

## Comparison of the Gray Scale Characteristics of Analog and Video (Digital) Formatters

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*The purpose of this study was to determine the relationship between optical density and image counts for video (digital) and analog formatters so that a video formatter could be adjusted to mimic the performance characteristics of an analog formatter. The relationship between optical density on film and image counts was determined for a video formatter and for four different analog formatters. All analog formatters demonstrated a similar logarithmic relationship, between optical density and counts, over the optical density range of 0–3.2. The video formatter gave the standard film density response curve for the film type, with a maximum optical density of 2.0. A gray scale map was created on a computer to permit the video formatter to simulate the performance characteristics of the analog formatter over the limited optical density range of 0–2.0. Both graphic and tabular techniques are described for the creation of such gray scale maps.*

The evolution of modern gamma cameras has led to the increased use of digital computers for image processing and for the generation of the final hardcopy image (1). While a considerable amount of attention has been paid to optimizing image processing techniques, there has been little effort directed toward improving hardcopy image quality (2).

In most older gamma camera systems, hardcopy image generation was facilitated by flying-dot cathode ray tube (CRT) displays (analog formatters). With these types of hardcopy devices, image quality was determined primarily by the type of film employed and by the intensity of the CRT dot. By comparison, in modern gamma camera systems, a digitized image is output as a video signal and the hardcopy is made by a video formatter. On such formatters, the user may adjust both the contrast and density of the film over a wide range and may alter the relationship between pixel count and optical density by means of gray scale maps. This adjustment ability makes it difficult to establish the correct settings for optimum image quality on video formatters. The problem is further compounded by the paucity of scientific studies on how to optimize such devices (2,3). It usually falls to the user

to determine, by trial and error, which settings will produce an acceptable image quality.

The optimum relationship between pixel count and optical density on film is difficult to define, and it has been shown that this relationship is partially dependent on the type of scintigraphic image being interpreted (2). Many nuclear medicine physicians have been trained to interpret the content of scintigraphic images generated with analog formatters. While this does not imply that analog formatters yield the optimum hardcopy display in nuclear medicine, they do generally represent the standard by which other hardcopy devices are assessed.

The manner in which analog formatters alter the relationship between the image count and optical density can be considered as equivalent to the effects of a computer gray scale translation map on a video formatter. The nature of this "analog" gray scale map has not been determined to date. The purpose of this study was twofold: first, to determine the relationship between optical density and the image count for analog formatters, and second, to use this relationship to design computer gray scale maps that would permit video formatters to simulate the performance of analog formatters.

### MATERIALS AND METHODS

#### Analog Formatters

For this study, four analog formatters were evaluated (two nuclear formatters, G. E. Medical Systems, Milwaukee, WI and two microdot formatters, Siemens Gammasonics, Schaumburg, IL). Each formatter was evaluated using both a low and high CRT dot intensity setting. The low intensity setting corresponded with that normally used for planar bone imaging. The high intensity setting corresponded with that used for flow studies (such as renal or bone). At each intensity setting, all formatters were evaluated using blue-base (Kodak NMB, Eastman Kodak, Rochester, NY) and clear-base films (Kodak NMC, Eastman Kodak, Rochester, NY).

To evaluate the formatters, 16 tissue culture flasks were each filled with 20 ml of water and varying amounts of technetium-99m ( $^{99m}\text{Tc}$ ) pertechnetate. The activity in each flask ranged from 0–150  $\mu\text{Ci}$  of  $^{99m}\text{Tc}$  in increments of ap-

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proximately 10  $\mu$ Ci. The flasks were arranged on the face of the gamma camera system as shown in Figure 1. Images of the flasks were acquired for preset counts, on both the analog formatter and the computer (Pinnacle system, Medasys, Ann Arbor, MI). Images were acquired for total counts of 0.5, 1.5, 2.5, 4, and 8-million counts (Mct) for low-dot intensity settings and for total counts of 0.1, 0.2, 0.6, 1.0, 1.6, and 3.2 Mct for high-dot intensity settings.

