Original Article

Methylene Diphosphonate Bone Scan Scintigraphic Image Enhancement using Gamma Correction and Optimizing the Value of Gamma

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Abstract

Introduction: Focal areas of high radiotracer uptake in a bone-scan image can result in dynamic range of the intensity value to exceed the dynamic range of the display, requiring multiple interactive contrast adjustments. This unnecessary burden on time of physician can be avoided using power law equation to brighten up the low-intensity areas in image. However, despite the widespread availability of this technique in commercial systems, for this clinical setting, the gamma-value needs to be standardized. **Materials and Methods:** Sixty dark bone scan images were selected. Ten randomly selected images from this set were evaluated qualitatively and quantitatively (perception-based image quality evaluator, absolute mean brightness error, structural similarity, and peak signal to noise ratio) to select a range of gamma values (from 0.1 to 0.9, increment of 0.1), where the results were acceptable. This range of gamma was then applied to rest of the 50 images to find the best value. Images were evaluated by two experienced nuclear medicine physicians. Although not ideal, but for the purpose of simplicity, we tried reaching a single best value. For this, the physicians were asked to reach consensus on the acceptable images. **Results:** In the first part of the study, after evaluation of 100 images (1 original and 9 processed images with 0.1–0.9 gammas), range of gamma values from 0.3 to 0.8 was found to be optimum. This range was then applied to rest of the 50 images. Evaluation of resultant 350 images (1 original and 6 processed for each input image) further narrowed this range to 0.4–0.7 (0.3 gamma selected only twice by one physician). The kappa for acceptable images was moderate at 0.482 (P <0.001). The single gamma value of 0.6 resulted in 72% of the images to be acceptable. **Conclusion:** Use of power law equation to brighten up the low intensity areas of dark bone scan images, without loss of clinically significant details, is feasible with single gamma value of 0.6 and range of 0.4–0.7 giving best results.

Keywords: *Dark bone scan images, gamma correction, methylene diphosphonate bone scan, power law equation*

Introduction

The bone responds to injury and disease with increased turnover. This osteoblastic process can be imaged with 99mTc-methylene diphosphonate (MDP) which binds in the hydroxyapatite mineral component of the osseous matrix by chemisorption.[1] Postradiotracer injection, whole body scintigraphic image of the patient is acquired with gamma camera and is displayed on either a high-resolution cathode-ray tube or liquid crystal display system for diagnostic interpretation.[2] The most commonly used display system has ability to display 256 intensity values accurately and is sufficient to produce a sequence of brightness levels perceived as continuous by the human observer.[3]

There are a few situations (for example, cases where there is high radiotracer activity in bladder or at site of extravasation or contamination and sometimes in cases of high-intensity focal uptake in primary tumor site or metastatic site) in which dynamic range of the intensity value in the image exceeds the dynamic range of the display system. Dark bone scan image can also be seen due to technical reasons like insufficient amount of activity present in the patient at the time of data acquisition, insufficient amount of counts collected, and poor uptake of the radiopharmaceutical. In all these cases, only high-intensity values in the image are displayed, and most of the other areas appear as black. Thus, overall, the image becomes a dark image, with many areas of relatively lower uptake, which are not clearly visible. [Figure 1]

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To visualize the details in areas of relatively low intensity values, interactive adjustment with contrast adjustment tool is often needed. This is often a linear contrast stretching tool which allows the users to customize the pixel intensity to suit their needs. However, this process also reduces the gray tone in the image, and multiple adjustments are needed to clearly visualize all the relevant details. Thus, interactive adjustment can result in unnecessary expenditure of time and energy.

Dark bone scan images can be processed to make them brighter while preserving clinically relevant details. In this way, the time spent by nuclear medicine physician in interactive contrast adjustment can be better utilized in reviewing other patient images. One of the methods to achieve this is based on the power law equation which states that $O = (I)^{\gamma}$, where O is the output image, I is the input image, and γ is the parameter, whose fractional values can be changed to convert a dark image into a bright image.[4,5] Gamma correction is available in most commercial systems; however, the challenging task is to determine the appropriate value of γ, which produces image acceptable to nuclear medicine physician for the purpose of reporting.

