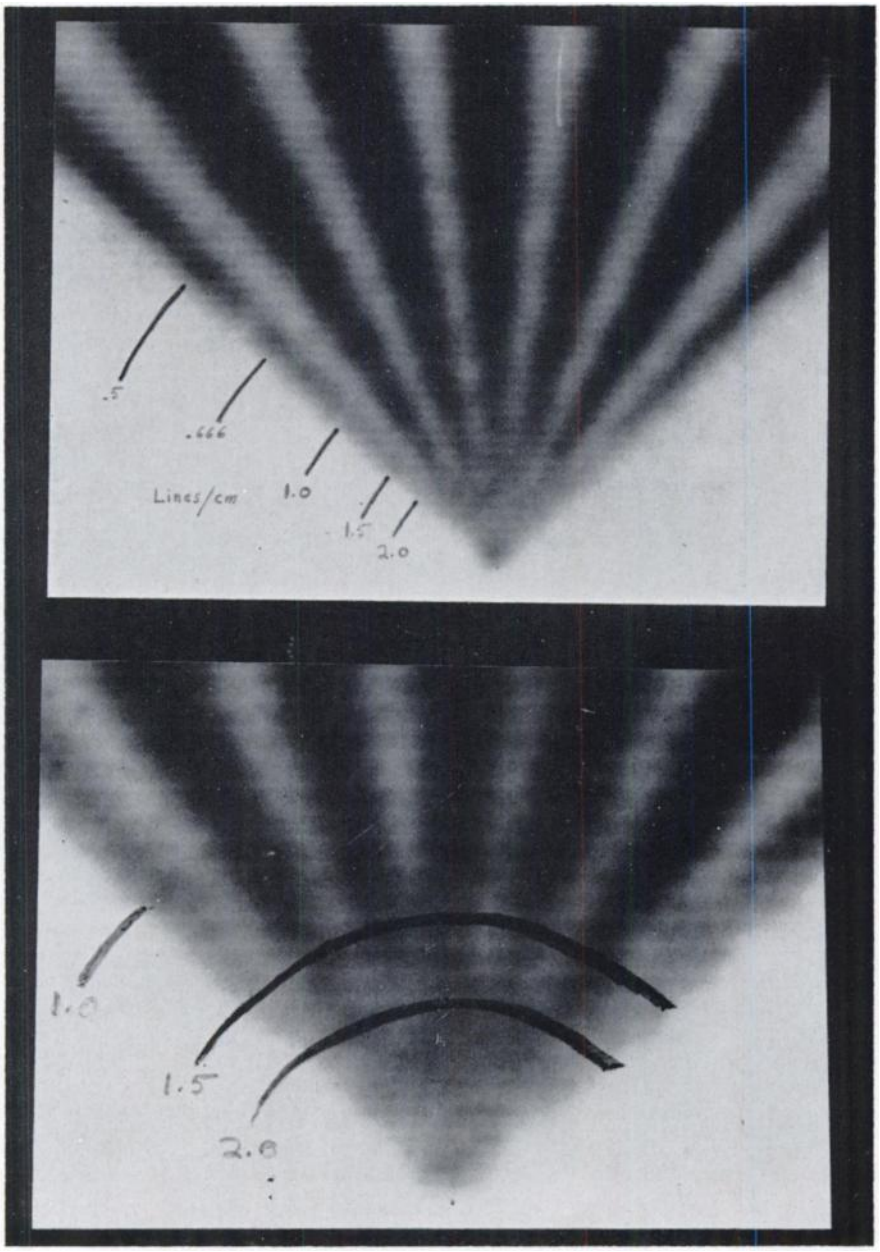

Fig. 1. ***Top:*** **Scan of the Siemens star phantom with no motion, using the high resolution scanning system. The numbers at the left indicate the frequency of the rays in lines/cm.** ***Bottom:*** **Magnified view of the high-frequency region. The end-point resolution is seen to lie between 1.5 and 2.0 lines/cm. Above the end-point frequency the sunburst pattern is distorted beyond recognition.**

active areas at the end point. The resolution distances were then compared to calculate the relative change caused by motion.

