Rectilinear Bone Scanning Techniques

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Rectilinear bone scans should present enough data to identify or exclude bone disease. An adequate count density based on a predefined survey area, and a thorough understanding of display factors (contrast enhancement, background subtraction, minification), is necessary for consistent results. Recognition of disease in the survey area and an alternate technique based on normally expected counting rates permit accurate assessment of change when studies are repeated at intervals. A technique is described which avoids artifactual distortion due to improper application of display factors and accurately defines extent of bone disease when the usual survey area is abnormal.

The availability of phosphate compounds easily labeled with ^{99m}Tc *(1)* and the application of image reduction *(2)* have made total-body bone scanning a common procedure in nuclear medicine laboratories. Two factors largely determine scan image quality and thus detectability of lesions in bone: study information content and display factors *(3)*. Although information density is a familiar concept, the choice of a counting rate to determine scan speed to yield a desired information density is not a straightforward problem in bone scanning. Display alterations by image contrast enhancement or background subtraction produce important image distortions which must be understood and appreciated if they are to be applied correctly. Additionally, it is important to consider factors which artifactually appear to alter scan appearance when repeated studies are done in the same patient. This presentation reviews these aspects of bone imaging and illustrates the problems involved. The scope is limited to the use of focused-collimator, dual-detector scanners employing image minification.

Methods

Bone scans were obtained approximately 3 h after the iv administration of 15 mCi of ^{99m}Tc-pyrophosphate (Mallinckrodt, St. Louis). Studies were performed on an Ohio Nuclear model 84 dual 5-in. detector scanner utilizing 24L low-energy collimators. A count density of 360 counts/cm^2 was required at a predetermined survey area using a 1/8-in. line spacing to determine scan speed. Patients were surveyed for counting rates over the sternum and anterior chest and over the cervical, thoracic, and lumbar spine to determine a "setup" counting rate. Observed counting rates normally ranged between 40,000 to 60,000 counts/min over the sternum and 50,000 to 70,000 counts/min over the thoracic spine. The highest thoracic spine counting rate was used to determine other scan parameters, unless that counting rate exceeded 70,000 counts/min. At that value it was assumed that the spine was diseased, and 70,000 counts/min was arbitrarily chosen as the "setup" counting rate. A background subtraction of about 15% (setting 3 on the Ohio Nuclear 84 scanner) was employed. This required depression of the picture intensity control (PIC) at identical counting rates for both detectors, which is most easily accomplished by the use of a signal generator. The signal generator eliminates statistical fluctuation in the counting rate, unavoidably present when a radioactive source is used as the PIC source (Fig. 1). The "setup" counting rate as determined above was introduced into the discriminators of the scanner and the PICs were depressed. Image minification of 5:1 was employed.

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Results and Discussion

Count density (C.D.). Information content of the bone scan is determined by scan speed, line spacing, and observed counting rates:

$$\text{C.D.} = \text{counting rate (cm/min)} \times \frac{1}{\text{speed (cm/min)}} \times \frac{1}{\text{line spacing (cm)}}. \quad (1)$$

Adequate information must be acquired in order to assemble a coherent image. For a fixed radiopharmaceutical dose, information content and image coherence can be increased by decreasing the scan speed. Information content should be adequate to identify lesions when present, but it is not helpful to spend more time than necessary (Fig. 2). In Fig. 2(A), 360 counts/cm^2 were collected from the thoracic spine. Bone definition is good and the liklihood of missing lesions is remote. In Fig. 2(B), 700 counts/cm^2 were collected from the thoracic spine. Bone definition is only slightly improved, but the scan took twice as long to complete. In order to ensure the desired information collection, a surveyed

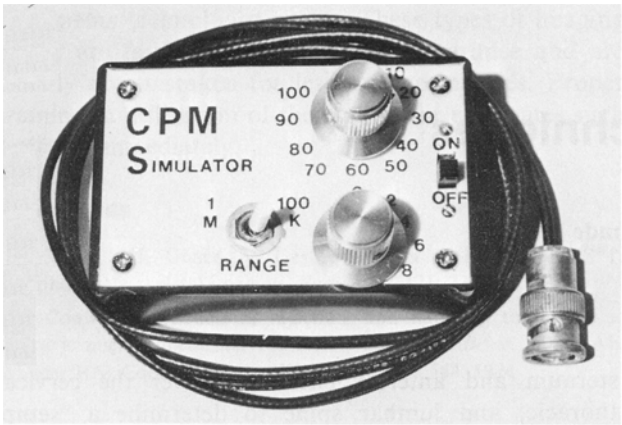

FIG. 1. Counts per minute simulator (Lintronics Industries, Inc., Cleveland, OH).