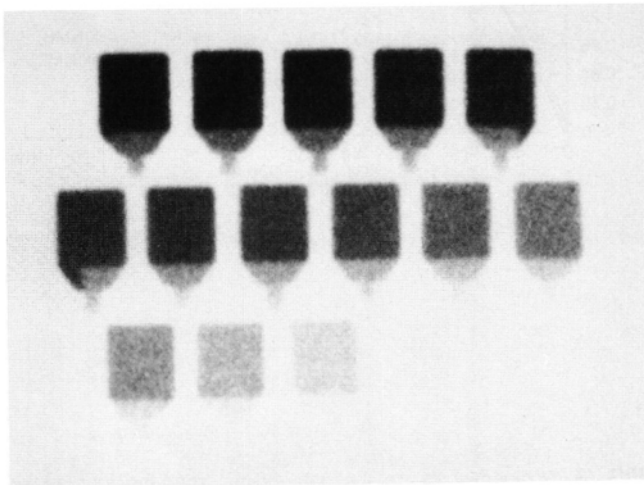
The computer images were analyzed by placing a rectangular region of interest (ROI) over the center of each flask and recording total counts in the ROI. The optical density of the corresponding region in the analog images was determined using a densitometer (Model TD932, Macbeth, Newburgh, NY). The results obtained from each set of 16 flasks were normalized to the maximum ROI counts in the 8-Mct image, for low-dot intensity settings, and to the maximum ROI counts in the 3.2-Mct image, for high-dot intensity settings. Optical density was then plotted against normalized counts for each combination of formatter type, film type, and dot intensity setting.

To permit comparison of the results obtained with different formatters and dot intensities, it was necessary to standardize all formatter studies to a maximum optical density. Hence, for each combination of formatter, film, and dot intensity, the counts required to produce an optical density of 3.2 was used as the 100% value. Counts corresponding to higher optical densities were discarded from the analysis. A polynomial fit was then performed on the remaining data points to yield a single curve, relating optical density to counts.

A total of 16 fitted curves were generated for the 4 formatters, 2 dot intensities, and 2 film types. All curves for a given film were summed and a new polynomial fit performed to give a single curve for each film type.

### Video Formatters

Prior to evaluation of the video formatter (Model 1000, Matrix Instruments, Orangeburg, NY), the contrast and



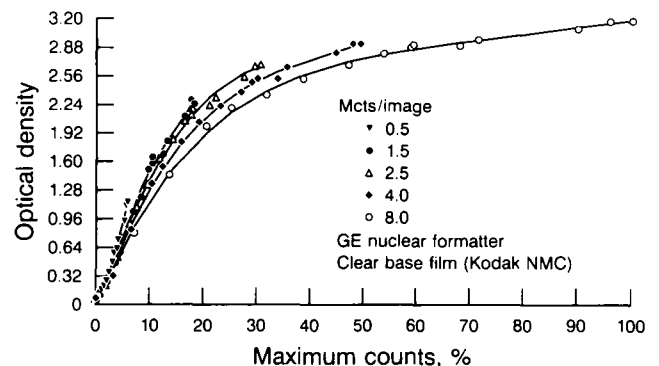
**FIG. 1.** Eight-million count analog formatter image of the 16 flasks. The image was acquired using a blue-base film and a low CRT dot intensity setting.

brightness settings were adjusted so that maximum image brightness corresponded to an optical density of 2.0 on film. To ensure appropriate contrast in the image, all settings were made using a Society of Motion Pictures and Television Engineers (SMPTE) video test pattern (4) and adjusted to permit visualization of the appropriate sections of the test pattern. This pattern provides a semiquantitative technique for standardization of the contrast and brightness settings of video monitors (4,5). A linear gray scale map was used to convert pixel counts to image brightness. The 8-Mct image was then printed from the video formatter using both blue-base and clear-base films. Using the film, the optical density of each flask was determined by densitometry and plotted against the counts in that flask (normalized to the counts in the hottest flask). A polynomial fit was then performed to the data points.