This study was conducted in order to optimize the value of γ for 99mTc-MDP dark bone scan images.

Materials and Methods

Image acquisitions: 60 dark bone scan images were selected from 101 99mTc-MDP bone scans performed in the department between January 1, 2018 and November 31, 2018.

The bone scan images were acquired with half-standard time protocols. The standard speed of acquisition used in our department varies between 20 and 30 cm/min, depending on the count rate. The average counts obtained were 933,264 ± 520,662, but no cutoff could be found to classify the images as dark, on the basis of counts.

The acquisition protocol for these images was as follows: "555–740 MBq 99mTc-MDP dose was administered intravenously to the patients and they were asked to drink plenty of water and void frequently during the uptake phase (3 h postinjection). After 3–4 h, anterior and posterior whole body images were acquired using Siemen's Symbia (dual head gamma camera) with low-energy high-resolution collimator at matrix size 1024 × 256, zoom-1, table speed 40–60 cm/min."

These 101 bone scan studies were exported in DICOM format. An R script was written to read, display and save the anterior and posterior images on hard disk in PNG format using oro.dicom, and EBImage library. After reviewing these images, 60 dark images were selected by a nuclear medicine physician.

Image processing

The optimum fractional value of γ that can produce acceptable image can theoretically range between 0 and 1. Getting the nuclear medicine physician to review a large number of images (using entire range of gammas) is extremely wasteful of their time. Therefore, we deemed it important to reduce the number of images to be reviewed, by limiting the range of gamma values.

Therefore, the study was divided into two parts. In the first part, 10 randomly sampled bone scan images were processed with gamma values in the range (0.1–0.9), at an increment of 0.1 and were then visually and quantitatively assessed to select the range of γ which consistently produced acceptable image. To draw these 10 sample images, sample function having parameter "using with replacement" of R base package was used. Ten images for each input image (one input and 9 processed images) [Figure 2] were inspected visually for any artifacts created by the processing algorithm. The quantitative image quality score for these images was also calculated, and the box plot of perception based image quality evaluator (PIQE), structural similarity (SSIM), peak signal to noise ratio (PSNR), and absolute mean brightness error (AMBE) score were also examined [Figure 3]. The PIQE, SSIM, PSNR, and AMBE score were calculated using MATLAB R2018b. PIQE is no-reference image quality score in the range (0, 100) and is inversely correlated to the perceptual quality of an image.[6] A low score value indicates high perceptual quality, and high score value indicates low perceptual quality. SSIM is based on the assumption that human visual perception is highly adapted for extracting structural information from a scene and assesses the image quality based on the degradation of structural information.[7] PSNR is an image quality estimator. A 20 dB or higher PSNR indicates that the image is of good quality. AMBE, which is the deviation of the mean intensity of the enhanced image from the mean intensity of the original image, is calculated by finding the absolute difference between the mean intensity of the output and the input image.[8] The mean intensity was calculated as the sum of all pixel values divided by a number of pixels in the image.

Based on both visual and quantitative assessment of image quality, it was decided that the image quality of the images processed with gamma value in (0.3–0.8) at the increment of 0.1 will be used for final evaluation by two nuclear medicine physicians. We decided to exclude the images processed at gamma 0.1, 0.2 (very bright image maximum number of pixels in the image were saturated), and 0.9 (the image was dark and almost similar to the input image).