Four systems were tested. The first was the conventional three-inch scanner with a 19-hole collimator at a speed of 60 cm/minute. The second was the high resolution 253-hole collimator with variable-speed scanner at a speed of 100 cm/minute. The third was the high-resolution 253-hole collimator with variable-speed scanner at a speed of 400 cm/minute. The fourth was the scintillation camera with three-inch multiaperture collimator. The results of these studies are given in Table I and illustrated in Figures 1 through 5.

DISCUSSION

The respiratory motion artifact is clearly accentuated most by the high-resolution scanning system. This result has been empirically obvious previously, and led Harper to block the right phrenic nerve in an effort to avoid motion entirely (3).

It is also of interest to compare the scans made by the high-resolution technetium collimator and the 19-hole collimator when no motion is present (Fig. 2).

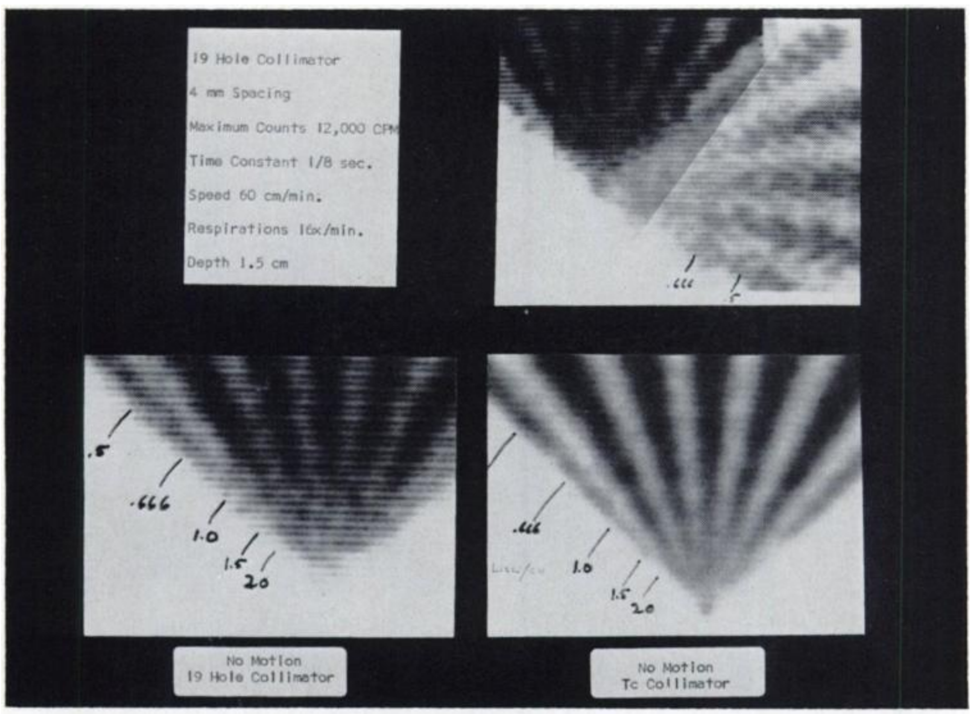

Fig. 2. ***Top-right:*** **Composite scan. The scans are purposely developed under slightly different conditions to illustrate the technique. The darker (top) scan represents the scan oriented parallel to the direction of motion. The lighter scan (on the right side) has the phantom oriented perpendicular to the direction of motion. The numbers at the bottom are frequencies in lines/cm.** ***Bottom:*** **Motionless scans of the Siemens star phantom to show the superior result obtained by the high-resolution scanner-collimator system compared to the conventional three-inch Magnascanner with 19-hole collimator.**