Using the method of Rogers and Keyes (3), a gray scale map was created on the computer system that permitted the video formatter to match the gray scale map of the analog formatter, over a limited optical density range. Briefly, this was achieved by subtracting the base plus fog value from the optical density values for the analog and video formatters. The optical density versus counts curve for the video formatter was then redrawn so that counts were replaced by the corresponding linear gray scale map value (i.e., 100% counts were equivalent to 255 gray levels). The analog formatter gray scale curve was divided by a factor of 1.6 to give a maximum optical density of 2.0. The resulting optical density values from both curves were cross-plotted to generate a new curve, relating counts to gray scale map value.

## RESULTS

Figure 2 illustrates the relationship between optical density and image counts for an analog formatter using a low dot intensity and a clear-base film. The optical density showed a logarithmic relationship with counts. Figure 2 also demonstrates latent image fading with a decrease in the optical density for a given number of counts as acquisition time increases. This effect was present in all analog formatter images to a greater or lesser degree.



**FIG. 2.** Optical density versus counts for a nuclear formatter using a low CRT dot intensity. Polynomial fits were performed to the data points from the images with 0.5, 1.5, 2.5, 4, and 8 Mct.

The relationship between optical density and image counts was found to be similar for the four analog formatters evaluated in this study and was not strongly dependent upon the dot intensity setting. Figure 3 presents the fitted curves for the four formatters at high- and low-dot intensities with blue-base (Fig. 3A) and clear-base (Fig. 3B) film. Using Figures 3A and 3B, an average curve for each film type was obtained (Fig. 3C). These curves effectively represent the "gray scale map" used by an analog formatter to convert counts to optical density over the optical density range of 0–3.2.

Figure 4 presents the relationship between optical density and image counts obtained with a video formatter and a linear gray scale map on the computer system. The maximum optical density was limited to 2 by the settings on the video formatter. This is the recommended upper limit for video formatters (5,6). These curves effectively represent the film-density response curves for the blue-base and clear-base films. A comparison of Figures 3 and 4 illustrates the dramatic difference in the relationship between optical density and counts for analog and video formatters, and highlights the difference in maximum optical density normally achieved by the two devices.