Thus, in the second part of the study, remaining 50 images were processed and 50 × 7 (one input image and six processed images) =350 images were obtained. Two experienced nuclear medicine physicians evaluated these images under the same ambient lighting condition on the

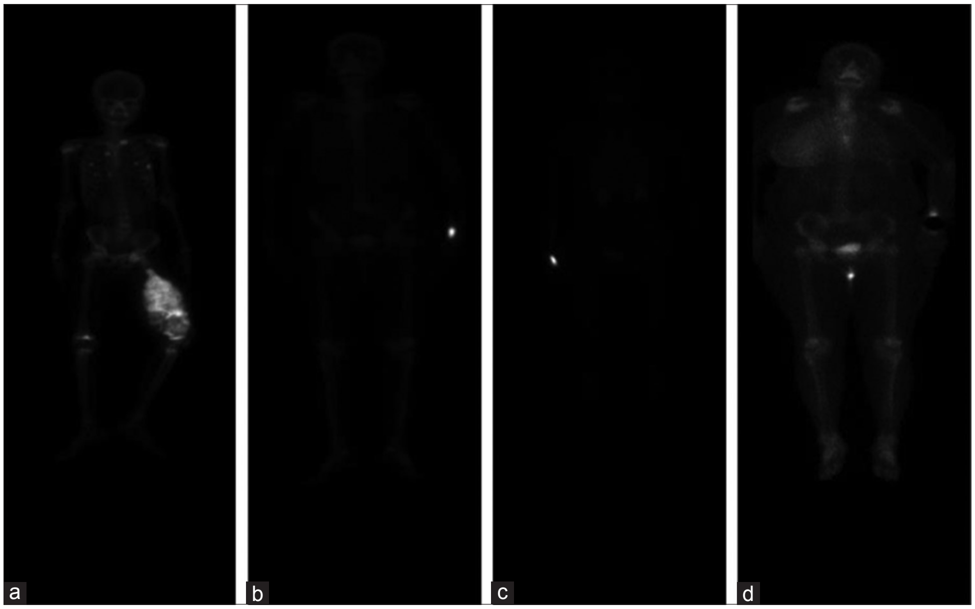

Figure 1: Examples of dark bone scan images. (a) The high uptake in primary mass; (b and c) extravasation at injection site; (d) low count image necessitates the need of multiple contrast adjustments for proper evaluation of other skeletal sites

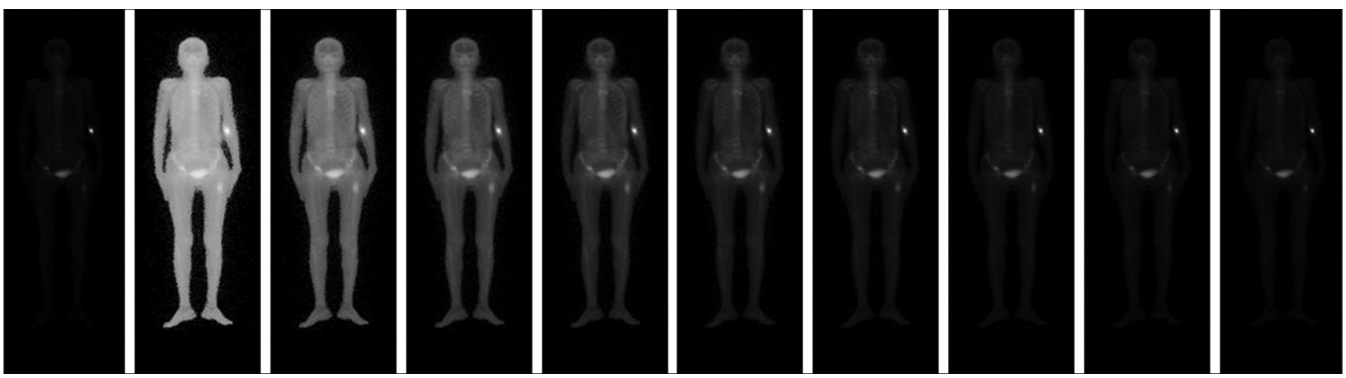

Figure 2: From left to right; 1st image in the original image and rest are processed images with gammas from 0.1 (2nd from left) to 0.9 (extreme right)

HP 120–1060 in Generic PnP LCD monitor with native resolution 1600 × 900 (HD+), diagonal size 20 inch, response time 5 ms, and image contrast ratio 1000:1. The experiments were performed on a personal computer having Windows 7 Home Basic (copyright©2009 Microsoft Corporation) 64-bit operating system, 2 GB RAM, and Intel (R) core (TM) i32120 CPU at 3.30 GHz processor, and the resulting images were viewed on the monitor specified above.