counting rate from some area in the normal skeleton is arbitrarily chosen. We have used the thoracic spine counting rate to determine other scanning parameters. Scan parameters should not be determined by using the counting rate from a "hot spot" in the spine, and recognition of disease is important at the time the spine is surveyed. In order to avoid a lower than desired count density from the remainder of the skeleton, it is necessary to know what the normal expected counting rates are. If higher than expected counts are seen throughout the preselected survey area, parameters for a more normal counting rate should be chosen. Figure 3 illustrates a scan setup over a "hot spot" in the spine.

Note that Eq. 1 does not include a factor for minification. Scan information content is not increased by display manipulations, including minification. The information present may be distorted by contrast enhancement, and the lower counting rate areas may be discarded by background subtraction.

Display factors. *Contrast enhancement.* Contrast enhancement means the imposition of a nonlinear relationship between film blackness and counting rate (Fig. 4.) In addition, lower counting rates are not recorded. This technique is advantageous in portraying "hot" lesions against a "cold" background in rectilinear brain scanning. The enhanced bone scan, however, presents some interpretive problems. The skeleton, unlike the brain, is seen as areas of normal activity. There are normally accentuated areas, such as the sacroiliac joints and scapular tips, and normally fainter-activity areas, such as extremity bones. The enhanced bone scan (Fig. 5) accentuates the areas of higher counting rates—the spine and pelvis—while the lower counting rate areas—the ribs and extremities—are seen faintly, if at all. Differences and interpretive problems are accentuated in scans of patients with widespread disease (Fig. 5). The identification of diffuse spine and pelvic involvement is virtually impossible when contrast enhancement is used *(4)*. The possibility exists that minimal lesions in the extremities may be missed entirely. These considerations suggest that enhancement should not be employed in rectilinear bone scanning.

Background subtraction. Images from rectilinear scans normally include areas of film exposure which are located in nontarget areas. These include data recorded outside of the body, representing scattered photons or collimator septal penetration, and soft-tissue activity due to radiopharmaceutical located outside of the bone.

