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THE EFFECT OF THE X-RAY SPECTRUM AND SCREEN-FILM
UNSHARPNESS ON THE IMAGING OF BLOOD VESSELS*

MASTER

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In the investigation of radiographic imaging it is important to gain information on the spatial distribution of x-ray intensity transmitted by the object being radiographed. This intensity distribution is called the x-ray pattern of the object. It is the output from the exposing operation and the input to the recording operation in the radiologic process. Thus, it is important to choose parameters of the exposing operation so that the x-ray pattern will contain as much diagnostic information as possible. Furthermore, parameters of the recording operation must be chosen so that the x-ray pattern is transferred with a minimum of degradation. The effect of many exposing parameters, such as focal spot size and object position, on the x-ray pattern are being studied.¹⁻⁶ There is, however, little quantitative information on the effect of the x-ray energy spectrum on the x-ray pattern.

The availability of solid state semiconductor detectors, such as lithium-drifted silicon and germanium detectors, has made it possible to measure the x-ray energy spectra emitted from diagnostic x-ray tubes with a relatively high degree of accuracy.⁷ In our laboratory a portable x-ray spectrometer, using a lithium-drifted silicon detector, has been constructed⁸ and used in experimental measurements of x-ray spectra from a diagnostic tube and their effects on the x-ray pattern. This facility, shown diagrammatically in Fig. 1, consists of an optical bench mounted on a steel truck and a 400 channel multichannel analyzer (not shown) from which the input is derived. The output from the multichannel analyzer is in the form of punch tape for computer processing. Mounted on the optical bench are a) the lithium-drifted silicon detector; b) a lead plate to hold the fabricated lead collimator which defines the focal spot of the tube; and c) the x-ray tube which is positioned and aligned on the optical bench. The experimental setup is shown in Fig. 2.

Fig. 3 shows a measured spectrum corresponding to a 72 Kvp console setting incident on a 20 cm-thick lucite phantom with an 8 mm aluminum cylinder at midline. Also shown are the spectra transmitted by the test object calculated at discrete increments of distance perpendicular to the cylinder axis, or along the scan axis in the image plane. From these spectra, the relative x-ray intensity profile or the calculated x-ray pattern in the image plane was calculated.⁹ Results are shown in Fig. 4 where the solid curves represent calculated x-ray patterns of a 4 mm Al and an 8 mm Al cylinder. The dotted curves represent the corresponding x-ray patterns measured from the radiographic images of the cylinder by means of a microdensitometer. The dashed curve represents the calculated profile modulated by the spectral sensitivity function of the film. The good agreement between these data indicates that the film scan method, which is the present method for determining the x-ray pattern, and the calculation method, which is important for future work, are both valid in determining the x-ray patterns.

Based on this encouraging preliminary investigation of the method, it is planned to mount a blood vessel phantom consisting of cylindrical holes in lucite filled with radiopaque dye on the optical bench in such a way that the cylinder can be positioned at increments perpendicular to the collimated detector for individual exposures. The incident energy spectrum and transmitted energy spectrum will be recorded, and ultimately the x-ray pattern will be determined on line in a similar manner as shown in Fig. 3. Various exposing parameters such as Kvp setting, tube filtration, and phantom thickness will be changed to observe and record on line the change in the x-ray pattern.

Another practical experiment was performed with the equipment when several radiologists in the department were disturbed that the radiographic contrast was significantly low on films taken at a given Kvp setting on a particular clinically used x-ray tube, in relation to films taken on other x-ray tubes at the same Kvp settings.

Fig. 5 shows spectra measured at several Kvp settings on this tube (tube B), compared to spectra measured on another tube (tube A) at corresponding Kvp settings. It is apparent from these data that, at all Kvp settings, tube B is operating at a higher peak kilovoltage than its console setting indicates. Tube A, on the other hand, seems to be operating at peak kilovoltages corresponding to the console Kvp settings.

To correlate the measured spectra to radiographic image quality of blood-vessel-like images radiographs of a test object were used. The test object consisted of a 20 cm thick lucite block with four aluminum cylinders of various diameters and a lucite cylinder placed at approximately midline in the block. The test object simulates the scattering properties of the head with the aluminum cylinders simulating blood-vessel-like structures but with slightly less contrast. Radiographs of the test object were made on tubes A and B using the same Kvp settings as in the spectrum measurements. From Fig. 6 it is clear that all the radiographs obtained on tube A have higher radiographic contrast at each Kvp setting than images obtained at corresponding Kvp settings on tube B. It is important to note that the 0.5 mm cylinder at the top of the test object is visible at all Kvp settings in the radiographs made with tube A. In the radiographs from tube B, however, it becomes increasingly difficult to visualize the cylinder at the 85 Kvp and 100 Kvp settings, and impossible to visualize it at the 120 Kvp setting. Thus the reduced radiographic contrast of the images obtained with tube B can be accounted for by the presence of higher energy spectral components and by the overall shape of the spectrum emitted by the tube.