They were asked to select one processed image that did not require window-level contrast adjustment tool and was acceptable for reporting purpose with high confidence and comment on "whether the selected processed image is having details clearly visualized in comparison to its input image?" Each processed image was labeled sequentially as 1, 2, 3, 4, 5, and 6 [Figure 4]. The reviewers were asked to record the label assigned to preferred processed image.

The statistical analysis was performed, and figures and graphs were generated using R version 3.5.1 (July 2, 2018), nickname feather spray. The unweighted Cohen's kappa for two Raters for interrater agreement was calculated using the irr package version 0.84.[9]

Results

In the first part of the experimentation, it was observed that smaller values of gamma made the processed image very bright resulting in washed-out appearance. With increase in value of γ, there was a decrease in overall image brightness, and with γ approaching the value of 1, the processed image became dark, same as the input image. Based on visual assessment of image quality, the gamma range of (0.3–0.8) gave best results. This was supported by quantitative assessment, where this range gave a PSNR above 20 with a lower PIQE and AMBE scores. Similarly, SSIM scores were higher. Furthermore, these indices for gamma values of 0.9 were almost similar to those of original image.

Of the 350 images (one input image and 6 processed images at different value of γ), approximately 72% (36 of

Table 1: (a) Tabulated value of the number of images acceptable by Nuclear Medicine Physician (NMP) 1 and NMP2 before consensus, (b) The number of images acceptable to NMP1 and NMP2, after consensus, 1, 2, 3, 4, and 5 are image labels, representing images processed with gamma 0.3, 0.4, 0.5, 0.6, and 0.7, respectively

NMP1	NMP2			
	2	**3**	**4**	**5**
1	2	0	0	0
2	3	0	0	0
3	0	3	0	2
4	0	9	28	1
5	0	0	0	2
a	Kappa=0.482, *P*<0.001, Before consensus			

NMP1	NMP2			
	2	**3**	**4**	**5**
2	5	0	0	0
3	0	6	0	0
4	0	0	36	1
5	0	0	0	2
b	Kappa=0.955, *P*<0.001, Before consensus			

50) of the dark images became acceptable for reporting purpose when processed with gamma 0.6. Both nuclear medicine physicians agreed that the selected processed image had clearly visualized details when compared to its input image. The unweighted Cohen's kappa for two nuclear medicine physicians was calculated, and a moderate agreement of 0.482 (P = 5.18e-09) was found. However, there was a possibility that despite disagreement, same image may have been acceptable to both reviewers. Therefore, both of them were asked to reach a consensus and select an image which was acceptable to both. In this case, in 72% cases, both the physicians rated image with label 4 (gamma of 0.6) as acceptable. [Table 1] As shown in Table 2, mean and median PIQE scores of processed images with gamma of 0.6 were lower than those with lower and higher gammas. The SSIM scores of processed image demonstrated that in majority of the processed images, this transformation resulted in more than 60% similarity in structure with the input image. PSNR scores of processed images were equal to or greater than 20 dB for gamma more than 0.5, meaning a good quality of the processed images. The AMBE score of processed images, numerically demonstrated that although the brightness

Table 2: Descriptive statistics of the processed images in terms of perception based image quality evaluator, structural similarity, absolute mean brightness error, and peak signal to noise ratio score

