Original Article

Investigating the Role of Global Histogram Equalization Technique for ^{99m}Technetium-Methylene diphosphonate Bone Scan Image Enhancement

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Abstract

Purpose of the Study: ^{99m}Technetium-methylene diphosphonate (^{99m}Tc-MDP) bone scan images have limited number of counts per pixel, and hence, they have inferior image quality compared to X-rays. Theoretically, global histogram equalization (GHE) technique can improve the contrast of a given image though practical benefits of doing so have only limited acceptance. In this study, we have investigated the effect of GHE technique for ^{99m}Tc-MDP-bone scan images. **Materials and Methods:** A set of 89 low contrast ^{99m}Tc-MDP whole-body bone scan images were included in this study. These images were acquired with parallel hole collimation on Symbia E gamma camera. The images were then processed with histogram equalization technique. The image quality of input and processed images were reviewed by two nuclear medicine physicians on a 5-point scale where score of 1 is for very poor and 5 is for the best image quality. A statistical test was applied to find the significance of difference between the mean scores assigned to input and processed images. **Results:** This technique improves the contrast of the images; however, oversaturation was noticed in the processed images. Student's *t*-test was applied, and a statistically significant difference in the input and processed image quality was found at $P < 0.001$ (with $\alpha = 0.05$). However, further improvement in image quality is needed as per requirements of nuclear medicine physicians. **Conclusion:** GHE techniques can be used on low contrast bone scan images. In some of the cases, a histogram equalization technique in combination with some other postprocessing technique is useful.

Keywords: *^{99m}Technetium-methylene diphosphonate bone scan, contrast enhancement, histogram equalization*

Introduction

^{99m}Technetium-methylene diphosphonate (^{99m}Tc-MDP) whole-body bone scans are routinely performed for different clinical indications. These images have limited a number of counts per pixel, and hence, they have inferior image quality compared to X-rays. Further, the pixel intensities in these images may have skewed distribution, for example, Figures 1 and 3 scans with pixel intensities clustered about low ranges. Such scans may be referred to as dark/low contrast bone scans. On visual assessment, we observed approximately 30% of the whole-body scan images to be in the category of dark/low contrast. There is an exhaustive list of image enhancement methods, many of which require manual input of parameter value(s) for their best performance, which needs a skilled person with considerable training and expertise for optimal results. Theoretically, global histogram equalization (GHE) technique can improve the contrast of a given image and does not require parameters from the user. GHE is one of the most popular techniques for contrast enhancement of images[1-5] and is a well-known method for enhancing the contrast of a given image in accordance with the samples distribution.[2,3] GHE has been widely applied when the image needs enhancement, such as medical image processing, radar image processing, texture synthesis, and speech recognition.[4,6,7]

GHE is a simple and effective contrast enhancement technique which distributes pixel values uniformly such that enhanced image has a linear cumulative histogram. In other words, the application of GHE would stretch the high-intensity histogram regions and compress the low-intensity histogram regions, as is evident in Figure 1. However, there are some downsides of GHE. As GHE is a global operation, it does not preserve the image brightness. It usually introduces two types of artefacts into the equalized image, namely, over-enhancement of the image regions with more frequent gray

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levels and the loss of contrast for the image regions with less frequent gray levels.[8]

Verdenet *et al*. have used GHE technique for the enhancement of bone scintigraphic images.[9] They found that the technique improves the readability of data and is suitable to bone scintigraphy. However, they have also mentioned observation of few false positive results as application of this technique. Jeong *et al*. compared six histogram equalization based techniques and have reported that exact histogram specification techniques give the best performance.[10] Besides these two, not many studies have been done in relation to GHE for bone scan image enhancement. In this study, we have investigated the effect of GHE technique for ^{99m}Tc-MDP-bone scan image enhancement.