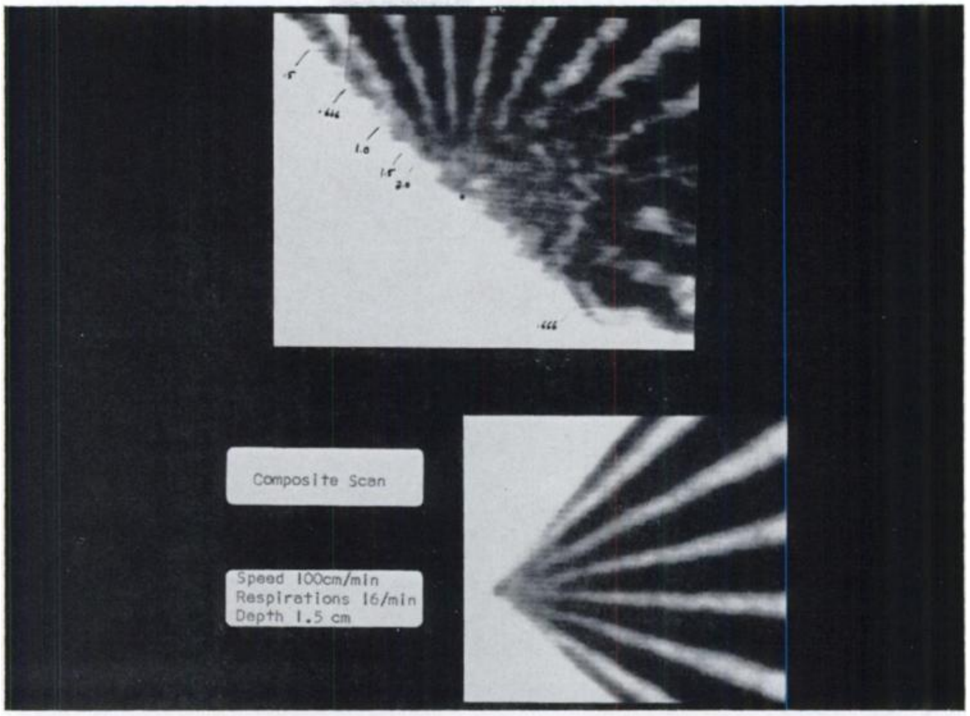

Fig. 3. *Top:* Composite scan with frequencies indicated in lines/cm. The direction of motion is along the vertical axis. The 253-hole collimator, high-resolution system was used. *Bottom:* Motionless scan for comparison.

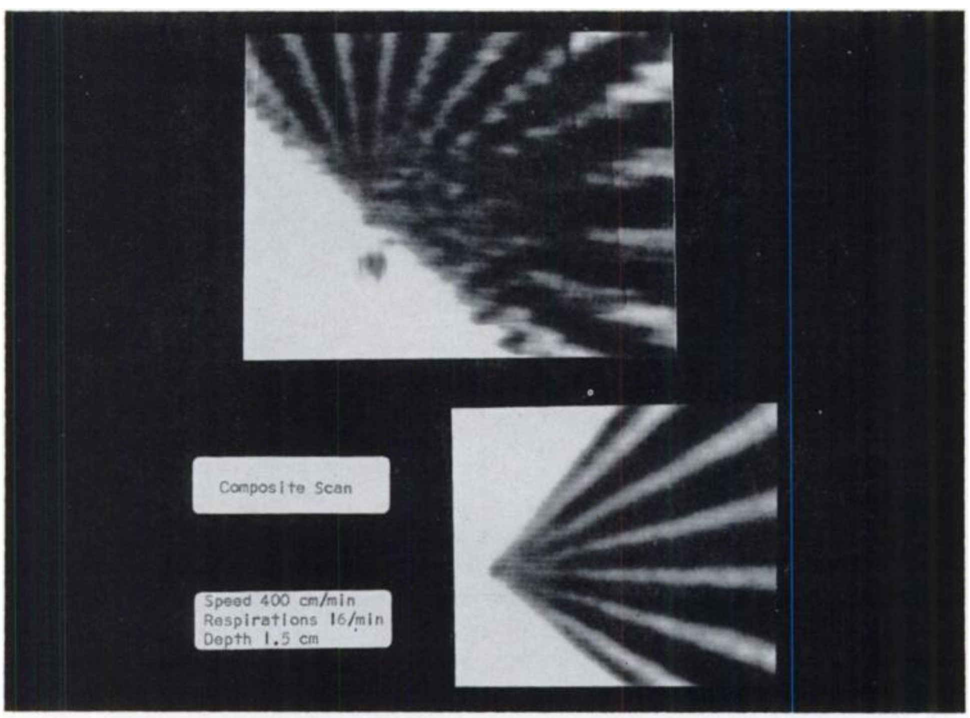

Fig. 4. The same as Fig. 3 except that the scan speed was increased from 100 cm/minute to 400 cm/minute.