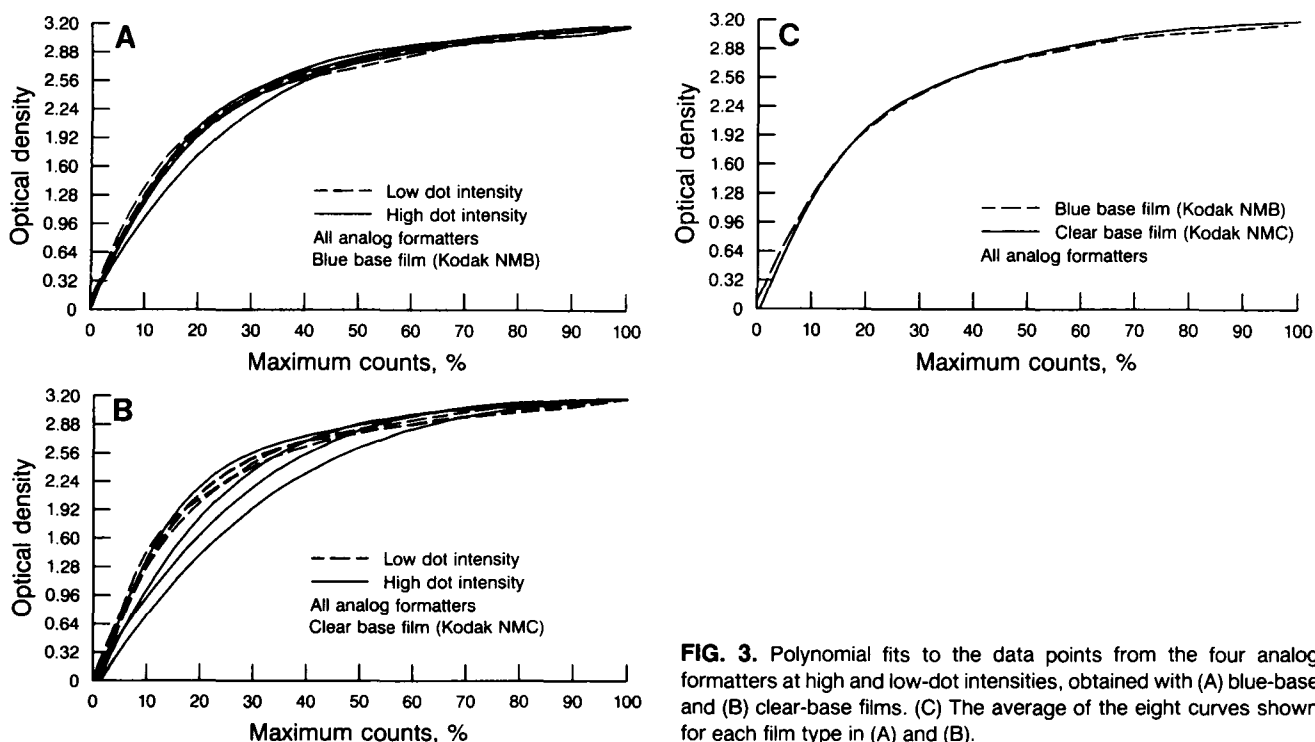
Figure 5 illustrates a method for creating a gray scale map that will allow the video formatter to match an analog formatter over a limited optical density range of 0–2 (3). The graph on the upper left plots the analog formatter response curve shown in Figure 3 for blue-base film. The maximum optical density on this graph has been rescaled from 3.2 to 2. The graph on the lower right plots the film response curve for the video formatter obtained with blue-base film. This is the same curve shown in Figure 4 (solid line), except that the ordinate and abscissa have been reversed and the abscissa has

been changed from counts to a gray scale map value. Since a linear gray scale map was used, counts were multiplied by a factor of 2.55 to give a maximum gray scale value of 255. The required gray scale map is then created by selecting an optical density value on the upper-left and lower-right graphs and cross-plotting this value onto the lower-left graph. For convenience, we describe a tabular method for generating such gray scale maps in the Appendix.

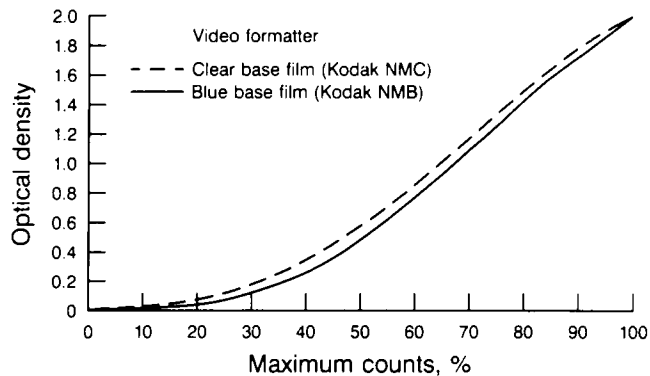
Figure 6 presents examples of planar bone scans printed from a video formatter using a linear gray scale and an "analog formatter" gray scale. Use of a linear gray scale leads to a loss of the low count detail in an image (Figs. 6A and 6C). While this may be considered acceptable for normal bone views, the presence of unusually hot regions leads to inferior image quality, unless an appropriate gray scale map is used. In Figure 6C, it was necessary to window the image counts between 0% and 60% to permit visualization of the spine. This led to loss of detail in the hot regions of the pelvis and spine and failed to restore the low count detail in the image.