Materials and Methods

Global histogram equalization

We assumed that the image to be processed has continuous gray level in the range (0, 1) and P_r (r) denotes the probability density function (pdf) of the variable r (the gray level of the input image). P_s (s) denote the pdf of the variable s (the gray level of the output image). Suppose, we perform the following transformation on the input gray levels to obtain output (processed) gray levels, s,

$$s = \mathrm{T}\ (r) = \int \mathrm{p}_{\mathrm{r}}\ (\mathrm{w})\ \mathrm{dw}$$

Where w is a variable of integration. It can be shown that the probability density of the output level is uniform (2) such that

$$p_s(s) = \begin{cases} 1 & for\, 0 \le s \le 1 \\ 0 & otherwise \end{cases}$$

In other words, this transformation generates an image whose gray levels are equally likely and, in addition, covers the entire range (0, 1). This is a continuous form of histogram equalization in which output image histogram becomes flat.

However, since we deal with digital images. The discrete form of histogram equalization is given by

$$S_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{N^2} = \sum_{j=0}^{k} P_S(r_j), 0 \le r_k \le 1,\ k = 0, 1, \ldots . L - 1$$

Where n_j is count in the j^{th} individual pixel, and N is the total number of pixels in horizontal/vertical direction.

When this transformation function is applied, the histogram of output will not be flat because of the discrete approximation of the pdf with the histogram function. However, the gray levels of an image that has been subjected to histogram equalization will spread out and always (tend to) reach white. That is, histogram equalization technique increases the dynamic range of gray levels and produces an increase in image contrast.

Creation of image database

Eighty-nine ^{99m}Tc-MDP whole-body images were included in this study. These images were acquired using following protocol: "Whole-body bone scan image was acquired using a gamma camera (Symbia E) about 3 h after intravenous injection of ^{99m}Tc-MDP. Eighty nine unprocessed bone scan images were exported in DICOM format. The scan speed was 10/min without zooming. The whole-body field was used to record anterior and posterior views digitally with resolution 256 × 1024 pixels. Image represents counts of detected gamma decays in each spatial unit with 16-bit grayscale depth." Unprocessed whole-body images were exported in the DICOM format for further processing using a personal computer-based application program.

Image processing and evaluation

A MATLAB script was written to process the image using histogram equalization technique. We investigated three different variations of histogram equalization techniques, (1) GHE; (2) GHE followed by normalization; and (3) GHE followed by contrast-stretch and then normalization. In the third technique, the contrast of the histogram equalized image was adjusted between 2% of the minimum gray level to maximum gray level of the histogram equalized image, the contrast adjusted image was then normalized in the range 0–1.

Each of the 89 input images was processed by the above-mentioned three techniques. Image quality evaluation was performed in two steps. In the first step, processed images were reviewed by the team itself. In this step, it was decided that input and processed images using third technique will be reviewed by two nuclear medicine physicians.

In the second step, two experienced nuclear medicine physicians evaluated 178 images (89 input and another 89 - corresponding output images obtained after application of histogram equalization followed by contrast stretch and then normalization). The physicians assigned a score of 1 (very low quality) to 5 (excellent) (descriptive scale as: 1 - not good at all, 2 - good, it is ok, but not able to report, 3 - better than 2, but not very confident to report, 4 - much better than 3, though further improvement is desirable, 5 - best, further improvement not required, diagnosis can easily be made with this image.) to each image.

Student's *t*-test was used for significance of difference of the mean image quality score assigned to input and processed images. The null hypothesis was "GHE followed by contrast stretch and then normalization technique provides image quality approximately equal to the input image," at significance level $\alpha = 0.05$.

Results

The significant contrast improvement using GHE was found in case of low contrast bone scan [Figure 1]. An input (low contrast bone scan) image and its histogram and the processed image using GHE with its histogram are shown in Figure 1. The input image is very dark, details are hardly visible. Inspecting the input histogram, one can find that more frequent gray levels are from dark regions (0–10 counts), and each detail of the dark region is visible in the output. The less frequent gray levels (from bone tissue uptake) are compressed in the output image, and hence, loss of contrast can be seen in the bone uptake. Figure 1 shows radionuclide uptake in soft tissue and the bone is visible, which was not visualized in the input image. However, the minute details of the bone cannot be distinguished due to gray-level compression. The technique improved all low contrast images significantly.