In addition to the high resolution provided by the technetium collimator, note that the inactive areas project much better.

Since the results clearly demonstrate that respiratory motion creates a severe resolution loss during radioisotope scanning, some attempts have been made to solve this problem. Because the motion artifact is not demonstrable in the portion of the phantom running parallel to the direction of respiration, a liver scan was made with the scanner moving along the patient's vertical axis. This was compared with the usual horizontal liver scan. This result is demonstrated in Figure 6. It is evident that, if anything, the motion artifact is made worse by this maneuver. A possible explanation is that the frequency of indexing and the effect of scalloping produced by the scanner are superimposed on the frequency of respiration. This accentuates both the technical and physiological artifacts.

We have made another approach utilizing the scintillation camera. In liver scintiphotography with ^{99m}Tc sulfur colloid, the agent regularly used at this institution, 300,000 to 400,000 dots are routinely collected per view. With the collimators available, this takes about one minute or less per exposure when a 2-3 mC dose is used. Consequently, an excellent scintiphotograph can be obtained with the patient holding his breath. It is not difficult, even for a very ill patient, to hold his breath for 15 to 30 seconds and, of course, some patients can go without breathing for longer periods. The scintiphotograph is exposed during the

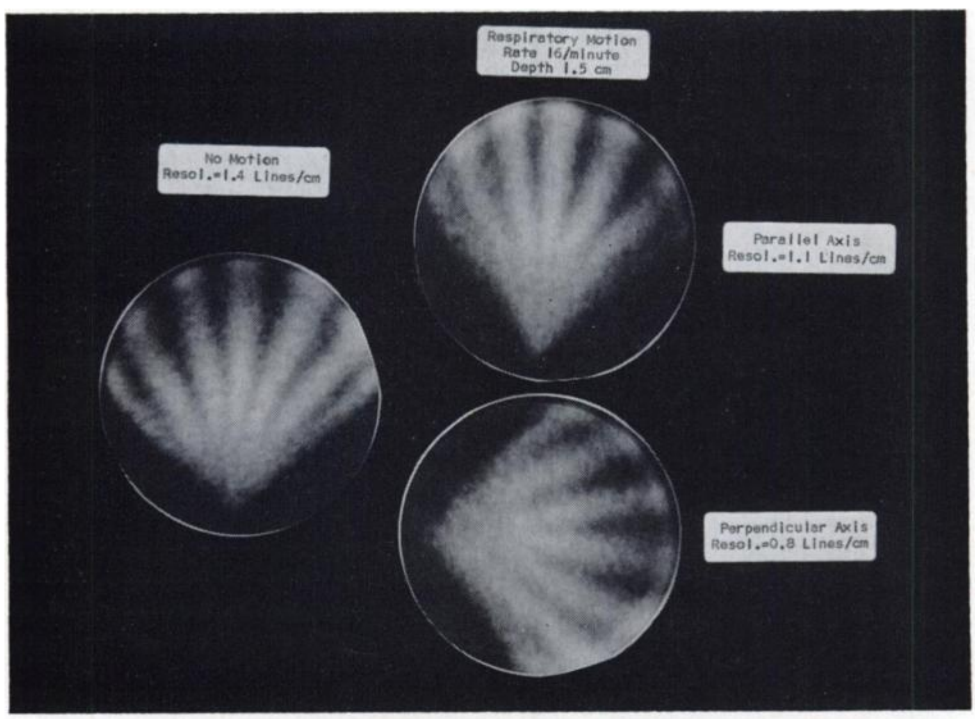

Fig. 5. The Siemens star phantom imaged with and without motion by the gamma scintillation camera. Although the read-out is minified, the phantom is readily calibrated by placing point sources of isotope over the *cold rays* at known distances from the point of the phantom.

episode of breath-holding. By a hand signal, the patient signifies that he wishes to breathe again and the exposure is stopped. The patient then breathes until he feels comfortable and is again asked to hold his breath, returning to the previous position of respiration. At this point the exposure is continued. The process

