Original Article

Near-lossless Compression of Tc-99 m DMSA Scan Images Using Discrete Cosine Transformation

Abstract

Aim and Objective: The objective of this study was to optimize the threshold for discrete cosine transform (DCT) coefficients for near-lossless compression of Tc-99 m Dimercaptosuccinic acid (DMSA) scan images using discrete cosine transformation. **Materials and Methods:** Two nuclear medicine (NM) Physicians after reviewing several Tc-99 m DMSA scan images provided 242 Tc-99 m DMSA scan images that had scar. These Digital imaging and communication in medicine (DICOM) images were converted in the Portable Network Graphics (PNG) format. DCT was applied on these PNG images, which resulted in DCT coefficients corresponding to each pixel of the image. Four different thresholds equal to 5, 10, 15, and 20 were applied and then inverse discrete cosine transformation was applied to get the compressed Tc-99 m DMSA scan images. Compression factor was calculated as the ratio of the number of nonzero elements after thresholding DCT coefficients to the number of nonzero elements before thresholding DCT coefficients. Two NM physicians who had provided the input images visually compared the compressed images with its input image, and categorized the compressed images as either acceptable or unacceptable. The quality of compressed images was also assessed objectively using the following eight image quality metrics: perception-based image quality evaluator, structural similarity index measure (SSIM), multiSSIM, feature similarity indexing method, blur, global contrast factor, contrast per pixel, and brightness. Pairwise Wilcoxon signed-rank sum tests were applied to find the statistically significant difference between the value of image quality metrics of the compressed images obtained at different thresholds and the value of the image quality metrics of its input images at the level of significance = 0.05. **Results:** At threshold 5, (1) all compressed images (242 out of 242 Tc-99 m DMSA scan images) were acceptable to both the NM Physicians, (2) Compressed image looks identical to its original image and no loss of clinical details was noticed in compressed images, (3) Up to 96.65% compression (average compression: 82.92%) was observed, and (4) Result of objective assessment supported the visual assessment. The quality of compressed images at thresholds 10, 15, and 20 was significantly better than that of input images at $P < 0.0001$. However, the number of unacceptable compressed images at thresholds 10, 15, and 20 was 6, 38, and 70, respectively. **Conclusions:** Up to 96.65%, near-losses compression of Tc-99 m DMSA images was found using DCT by thresholding DCT coefficients at a threshold value equal to 5.

Keywords: *Discrete cosine transform, image compression, Tc-99 m DMSA scan images*

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Introduction

The number of studies performed in nuclear medicine (NM) is increasing day by day, and consequently, the amount of data generated too. Since, the volume of data is a major issue in the processing, storage, transmission, and display of image information due to the limited storage space available and limited transmission bandwidth. There is a recent interest in the compression of NM images.[1-3]

The DMSA study is performed for clinical indications such as to detect areas of pyelonephritis and to differentiate areas of scarring. Pyelonephritis causes tubular dysfunction and thus reduced uptake of Tc-99 m DMSA. Forty to fifty percent of Tc-99 m DMSA binds to renal cortical tubules and thus, helps in the detection of the scar.[4] Usually, three projection images of the kidney are acquired in 256 × 256 matrix having a pixel depth of 16 bits and stored in a DICOM file. Hence, the storage requirement of one DMSA study is 3,145,728 bits. Processing, storing, and transmitting (reading/writing on CD, USB, PACS, or network) of one DMSA study (3MB file) does not seem to be an issue.

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However, the processing, storing, and transmitting of a large number of DMSA studies (i.e. large volume of data) becomes a major issue, and the need for reducing the volume of data (compressing image) is recognized. With the reduction in the volume of data, transmission becomes faster, and large number of studies can be stored on physical data storage devices. With this motivation, we have conducted the study for compression of Tc-99 m DMSA scan images.

The compression of Tc-99 m DMSA studies was performed using discrete cosine transformation. In a discrete cosine transform (DCT)-based compression scheme, larger DCT coefficients contain significant information of the image while smaller coefficients contain the least significant information of the image which can be discarded. That is, only high-amplitude DCT coefficients were retained. DCT coefficients which are smaller than a threshold are set to 0, and then inverse DCT is applied to obtain the compressed image. The value of the threshold has been optimized and the percentage compression at each threshold has been calculated. The quality of compressed images at each threshold has been visually and objectively assessed.