## DISCUSSION

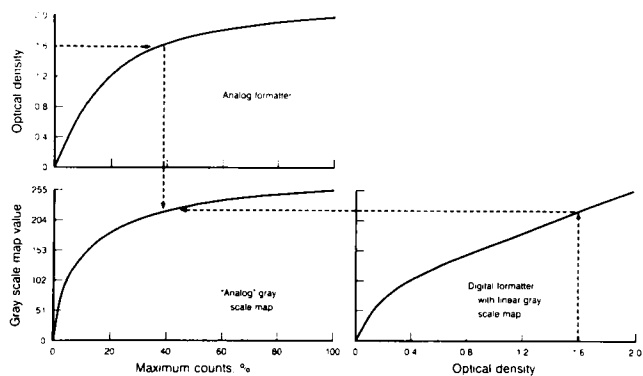
Analog formatters have been the standard method for providing hardcopy images in nuclear medicine over the last decade. In general, once the appropriate dot intensity setting has been determined for a particular type of examination, the analog formatter provides reliable image quality and has long-term stability. Furthermore, its optical density range is limited only by the characteristics of the film, thereby accommodating a wide latitude of count densities. Figures 2 and 3 indicate that the formatters evaluated in this study had similar performance characteristics. Their film density response curves



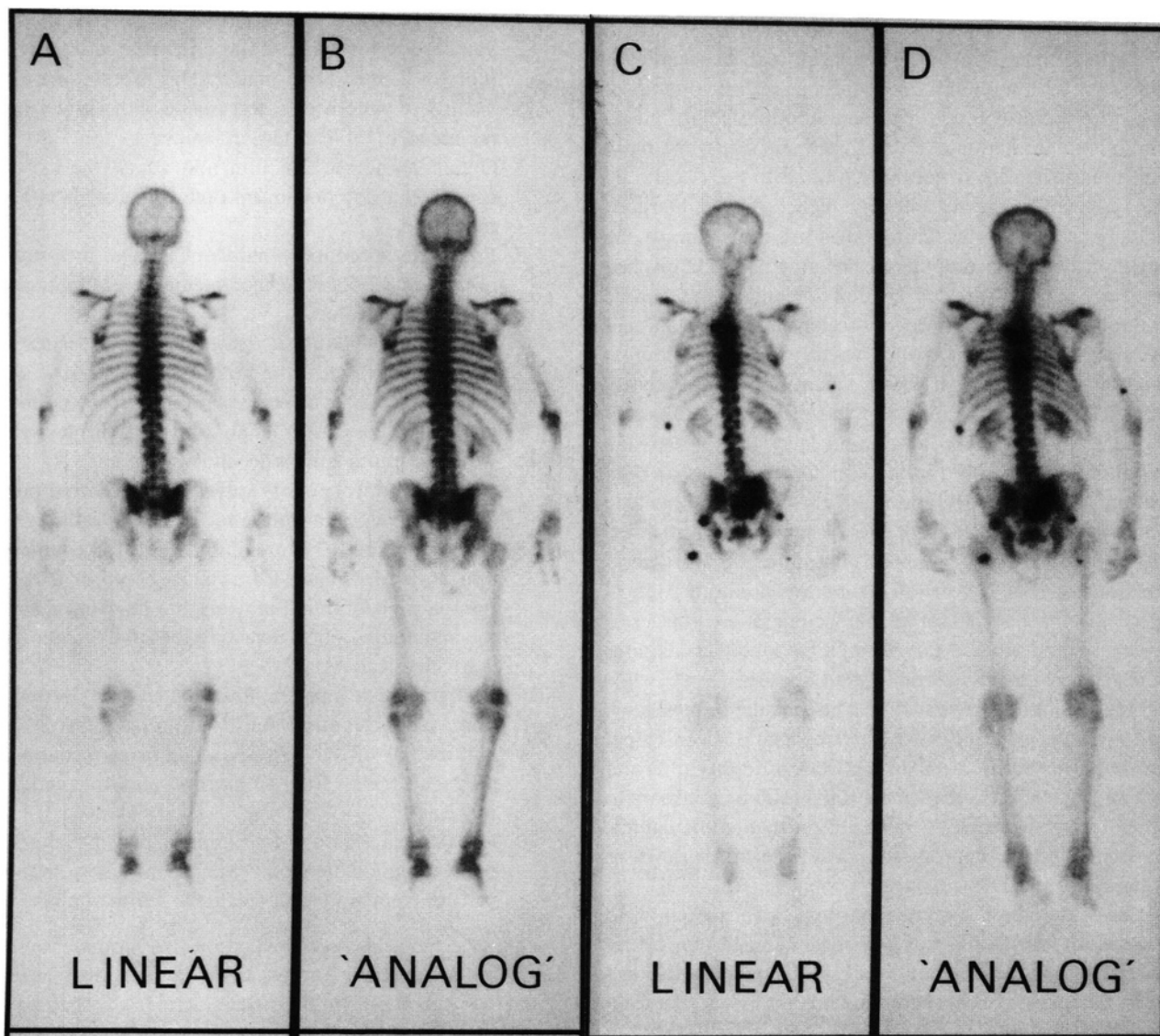
**FIG. 3.** Polynomial fits to the data points from the four analog formatters at high and low-dot intensities, obtained with (A) blue-base and (B) clear-base films. (C) The average of the eight curves shown for each film type in (A) and (B).