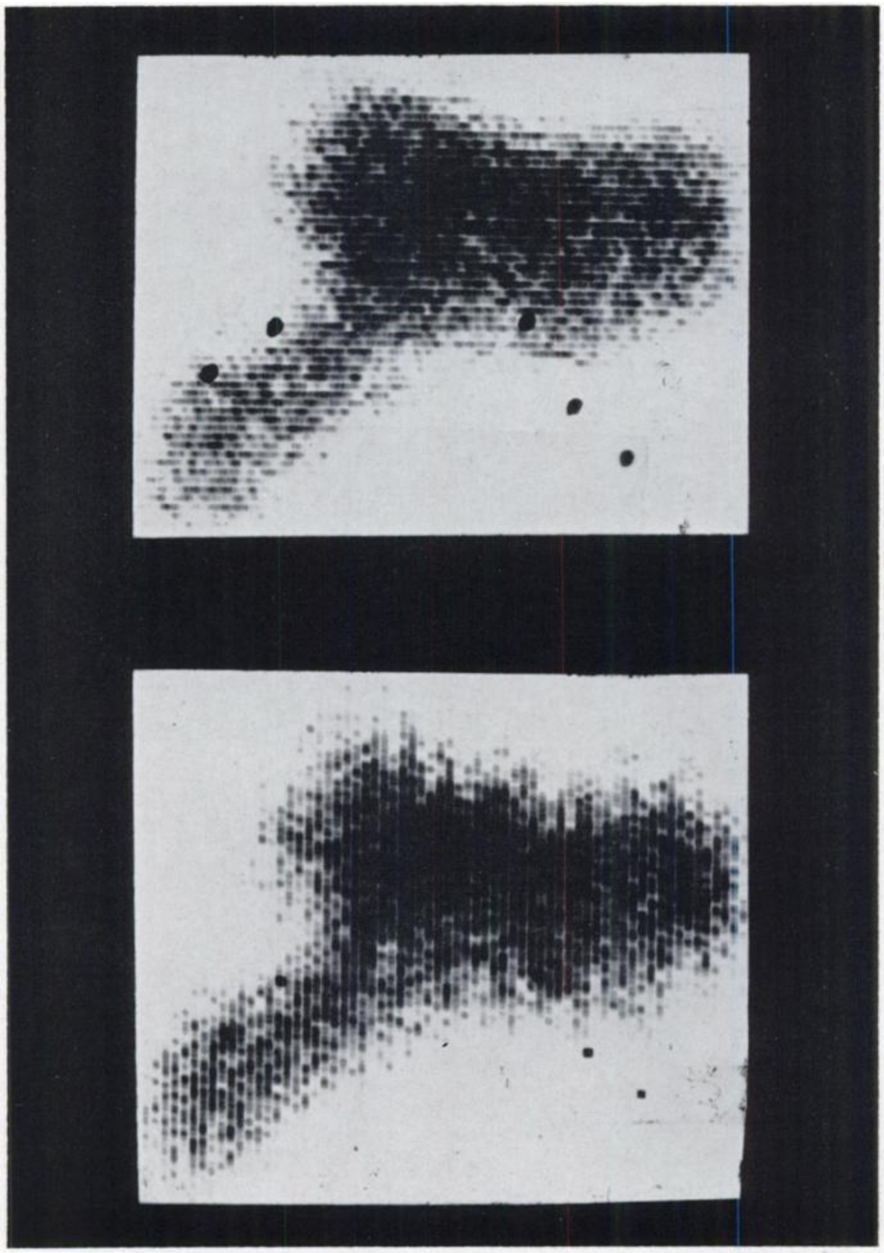

Fig. 6. ***Top:*** **Conventional liver scan with a large lesion in the lateral aspect of the right lobe. The motion artifact is obvious. It is particularly prominent over the superior aspect of the liver.** ***Bottom:*** **The same patient with the scan directed vertically. The motion artifact is accentuated even more.**

is repeated until sufficient counts are accumulated, and a scintiphotograph with *suspended respiration* is achieved (4). An example of this technique is illustrated in Figure 7. This method could be extended in the near future by electronically correlating exposure intervals with organ dynamics; for example, the ECG could be used to regulate heart scintiphotography.