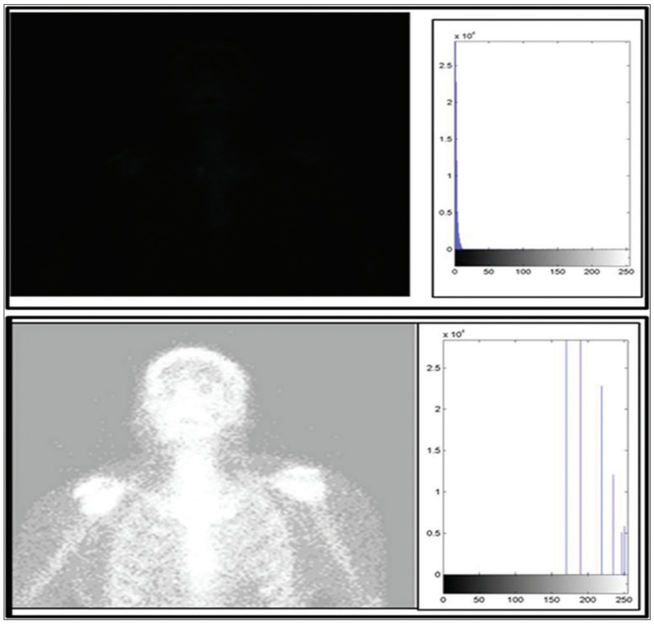

Figure 1: Upper row: Input image and its histogram, lower row, output image with its histogram, only part of whole-body image with zoomed view

A region of interest (ROI) is placed on input image in Figure 1; the ROI image was processed using GHE. The processed ROI image along with its histogram is shown in Figure 3. The same type of foggy appearance, as in the previous case, in the processed image can be seen though contrast in image is much better and it is more visually appealing in comparison to processed image in the Figure 1 [see Figure 3b, processed image of chest region]. This is because the frequency of low gray level (0–10) has reduced in comparison to the reduction in the gray level corresponding to the bone. Now, the ribs are very clearly visible in the processed image [Figure 3b]. Figure 3c shows the processed ROI image using GHE followed by normalization, this image is better than the processed image using GHE alone. Figure 3d shows the processed ROI image using GHE followed by linear contrast stretch and then normalization. The processed image using GHE followed by linear contrast and then normalization was found to be the best among the three variants of the histogram equalization technique investigated in this study. With even smaller ROI placed on the sternum, the characteristics of output are similar as before [Figure 2].

Figure 4 shows a low contrast whole-body image (input image) and processed images along with their histograms. To compare the result with the most widely used techniques for contrast adjustment, the contrast of the input image was adjusted using the most widely used window-level contrast adjustment tool. Figure 5 shows six images (one input and five processed images), from left to right, 1st input image,