Materials and Methods

Discrete cosine transformation

The DCT was proposed by Ahmed[5] and is adopted by the Joint Photographic Experts Group (JPEG)-the most widely used image file format.[6]

The DCT is a fast transform. It is a widely used and robust method for image compression. It gives good compromise between information packing ability and computational complexity.[7]

The forward two-dimensional (2D) DCT[8] of a signal *f (m, n)* is given by

$$F\left[k,l\right]=\alpha\left(k\right)\alpha\left(l\right)\sum_{m=0}^{N-1}\sum_{n=0}^{N-1}f\left(m,n\right)cos\left[\frac{(2m+1)\pi k}{2N}\right]cos\left[\frac{(2n+1)\pi l}{2N}\right]$$

Where $\alpha\left(k\right)=\begin{cases}\frac{1}{\sqrt{N}} & if\ k=0\\ \sqrt{\frac{2}{N}} & if\ k\neq 0\end{cases}$

Similarly, $\alpha\left(l\right)=\begin{cases}\frac{1}{\sqrt{N}} & if\ l=0\\ \sqrt{\frac{2}{N}} & if\ l\neq 0\end{cases}$

The 2D inverse DCT is given by

$$f\left[m,n\right]=\sum_{k=0}^{N-1}\sum_{l=0}^{N-1}\alpha\left(k\right)\alpha\left(l\right)F\left(k,l\right)cos\left[\frac{(2m+1)\pi k}{2N}\right]cos\left[\frac{(2n+1)\pi l}{2N}\right]$$

f (m, n) represents the pixel value corresponding to m^{th} *row* and n^{th} *column* of the image matrix. *m* ranges from 0 to N-1 and n ranges from 0 to N-1, where N is the block size. In this study, the block size (N) was equal to the image matrix size; i.e. block size (N) was equal to 256 for a 256 × 256 image matrix.

The forward 2D DCT of a signal *f (m, n)* results in DCT coefficients (F [k, l]) of the image; here, k and l also range from 0 to N-1.

Compression ratio and percentage compression

Compression ratio (CR) was calculated as the DCT of a given image gives DCT coefficients of the image. After thresholding, the matrix of DCT coefficients will become a sparse matrix (i.e. a matrix having very few numbers of nonzero elements). For a sparse matrix, we only need to store nonzero elements resulting in large reduction in size. The full matrix can be reconstructed from the sparse matrix when needed. The inverse DCT will be applied on the sparse matrix data to reconstruct the image in the spatial domain. The CR was calculated as the ratio of the nonzero elements in the DCT coefficients matrix without thresholding to the number of nonzero elements in the DCT coefficients matrix after thresholding.

The percentage compression is calculated using the formula: $(1-\frac{1}{CR})\times 100.$

Where CR is CR.

Image acquisition protocol and image data collection

Tc-99 m DMSA scan images were acquired using the following protocol: "*Patients were instructed to drink at least 1 to 2 liters of water and void their bladder frequently to reduce the radiation burden in the body. Then, 185 MBq (5 mCi) DMSA was administered, and then 3 h later, three projection images (namely posterior, left posterior oblique, and right posterior oblique) were acquired on Siemens Symbia T6 Single-photon emission computed tomography (CT) CT dual-head gamma camera. The scanner was equipped with low energy high-resolution collimator, and image acquisition matrix size was 256× 256 with zoom 1.5.*"

Two NM Physicians after reviewing several Tc-99 m DMSA scan images provided 242 Tc-99 m DMSA scan images that had scar. These DICOM images were converted in the Portable Network Graphics format.