Although this work is only a first qualitative step in linking the x-ray energy spectrum to the imaging process, a method has been established for studying the x-ray pattern of blood-vessel-like objects under various conditions of exposure.

To evaluate the impact of the exposing operation on the image of blood-vessel-like

objects, one must also understand the effects of other parameters such as geometrical unsharpness and screen film unsharpness. The x-ray pattern was used to study these effects, as illustrated in the following experiments.^{10,11} In Fig. 7, the input to the imaging system or the x-ray pattern of a 0.5 mm diameter blood vessel phantom in contact with the cassette (no magnification) measured from an image on film exposed without screens is shown. Also shown are outputs or relative illuminance distributions in the emulsion which result in the cylinder image when TF-2 screens with RP film, Par Speed screens with RP/R film, and Detail screens with RP/R film, respectively, are used, as well as the input pattern using a 1.1 magnification with a 1.2 mm focal spot showing the geometrical unsharpness commonly encountered in cerebral angiography. It is clear from these data that screen-film unsharpness plays a dominant role in image degradation under such conditions. Furthermore, the blood-vessel-like image obtained with the widely used fast TF-2, RP system is significantly lower in contrast and is less sharp, as is shown by the flaring out at the vessel edge, than the images obtained with the other screen systems. Since geometrical unsharpness has little effect on the image under these conditions, there is a significant improvement when Par speed screens are combined with presently available RP/R film (which has approximately twice the speed of RP film), compared with the widely used TF-2, RP combination, and there is no increase in patient exposure.

The above mentioned work was accomplished with a tube setting of 72 Kvp, which is commonly used for lateral cerebral angiograms. When the fast combination of TF-2 screens and RP/R film is used, then the Kvp setting can be reduced to 60 Kvp in order to match system speed to the Par Speed, RP/R combination exposed at 72 Kvp. This reduction in Kvp results in higher radiographic contrast. Moreover, in order to make the slow combination of Detail screens and RP/R film practically usable without altering exposure time

or number of frames per second on the rapid changer, and still remain within tube load specification, the Kvp setting must be increased to 95 Kvp to match the system speed to the Par, RP/R combination exposed at 72 Kvp.¹⁰ To evaluate the effect of these techniques on the input to the imaging system, the x-ray patterns of a 1.0 mm diameter vessel at 60, 72 and 95 Kvp were obtained with the blood vessel phantom, and are shown in Fig. 8. The changes in subject contrast due to the Kvp changes are clearly demonstrated.

To assess the effect of such changes in subject contrast on the output from the screen-film system, these x-ray patterns were convolved with the line spread functions of various screen-film systems.¹² The resulting calculated output intensity distributions are shown in Fig. 9. Here it is seen that there is a negligible difference between the outputs of the TF-2, RP/R combination at 60 Kvp and the TF-2, RP combination at 72 Kvp, which indicates that the increased subject contrast at 60 Kvp does not significantly improve the radiographic contrast when the unsharp TF-2 screen is used. When comparing the output from the TF-2 RP/R combination at 60 Kvp to the Par RP/R output at 72 Kvp, it is evident that the sharper Par speed system still maintains greater radiographic contrast and sharpness of the vessel edge although the subject contrast at 60 Kvp is somewhat greater. Comparing the Detail screen outputs at 72 and 95 Kvp, there appears to be a negligible reduction in sharpness at the vessel edge at 95 Kvp, but an appreciable loss of radiographic contrast exists because of reduction in subject contrast. To what degree this loss in radiographic contrast affects detail visibility of small blood vessels imaged with sharp screens remains unclear. It is apparent, however, that there is significantly less flaring out at the vessel edge when Detail screens are compared to other screen systems, so that in some cases the loss of contrast may be acceptable to obtain the sharper blood-vessel-like image.

The imaging of small blood-vessel-like objects with the screen-film combinations and Kvp settings described in Fig. 9 was visually demonstrated by using a steel wool test

object consisting of 75 μ m diameter wire. Radiographs of this object are shown in Fig. 10. Although the subject contrast of these wires is higher than that of blood vessels, it is considered that these radiographs demonstrate in principle how blood-vessel-like structures are imaged with the screen-film systems described.