Gamma	Mean±SD, median (minimum-maximum)			
	PIQE	**SSIM**	**AMBE**	**PSNR**
0.4	68.27±3.21, 61.48 (58.46-70.15)	0.61±0.09, 0.59 (0.48-0.71)	19.37±8.00, 21.13 (9.80-30.76)	17.55±2.77, 16.81 (13.82-21.16)
0.5	63.45±5.74, 63.84 (56.63-71.17)	0.60±0.06, 0.61 (0.50-0.67)	13.60±3.66, 13.46 (7.54-18.61)	20.30±2.18, 20.02 (18.01-24.32)
0.6	64.52±4.14, 65.57 (55.48-72.39)	0.63±0.04, 0.62 (0.54-0.76)	13.03±2.65, 12.89 (7.81-18.35)	21.06±1.29, 21.06 (18.83-24.03)
0.7	73.77±5.68, 72.39 (68.91-80.02)	0.80±0.08, 0.74 (0.64-0.90)	7.62±5.85, 10.41 (0.95-11.64)	27.78±9.41, 22.74 (21.96-38.64)

PIQE: Perception-based image quality evaluator, SSIM: Structural similarity, AMBE: Absolute mean brightness error, PSNR: Peak signal to noise ratio, SD: Standard deviation

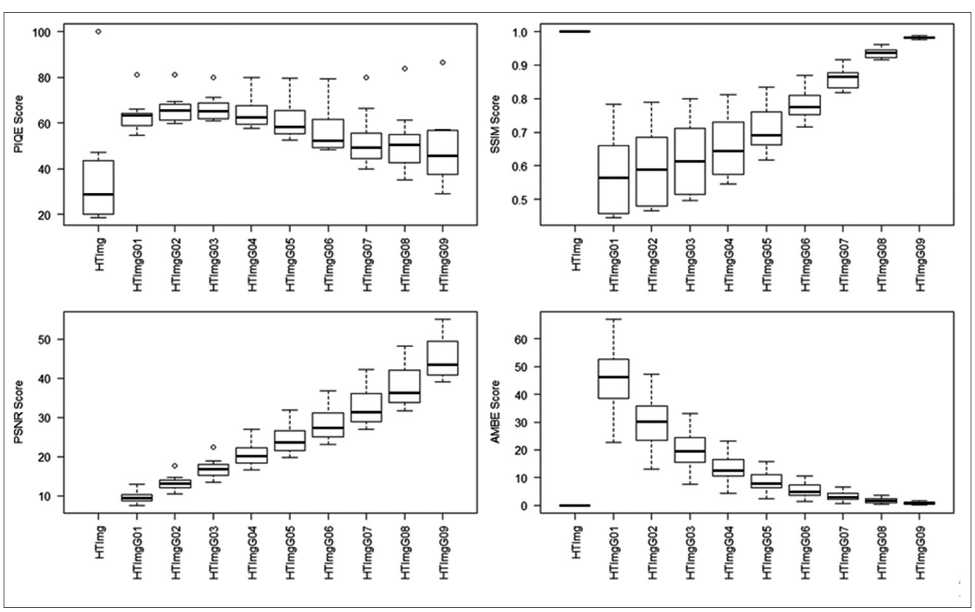

Figure 3: Box plot of perception-based image quality evaluator, structural similarity, peak signal to noise ratio, and absolute mean brightness error score of 10 sampled images, input image dataset and 9 image dataset processed with gamma (0.1–0.9) at the increment 0.1 of 10 randomly sampled images in each data set