**FIG. 4.** Optical density versus counts for a video formatter. Results obtained using a linear gray scale map.



**FIG. 5.** (Upper left) Figure 3C redrawn to a maximum optical density of 2. (Lower right) Figure 4 redrawn with ordinate and abscissa reversed and maximum counts replaced by corresponding gray scale value. (Lower left) "Analog" gray scale map for computer obtained by cross-plotting upper-left and lower-right graphs.



**FIG. 6.** Normal and positive bone scans printed from a video formatter with (A, C) linear gray scale and (B, D) "analog" gray scale.

showed a very rapid rise in optical density at low percent counts, permitting the formatter to show low-count background information even in the presence of very hot activity.

The increasingly prevalent integration of gamma cameras and computer systems has led to increased dependence upon video formatters to provide hardcopy images. The principle advantage of video formatters over analog formatters is their ability to rephotograph an image if required. These formatters are generally more susceptible to drift than their analog counterparts and their performance characteristics are highly dependent upon the contrast and brightness settings. Although there is an absence of well defined techniques for the standardization of the contrast and brightness, these settings have been used as a means of achieving an acceptable hardcopy image quality. While this may be satisfactory for one type of scintigraphic study, it is unlikely to be acceptable for all types of studies (7). Furthermore, incorrect contrast and brightness settings can eventually cause phosphor burn on the monitor and lead to poor monitor performance.

A comparison of Figures 3 and 4 indicates the significant difference in the way images are developed on analog and video formatters. Clearly use of a video formatter with a conventional linear gray scale map will lead to significant suppression of low count information and will provide a clearer distinction between high count regions of an image. An additional limitation of video formatters is that the maximum optical density is normally limited to  $\sim 2$  (5). While there is no technical reason why higher optical densities cannot be achieved, the limitation is primarily due to the manner in which a computer scales an image for display. Images are normally scaled so that the maximum counts correspond to the maximum gray scale value. Hence, a high maximum optical density would result in apparent overexposure of the image. Even with a maximum optical density of 2, it will often still be necessary to set the maximum gray scale value to correspond to a count level greater than the maximum count in the image. This forces the image data down onto the lighter section of the gray scale map. Analog formatters do not suffer from these limitations because the image data is not scaled before it is output to the formatter.