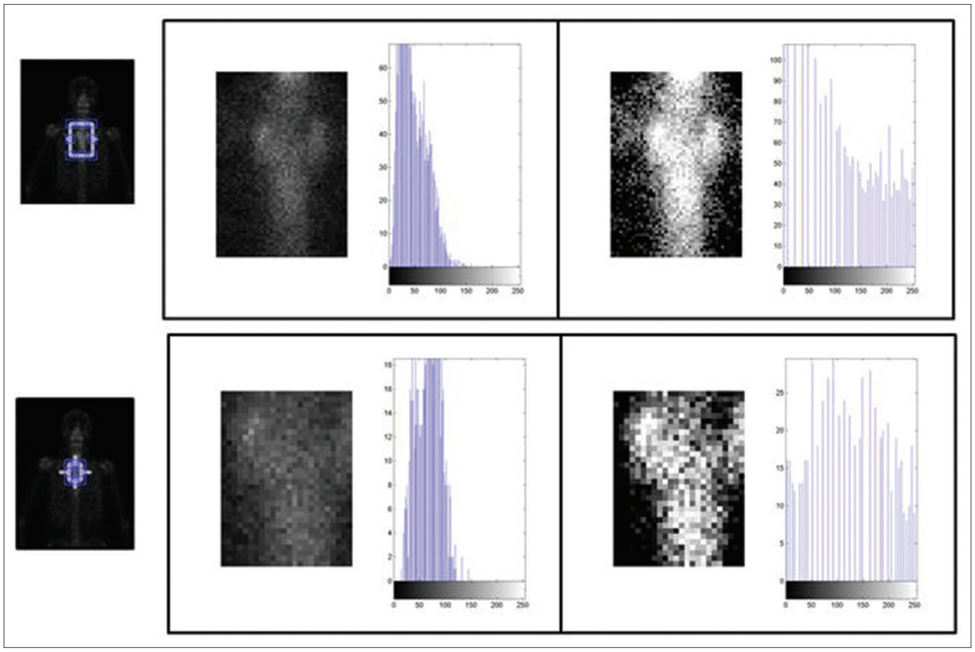

Figure 2: Region of interest, input and output image with their histogram. Even at smaller sized region of interest also, there is a washout appearance. The right side of the figure shows the histograms corresponding to these images

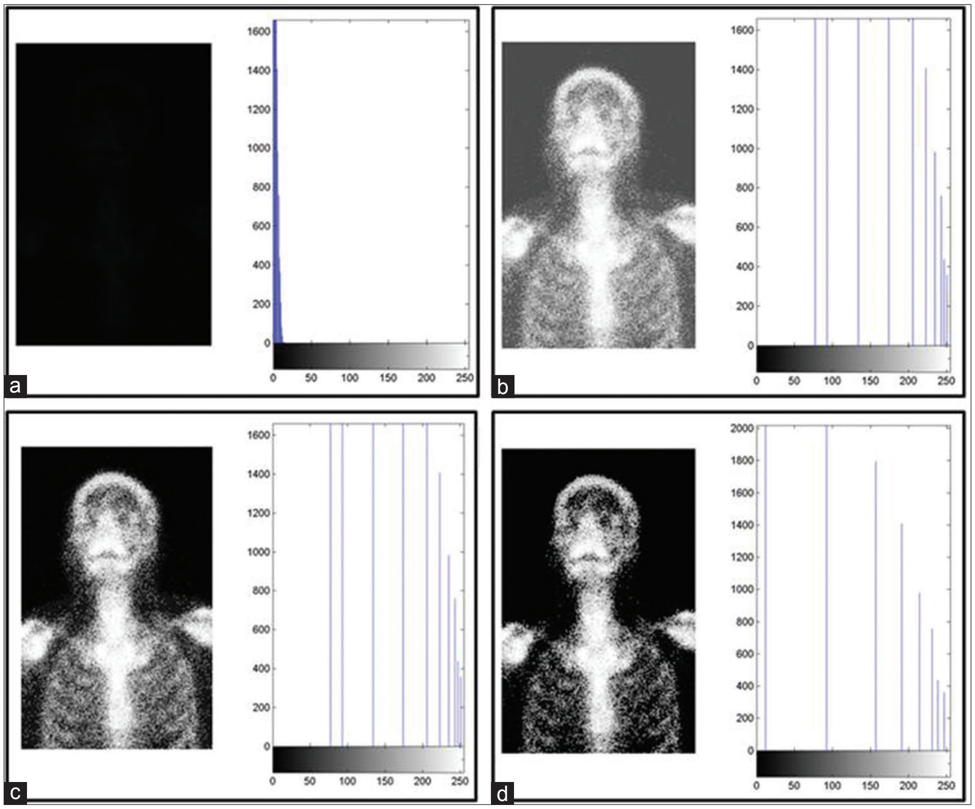

Figure 3: (a) Input image and its histogram, (b) processed image with global histogram equalization and its histogram, (c) Processed image with global histogram equalization followed by normalization and its histogram, (d) global histogram equalization, contrast stretch, and normalization