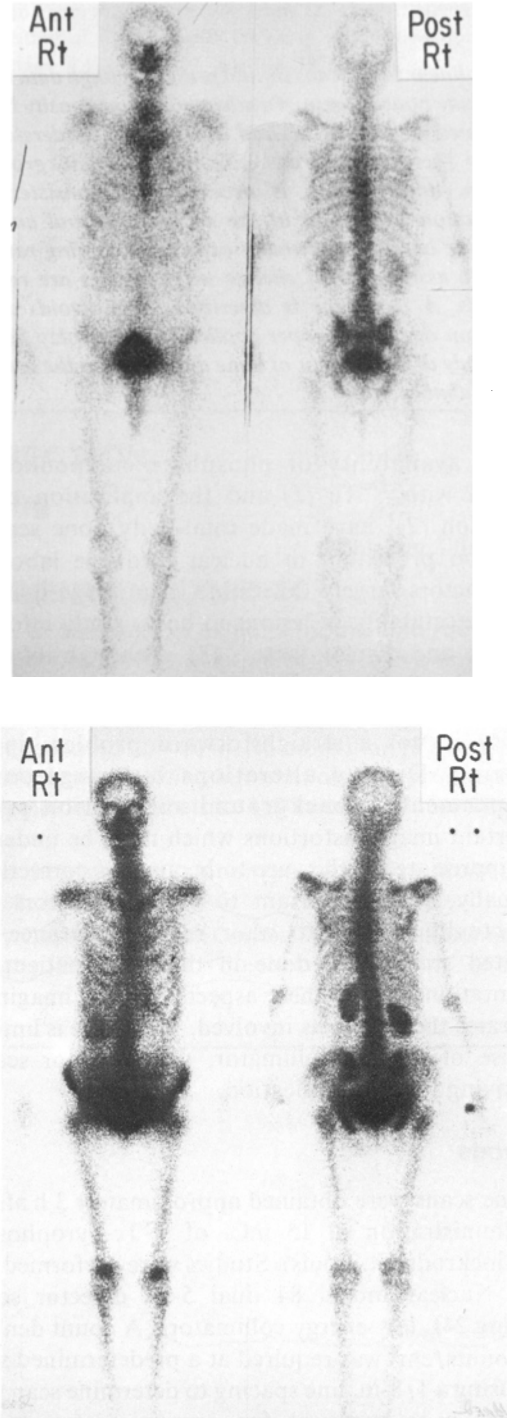

FIG. 2. (Top) Normal bone scan. Count density is 360 counts/cm² over thoracic spine. (Bottom) Normal bone scan. Count density is 700 counts/cm² over thoracic spine.

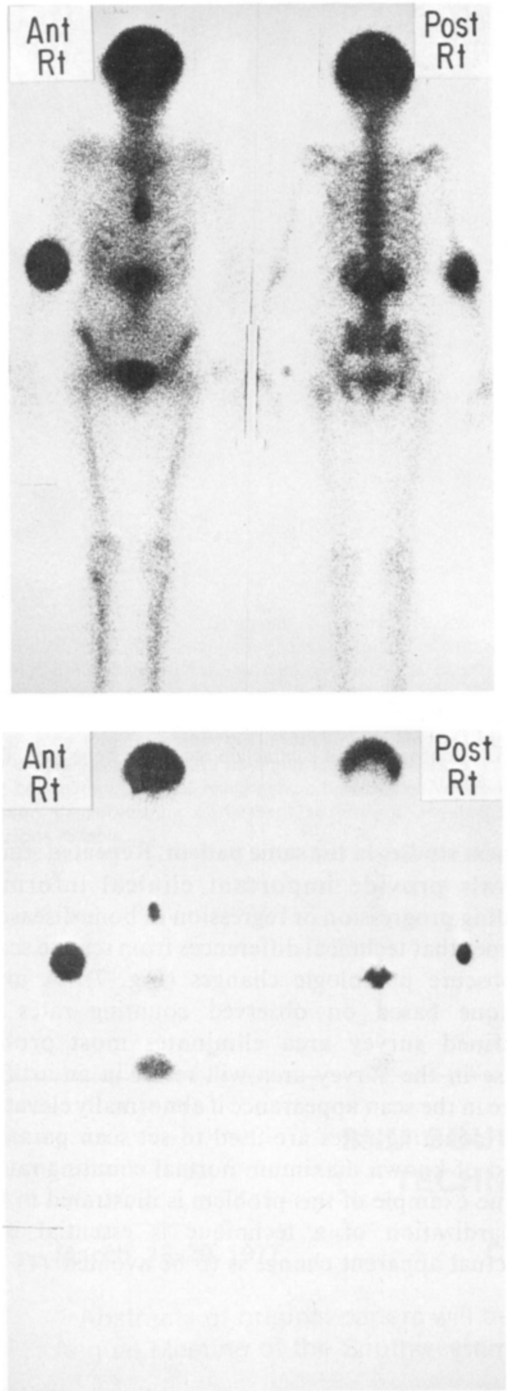

FIG. 3. Paget's disease in skull. Injection artifact (infiltration), right arm. Compression fracture in upper lumbar spine. Counting rate from this area was 240,000 counts/min. (Top) PIC depressed over 70,000 counts/min. (Bottom) PIC depressed over 240,000 counts/min. (Count density for these studies was 720 counts/cm².)

Several approaches are helpful in suppressing this nontarget information. Septal penetration can be reduced by improving collimator characteristics. Older Ohio Nuclear 24L collimators were designed with 151 holes; newer models have 127 holes with the same radius of resolution but about 30% less sensitivity at 140 keV. This decreased sensitivity is due to reduced septal penetration. Raising the spectrometer baseline will also eliminate some unwanted scattered photons *(5)*. Although either approach improves images significantly, counting rates are reduced, which results in longer scanning times. Image background subtraction results in nonrecording of the lower counting rates (Fig. 6). The higher counting rate data are recorded linearly and are not subjected to the distortion of contrast enhancement (Fig. 4). When employed at levels which suppress background counting rates but not areas of interest, the target areas may be displayed in slightly sharper contrast without loss of important information. Application of background subtraction levels which result in nonrecording of target areas must be avoided.