Previous studies have shown that the optimum optical density for many types of planar scintigraphic images is between 1.3 and 1.6 (2). For example, a bone scan requires that the spine or pelvis have an optical density of  $\sim 1.6$ , while other regions in the image, such as a hot bladder or metastatic lesion can have optical densities greater than 3. Even with a video formatter set to a maximum optical density of 2 and use of an "analog" gray scale map, it may still be necessary to set the maximum gray scale value greater than 100% counts, in order to shift the appropriate part of the image down to the required optical density range.

Much of the above assumes that analog formatters yield the optimum format and gray scale characteristics for planar scintigraphic studies. Previous work has shown that a logarithmic relationship exists between perceived changes in optical density and image counts (8,9). The similarity between the analog gray scale curve (Fig. 3) and a logarithmic curve

indicates that analog formatters are well suited to the display of scintigraphic images. Conversely, video formatters, using a linear gray scale map, show an exponential response at low count levels, which can lead to significant loss of detail in the low count regions of an image.

In conclusion, our results have indicated that analog formatters have a logarithmic relationship between optical density and image counts that is essentially independent of the type of formatter, the CRT dot intensity setting, or the film type. This logarithmic relationship can be modeled on a video formatter through the use of a special gray scale map.

## APPENDIX

The steps outlined below allow the user to create a gray scale map on computer. This map will allow the video formatter to simulate the gray scale characteristics of an analog formatter, over the optical density range of 0-2. In all cases, it is first necessary to determine the existing optical density versus counts relationships for the video formatter.

### Procedure

1. Load a linear gray scale map onto the computer system.
2. Standardize the contrast and brightness settings on the monitor face of the formatter. This is best done with a video test pattern or a test image with known incremental steps (at least ten) in counts.
3. Obtain hardcopies on film and adjust the exposure time so that the maximum optical density is approximately 2.
5. From the appropriate hardcopy image, measure the optical density of each incremental level. Subtract the base plus fog value.
6. Measure the counts in each increment (using ROI analysis), normalize the hottest region to 100%, and multiply by 2.55 to convert from percent counts to gray scale value (assumes an 8-bit deep display system with maximum gray scale value of 255).
7. Write the optical density values and the corresponding gray scale values in Columns 3 and 4 of Table 1.
8. Columns 1 and 2 represent the percent counts and optical density values from Figure 5 (upper left). The numbers in Column 2 may need to be rescaled so that the maximum optical density values in Columns 2 and 3 are identical.
9. The gray scale map is now created by selecting the same value of optical density from Columns 2 and 3 and reading off the corresponding percent counts and gray scale values from Columns 1 and 4, as indicated in Table 1.
10. Repeat Step 9 for a range of optical density values and plot the gray scale values against their corresponding percent count values to create the required map.

Once the map has been created on the computer system, some fine-tuning may be necessary, particularly over the range of 0%-15% counts, as minor inaccuracies in the shape of the gray scale map for this region significantly affect the appearance of low count background activity in clinical images.

**TABLE 1. Conversion of Percent Counts to Gray Scale Value**

Analog Formatter		Video Formatter	
% Counts	Optical Density	Optical Density	Gray scale value
0	0.04	0.00	0
5	0.47	0.03	13
7	0.61	0.04	18
10	0.79	0.06	25
20	1.24	0.11	51
30	1.51	0.20	77
40	1.66	0.37	102
50	1.76	0.61	128
60	1.83	0.88	153
70	1.89	1.17	179
80	1.93	1.45	204
90	1.96	1.71	230
100	2.00	2.00	255

Columns 1 and 2 are taken from Fig 5 (upper left), and Columns 3 and 4 are determined by the user for a given video formatter. The gray scale map is created by plotting the gray scale value against percent counts for like values of optical density (e.g., a percent count of 7 corresponds to a gray scale value of 128).

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