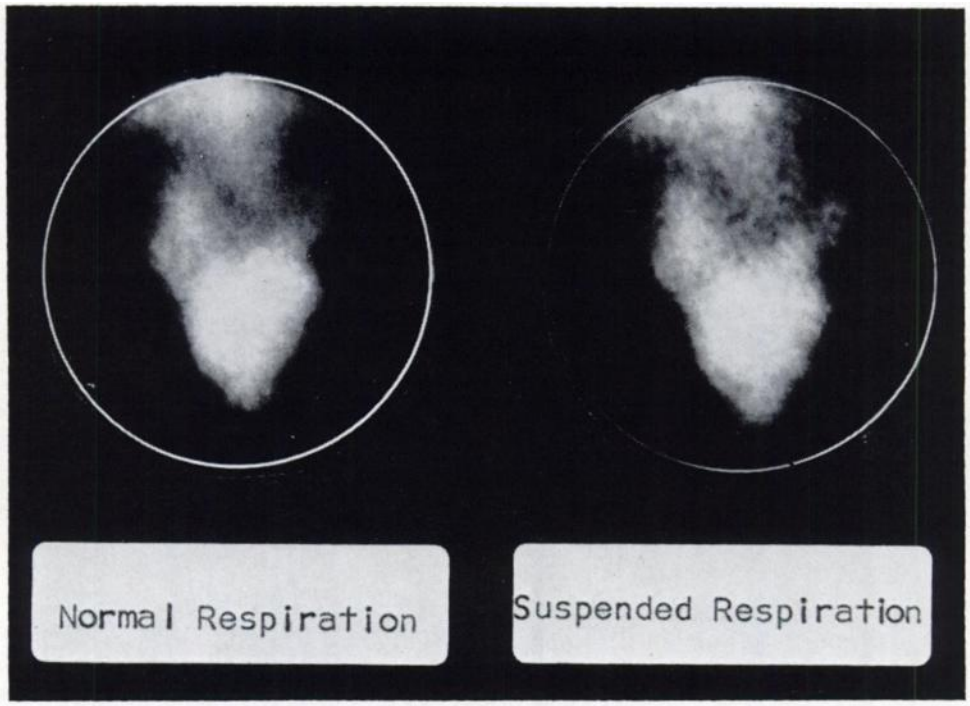

Fig. 7. Scintillation-camera views of the inferior margin of the right lobe of a liver containing widespread metastases. With respiration, several small lesions on the edge of the liver are almost obscured. When respiration is suspended, they are easily identified.

CONCLUSIONS

1. Quantitative studies with phantoms indicate that respiratory motion *doubles* the resolution distance for the gamma camera and conventional scanner, and *triples* the distance for the high-resolution scanning system.

2. The resolution (centimeters per line) of the moving phantom is best with the gamma camera; less good with the high-resolution scanning system; and worst with a conventional scanner and 19-hole collimator.

3. High-speed scanning does not appear to affect the resolution distance but seems to improve the appearance of the scan during simulated respiration.

4. "Stop motion" liver scintiphotographs are feasible and provide a means of avoiding respiratory motion altogether.

5. Respiratory motion is responsible for a significant loss of resolution in lung, liver, and spleen scans, and should not be ignored. It is hoped that these studies will aid in directing other investigators to a consideration of this important problem.

TABLE I
RESULTS OF THE FOUR MOTION STUDY EXPERIMENTS

Technique	Type of Motion	Resolution Lines/cm	Resolution cm/Line	Relative Resolution Loss[1]
Scan with 19-hole collimator	NONE	1.20	0.83	(1.0)
	Parallel	1.20	0.83	1.0
Speed 60 cm per minute	Perpendicular	0.55	1.82	2.2
Scan with 253-hole collimator	NONE	1.75	0.57	(1.0)
	Parallel	1.50	0.67	1.2
Speed 100 cm per minute	Perpendicular	0.60	1.67	2.9
Scan with 253-hole collimator	NONE	1.75	0.57	(1.0)
	Parallel	1.50	0.67	1.2
Speed 400 cm per minute	Perpendicular	0.60	1.67	2.9
Scintillation camera	NONE	1.4	0.71	(1.0)
with 3-inch, multi-	Parallel	1.1	0.91	1.3
aperture collimator	Perpendicular	0.8	1.25	1.8

[1]Represents the magnitude of *Resolution Loss* when the motion scans are compared to the motionless scan, which is considered to be 1.0.

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