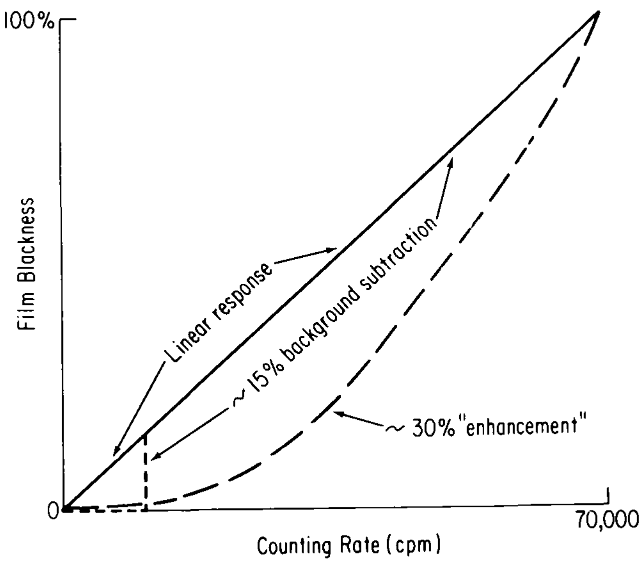

FIG. 4. Effects of contrast enhancement and background subtraction on film blackness response to increasing counting rate. Enhancement of nonlinear film response has been ignored.

PIC circuit. Application of either contrast enhancement or background suppression on the Ohio Nuclear model 84 dual-detector scanner involves setting maximum film blackness to correspond to a "setup" counting rate by depressing the PICs. The counting rate being recorded when the PICs are depressed is then portrayed as maximum blackness. Higher counting rates may be encountered, but will not be displayed as darker areas on the scan. This "PIC point" should be chosen in such a way as to allow for reproducibility from patient to patient and from study to study in the same patient. In older model 84s the time constant which averaged the PIC counting rate was relatively short, which resulted in unavoidable nonuniformity in the images. Newer model 84s have a longer time constant, and depression of the PIC for 30 s results in more uniformly normalized scans. The same PIC counting rates should be used for both detectors.

Setup considerations when PIC is not employed. Some counting rate must be chosen to determine the scan speed to yield the desired information content. This is then associated with an "intensity" setting (actually, duration in microseconds of the light flash) which determines how