The difference in sharpness between the TF-2,RP combination and the Par Speed, RP/R combination at 72 Kvp is clearly demonstrated. The TF-2,RP system at 60 Kvp shows slightly increased contrast compared to the TF-2,RP system at 72 Kvp, but it is evident that the increase is insignificant especially when compared to the Par-RP/R system at 72 Kvp. The Fast Detail and Detail systems made at 72 Kvp show increased sharpness and resolution. The reduction in subject contrast using the Detail system at 95 Kvp is evident, but the wires still appear to be imaged more sharply when compared with the Par Speed system. It should be noted that in this experiment only a Kvp increase was used to compensate for the slow speed of the Detail,RP/R system. In practice, however, other exposure parameters may be adjusted to keep the necessary Kvp increase to a minimum.

For example, excellent sharpness and contrast can be obtained with the Detail, RP/R system if the frame rate is reduced to one per second. Fig. 11 shows, on the left, a section of a lateral cerebral angiogram made with the TF-2,RP combination at 70 Kvp with a frame rate of 2 per second and an exposure time of 0.16 second. On the right is the same section using Detail screens with RP/R film. The Kvp setting was increased to 76 Kvp and the frame rate was reduced to one per second with an exposure time of 0.4 seconds to compensate for the low exposure speed of the Detail system while remaining within tube load specifications. The increase in exposure time made it necessary to immobilize the patient's head so as to avoid unsharpness due to patient motion. It is clear from these radiographs that sharpness in the imaging of blood vessels can be con-

siderably increased by using the Detail RP/R combination. If the sacrifice in frame rate cannot be made in order to obtain a clinically acceptable diagnostic radiograph, it may still be possible to use the Detail RP/R combination for cerebral angiography in many patients, especially in children, where the increase in Kvp (necessary for a frame rate of 2 per second) does not result in a significant reduction in radiographic subject contrast.

To summarize, it is well known that the entire radiological process leading to the blood vessel image is a complicated one: The practical problems involved in the exposing operation play a vital role in this process because compromises in beam quality must be made to obtain flexibility in selection of exposure time, frame rate, geometry, and screen-film system. Preliminary spectroscopic measurements of beam quality were made and related qualitatively to subject contrast. Measurements of the x-ray pattern of blood-vessel-like objects aided in the study of geometrical unsharpness and screen-film unsharpness. Further studies will be carried out to determine the relative effect of the x-ray energy spectrum on the imaging process by measuring many x-ray spectra and the resulting x-ray patterns of the object. In addition, radiographs of a simulated head phantom with contrast-filled blood-vessel-like structures will be made at exposure conditions corresponding to those used for recording the x-ray pattern. These radiographs will be compared and evaluated by radiologists to determine which parameters afford the greatest diagnostic information. This information can then be related to the corresponding x-ray pattern to determine the best combination of beam quality, exposure time, frame rate, geometrical unsharpness and screen-film system.

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Figure Legends

Fig. 1. Diagrammatic representation of portable x-ray spectrometer.

Fig. 2. The experimental x-ray spectrometer setup.

Fig. 3. Schematic characterization of the process leading to the formation of the relative x-ray pattern.

Fig. 4. Intercomparison plot of the relative x-ray patterns (solid curves), the sensitivity modulated x-ray patterns (dashed curves) and the experimentally measured effective relative x-ray patterns (dots) for 4 and 8 mm diameter aluminum rods.

Fig. 5. Comparison of spectra taken from units A and B at the four indicated Kvp tube settings.

Fig. 6. Test object radiographs taken with units A and B for image inter-comparisons.

Fig. 7. Input x-ray pattern of a 0.5 mm diameter blood vessel phantom with no magnification and corresponding outputs or relative illuminance distributions in the emulsion using several screen-film systems. Also shown is the input pattern using 1.1 magnification with a 1.2 mm focal spot demonstrating the effect of geometrical unsharpness commonly encountered in cerebral angiography.

Fig. 8. The input x-ray pattern of a 1.0 mm diameter blood vessel phantom at tube settings 60 Kvp, 72 Kvp and 95 Kvp.

Fig. 9. The calculated intensity distributions when the inputs from Fig. 8 are convolved with the line spread functions of various screen film systems.

Fig. 10. Radiographs of a steel wool test object using the screen-film combinations and Kvp settings shown in Fig. 9.

Fig. 11. Lateral cerebral angiograms of a patient.

85 kVP
A B

120 kVP
A B

50 kVP
A B

100 kVP
A B

TF-2, RP
72 kVp

Par, RP/R
72 kVp

Detail, RP/R
95 kVp

TF-2, RP/R
60 kVp

Fast Detail,
RP/R
72 kVp

Detail, RP/R
72 kVp

TF-2, RP, 70 kVp, 2/sec

Detail, RP/R, 76 kVp, 1/sec