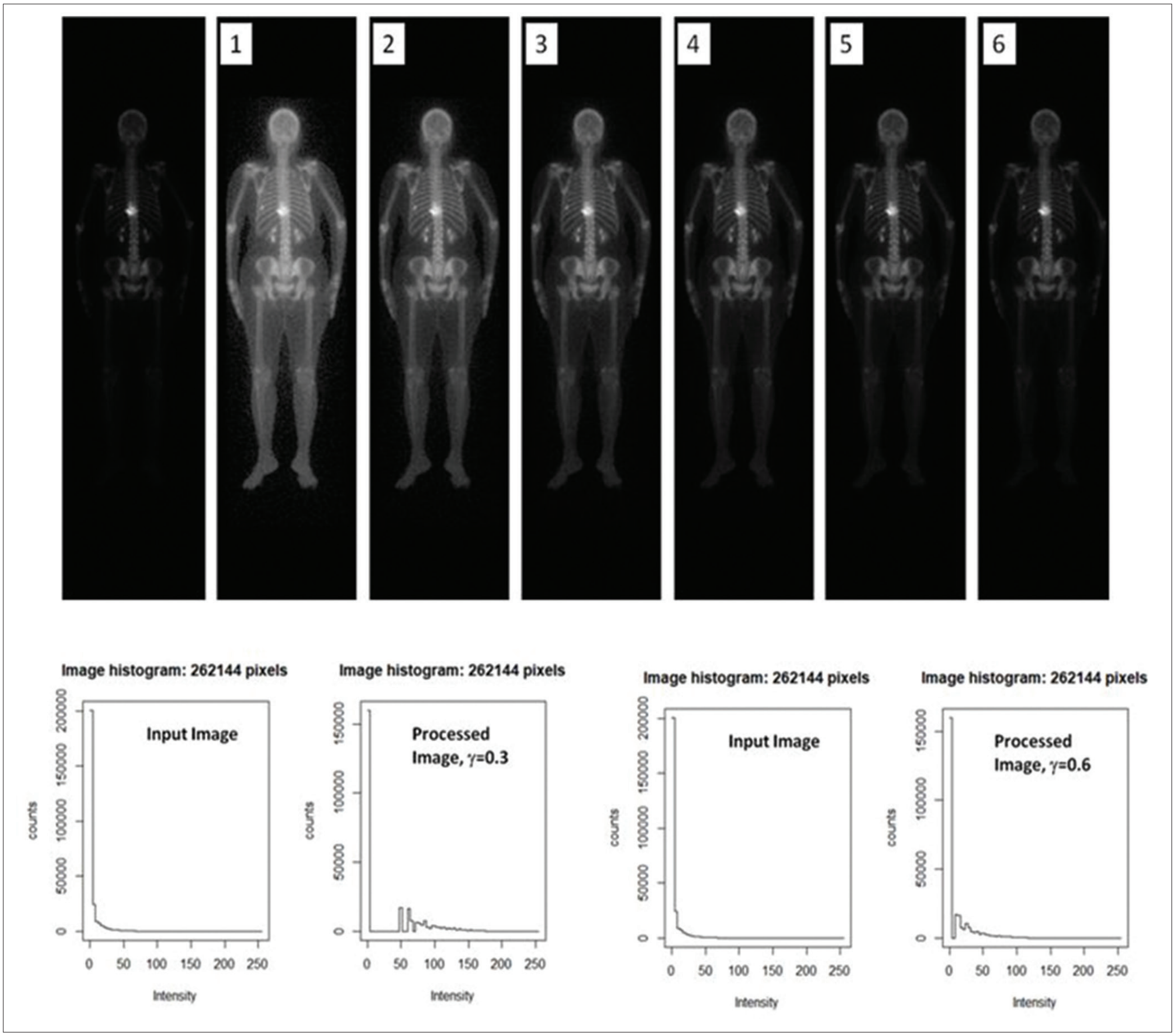

Figure 4: Top row images - An example in which each processed image was assigned a label (label 1 - gamma of 0.3 to label 6 with gamma of 0.8). Nuclear medicine physician was asked to record the label of their preferred processed image. Bottom row - the histogram of input and processed images at γ = 0.3, an 0.6 respectively. The transformation function did not disturb the characteristics of input image significantly

of the processed image was visually improved, there was little deviation from the mean intensity of input image, thus avoiding a washout appearance.