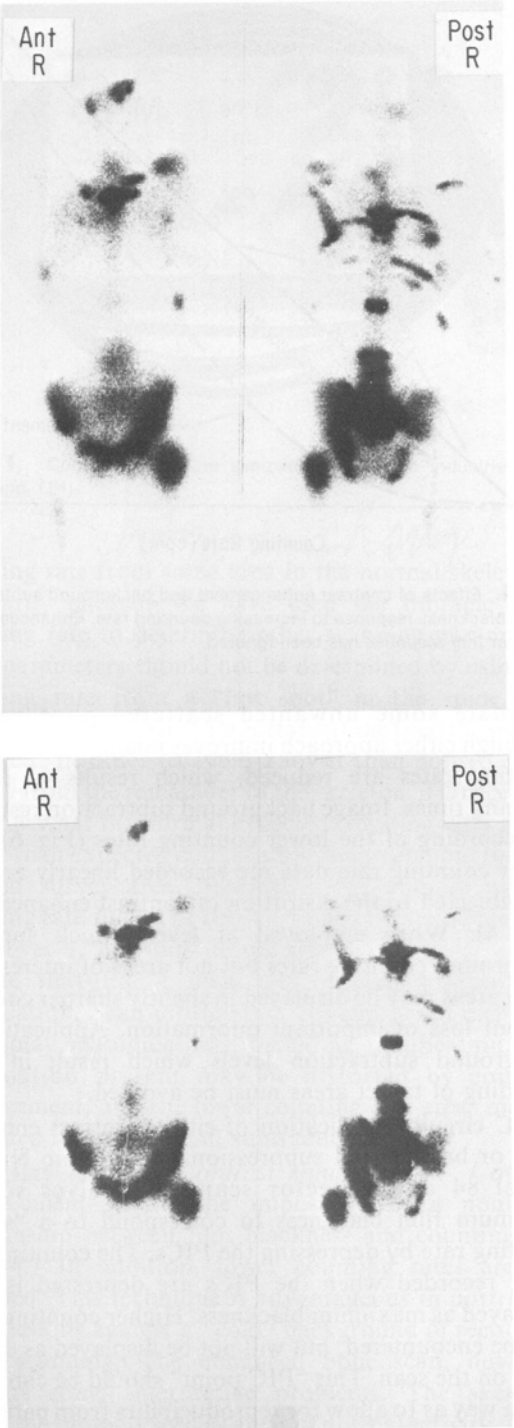

FIG. 5. Effects of contrast enhancement on rectilinear bone image. (Top) No enhancement. Scan parameters chosen as described in methods. PICs depressed over 70,000 counts/min. 200,000 counts/min observed from involved spine. (Bottom) Enhancement of 30% (setting 3 on Ohio Nuclear 84). Background erase is 0. All other parameters are same as on top.

dark the chosen counting rate will be represented on the film. This setup counting rate should be defined based on actual survey counting rates for the specified area. Higher than expected counting rates are presumptive evidence of involvement in the survey area by disease, and scan parameters should then be set for a predefined maximal normal counting rate.

FIG. 6. Nonbackground subtraction rectilinear bone scan. Contrast with Fig. 2(top).

Repeat studies in the same patient. Repeated studies at intervals provide important clinical information regarding progression or regression of bone disease. This presumes that technical differences from scan to scan will not obscure pathologic changes (Fig. 7). A uniform technique based on observed counting rates for a predefined survey area eliminates most problems. Disease in the survey area will result in an artifactual change in the scan appearance if abnormally elevated observed counting rates are used to set scan parameters, instead of known maximum normal counting rates. An extreme example of this problem is illustrated in Fig. 3. Standardization of a technique is essential if such artifactual apparent change is to be avoided *(4)*.

Summary

Rectilinear bone scanning requires specification of instrument factors to assure that scans (A) contain adequate information for correct interpretation, (B) do not vary in appearance and interpretability from patient to patient, and (C) remain consistent when serial studies are performed on a single patient. Choice of a technique should be based on a desired count density calculated for a predefined surveyed area. Effects of display factors, including contrast enhancement, background subtraction, and image minification, should be thoroughly understood. Contrast enhancement produces image distortion and should not be used in rectilinear bone scanning. Background subtraction may improve image appearance without loss of information of interest, if

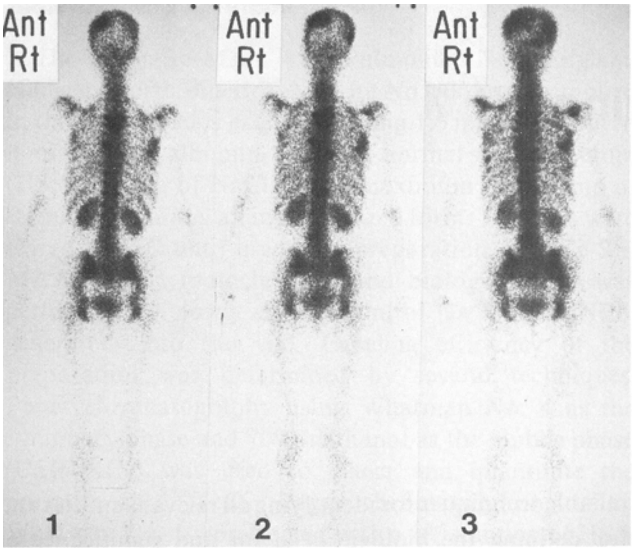

FIG. 7. Series of posterior rectilinear bone scans, PIC depressed over 70,000 counts/min. (1) Initial study demonstrating multiple lesions. Maximum counting rate from thoracic spine was 70,000 counts/min. (2) Followup study three months later. Interval progression is obvious. Maximum counting rate from thoracic spine was 110,000 counts/min. (3) Followup study 12 months after the initial study. There has been further disease progression. Maximum counting rate from thoracic spine was 180,000 counts/min. Normal relationships between noninvolved bones have been preserved by consistent technique, making interval comparisons reliable.

employed sparingly. Image minification does not alter the study information content. An alternative to the surveyed "setup" counting rate, represented as maximal film blackness, must be defined for those situations when greater than expected counting rates are encountered. Recognition of disease involvement in the usual survey area is essential if artifactual distortion of scan appearance is to be avoided. Definition of scan technique and adherence to the above principles will yield reliably reproducible bone scans of maximal clinical usefulness.

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