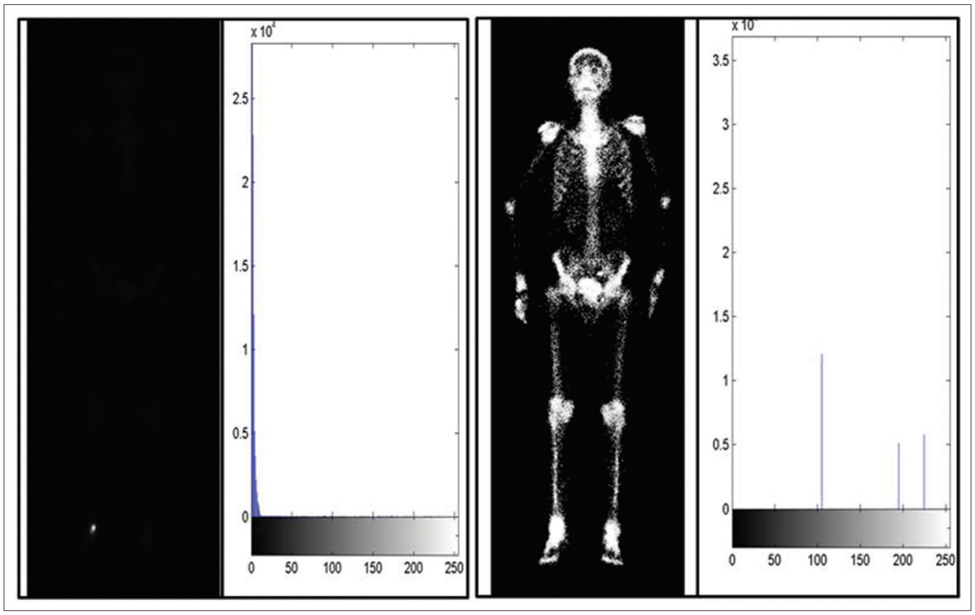

Figure 4: One representative input and processed image with their histograms

2nd and 3rd images using window-level contrast adjustment tool and 4th image using GHE, 5th image using GHE followed by normalization, and 6th image using with GHE followed by contrast adjustment then normalization.

All 89 input and their corresponding processed images with GHE followed by contrast adjustment and then normalization were reviewed by two nuclear medicine physicians.

The scores assigned to each image by the physicians were averaged and the descriptive statistics were calculated [Table 1]. Student's *t*-test was applied to find whether the mean score difference of the input and

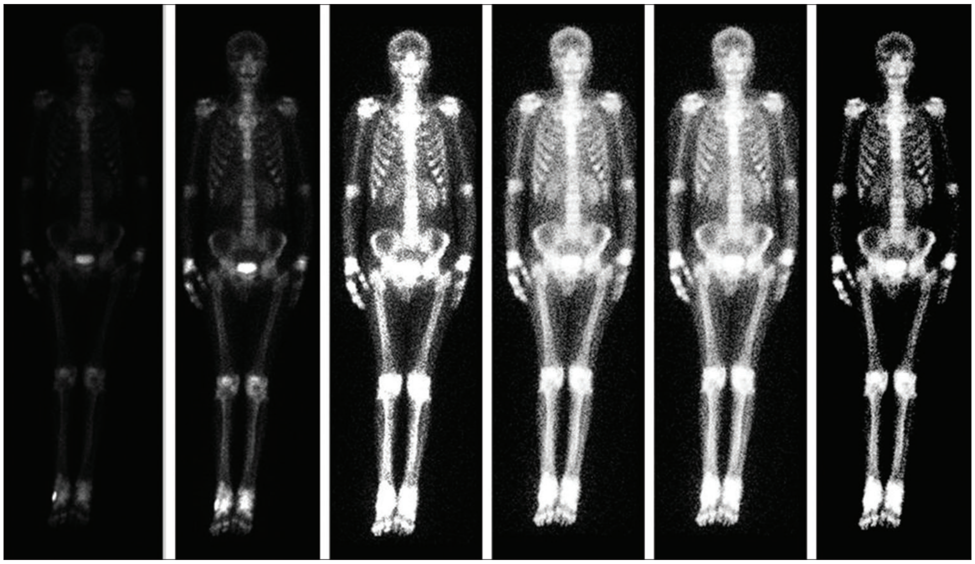

Figure 5: Input image, processed image using window-level contrast adjustment tool (2nd and 3rd), processed images using 1st, 2nd, and 3rd method used in this study (from left to right)