Discussion

Interactive adjustment of image intensity with contrast adjustment tool is often needed to visualize low intensity areas, in cases with regional high radiotracer activity. However, this reduces gray tone, and multiple adjustments are necessary. There are number of techniques available for image enhancement; each technique has been developed to solve a specific problem.[4,5] Histogram equalization has been used to improve the quality of bone scintigraphic images.[10,11] Ardenfors *et al*.[12] applied Pixon algorithm to improve the bone scintigraphic images acquired with half the standard scan time. They found that the processed images have sufficient clinical information; however, these images were graded lower in comparison to images acquired with full time protocol.[12] Pandey *et al*. have used intensity transformation function to improve the quality of dark bone scan images.[13] This idea to improve the contrast was to compress the dark pixels toward more darker and bright pixels toward brighter and hence increase the contrast of the image. The transformation curve passes through the mean intensity of the pixel. Another technique available for this purpose is using the power law transformation. Similar to intensity transformation function, this technique performs the task of contrast enhancement; however, the transformation curve does not pass through the mean intensity of the pixel, and hence, the amount of contrast enhancement produced in the processed image is different.

Power equation law can be used to brighten image without loss of clinically relevant details, thus saving time and energy. Furthermore, gamma correction tools are commonly available in most commercial systems. However, gamma values need to be standardized. In this study, we found gamma range of 0.3–0.8, to encompass the optimum value of the gamma. This allowed us to reduce the total number of images to be evaluated. Further, we were able to narrow this range to 0.4–0.7. The gamma of 0.6 alone was able to improve 72% of the dark images. The result of the study demonstrates that although a unique value of γ is not sufficient to improve the image quality of every dark bone scan image, still in majority of cases, we can use this single value.

We further validated our findings by comparison with objective parameters such as PIQE[6], SSIM[7], PSNR, and AMBE[8]. Although absolute values of these individual parameters are of little importance in cases where clinically relevant details occupy higher significance, even when image is perceptually inferior, their values can be used for comparison. For example, the lower PIQE score at gamma of 0.6, when compared to both higher and lower values, signifies better perceptual quality of the image. SSIM score showed that processed images were at least 60% similar to the original, meaning that processing method had not introduced too much deviation from original. Low AMBE signified low deviation from mean intensity of the original image, thus brightness increase had not caused washout. Finally, PSNR values of above 20 signified good quality. Thus, our results were matched both qualitatively and quantitatively.

It must be noted that for final analysis, using effect of gamma correction on normal aspects of the image than clinical abnormalities in the image, can be counterintuitive. However, in dark bone scan images and in half-time acquisitions like we used for this study, the normal aspects of the scan (i.e. uninvolved bone) are the ones which suffer the most. Involved areas usually have counts a few standard deviations above the normal bone and many techniques for improving the image do not necessarily deteriorate these areas to the same extent as normal areas. Therefore, before evaluating the images, the physicians were asked to focus on evaluating uninvolved areas and how confident they were in reporting these aspects as normal.

This study has demonstrated that power law equation can used to process the dark bone scan images. These processed dark bone scan are in the visual state that does not require contrast adjustment tool, in majority of the cases. Therefore, the use of this technique can save the time spent during interactive adjustment of the contrast.

Furthermore, this is a simple procedure which can be easily automated. In future, we would like to work on the automation of this procedure, in which the program will accept the input image and make a proper decision on the value of gamma to be used to enhance the input image and display the final output image. It was to this end that despite getting a range of 0.4–0.7, which consistently gave acceptable results, we still strived to reach a common value. Although asking two physicians to reach consensus was less than ideal, this was based on observation that multiple images can be agreeable to both physicians and therefore a possibility to reach a single result is there.

Conclusion

There is no unique value of gamma with which all dark bone scan images can be converted into a bright image acceptable to nuclear medicine physicians. However, best results can be obtained for bone scan images with a gamma range of 0.4–0.7.

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Conflicts of interest

There are no conflicts of interest.

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