Table 1: Average score assigned to the input and processed images

	Input image	Processed image
Average score	1.74	3.47
Median	1.5	3.5
Mode	1	4
SD	0.74	0.72
Maximum	3.5	5
Minimum	1	1
Total number of image	89	89

SD: Standard deviation

processed image was statistically significant or not. We found statistically significant difference between the input and output image score with $P < 0.001$ (with $\alpha = 0.05$). The mean and variance of the input and output image score were 1.74 and 0.55 and 3.47 and 0.52, respectively. The plot of individual image score assigned by two observers is given in Figure 6.

Discussion

The humans can only perceive <100 different gray levels in the image.[11] Thus, contrast enhancement is usually needed for better clinical readings. Linear intensity windowing techniques are the simplest and most commonly used method.[12] This process of selecting parameter values and interpreting resultant windowed ^{99m}Tc-MDP bone scan image is time-consuming, even with the availability of digital imaging with displays that allow window settings to be varied rather quickly through an interactive console.

There is no general unifying theory of image enhancement at present. One of the most common defects of scintigraphy images is poor contrast resulting from a reduced (and perhaps nonlinear) image amplitude range. Image contrast can often be improved by amplitude rescaling of each pixel.[13] The histogram of a ^{99m}Tc-MDP bone scan is usually highly skewed toward the darker levels; most of the pixels possess counts less than the average. In such images, detail in the darker regions is often not perceptible. There are studies in which authors have produced enhanced images using histogram equalization process in which the histogram of the enhanced image is forced to be uniform.[14-16]

The enhanced images provide subtle details of tissues that are only visible with tedious contrast/brightness windowing methods currently used in clinical reading [for example ribs are very clearly depicted in Figures 3d, 4 and 5]. However, there is also grayscale compression in high gray-level regions. We have applied the technique on small ROI image also and have found the similar results as applied on the whole-body image.

The technique is fully automatic and improves readability of the low contrast ^{99m}Tc-MDP bone scan. Using input and processed images in combination, many clinical questions can be answered.

Such output images may produce false-positive results in some cases if the reporting is made solely based on histogram equalization followed by contrast stretch and the normalization as authors have mentioned in the study.[9] Since this was a retrospective study, number of false-positive results were not considered or investigated in this study. This technique can be applied on low contrast studies and can be, especially, useful if one is not interested in looking for contrast between bone tissue uptakes and is only interested in looking for the presence of a lesion. Still, there is a need for finding a method that can improve the histogram equalized image significantly for the

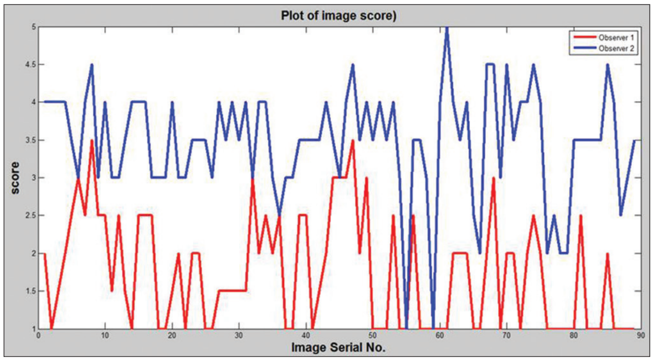

Figure 6: Images and their corresponding image quality score (ordered by same serial number for comparison along vertical)

visualizing purpose as is indicated by the nuclear medicine physicians through the average image score of 3.5. In future, we would like to investigate another postprocessing method that can be applied after histogram equalization technique in an attempt to mitigate the negative effect of histogram equalization technique, that is, compression of gray-level range in the high amplitude gray levels, for the enhancement of ^{99m}Tc-MDP bone scan.

Conclusion

GHE techniques can be used on low contrast images. In some of the cases, a histogram equalization technique in combination with some other postprocessing technique is useful.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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