Image processing

Total number of images in the study was 242. The following procedure was repeated for each image; "*The DC transformation on the image was applied which resulted in DC transformation coefficients. Four different thresholds (5, 10, 15, and 20) were applied on the resulted DC transformation coefficients and then inverse DC transformation was applied to get the compressed image.*"

Thus, based on our previous experience, we choose the four different thresholds.[9] All experiments were performed on a 3.30GHz i3-2120 CPU with 2 GB RAM, running 64-bit Microsoft Windows operating system. A personal computer program was written in MATLAB R2020b (The Math Works, Inc. 3 Apple Hill Drive Natick, MA 01760-2098) to read and compress DICOM images using DCT.[10]

Subjective assessment of images quality

Two hundred and forty-two sets of five images (one input and its corresponding four compressed images obtained at thresholds 5, 10, 15, and 20) were compared. The two NM physicians who provided the input images; performed the task of comparing the images. They categorized the compressed images as either acceptable or unacceptable. The size of the scar can be small, medium, and large. NM Physicians compared the appearance of scar (i.e. its size and position) in input images with its corresponding compressed images at different thresholds. If they found reduction or enlargement in the size of the scar then they consider these images as unacceptable.

Objective assessment of image quality

The quality of input and compressed images was also evaluated objectively. The image quality metrics used for this purpose were brightness, perception-based image quality evaluator (PIQE),[11] structural similarity index measure (SSIM),[12] multiscale-SSIM (MS-SSIM),[13] feature similarity indexing method (FSIM),[14] blur,[15] global contrast factor (GCF),[16] and contrast per pixel (CPP).[17]

Lower the PIQE score, higher the quality of images and vice versa. The SSIM measures perceived quality between an image and reference image. Higher the SSIM, the more the compressed image is to its input image. MS-SSIM function calculates the MS-SSIM index by combining the SSIM index of several versions of the image at various scales. The MS-SSIM index can be more robust when compared to the SSIM index with regard to viewing conditions. MATLAB MS-SSIM function calculates the MS-SSIM index, score for input-image, using a reference image. A value closer to 1 indicates better image quality and a value closer to 0 indicates poor quality. FSIM gives the normalized mean value of feature similarity between two images, i.e. higher the FSIM, higher the feature similarity between two images. Brightness was estimated as the mean intensity of the image which measures the perceived brightness of the image, i.e. it should be optimum. GCF is the average local contrast of smaller image fractions. Higher the GCF, higher is the detail in the image. CPP is defined as the average of the absolute difference of luminance value with the adjacent pixels. Higher the CPP value, the more the CPP. In general, if the difference with the neighboring pixels is high, distinguishing object details is easy. Blur is the nonreference perceptual blur metric with values ranging from 0 to 1. Zero value of blur indicates no smoothing while 1 indicates heavy smoothing.

Statistical analysis

A pairwise comparison using Wilcoxon rank-sum test with continuity correction was performed to find the statistically significant difference between the value of image quality metrics (i.e. PIQE, SSIM, MS-SSIM, FSIM, brightness, GCF, CPP, and blur) of the input image and the compressed images obtained at different thresholds 5, 10, 15, and 20. The level of significance for the test was 0.05. R open-source statistical software[18] was used for the statistical analysis (for Wilcoxon signed-rank test) and the boxplots. The EBImage package[19] developed to be used with R software was used for arranging the images.

Results

Subjective assessment of image quality

All compressed images at threshold 5 were acceptable to both the NM Physicians, and according to them, compressed image looks identical to its input image, and they labeled all compressed images as acceptable. At thresholds 10, 15, and 20, some of the compressed images were also labeled as unacceptable. It was predecided that if any image is unacceptable to any one of the NM Physicians, then that image will be labeled as unacceptable. The result of visual assessment is summarized in Table 1. Figure 1 shows the example of acceptable image by both the NMPs.

NM Physicians observed that the small scars in the kidneys are clearly visualized in the compressed images at thresholds 5 and 10, whereas the medium and large scars in the kidneys are clearly visualized at thresholds 15 and 20 images. The size of the small scar in the input image appeared as large scar in some of the compressed images at thresholds 10, 15, and 20; and thus, labeled as unacceptable compressed images because these images are not providing true clinical details of the patients. One representative image of this kind is given in Figure 2.

Objective assessment of image quality

Our quantitative analysis supported the result of the visual analysis. The median value of PIQE, SSIM, MS-SSIM, FSIM, blur, GCF, CPP, brightness, CR, and percentage compression is given in Tables 2 and 3 with box plot in Figures 3 and 4. The median value of PIQE of the

Table 1: The number of acceptable and unacceptable compressed images at different thresholds out of total number of images 242

	Acceptable images	Unacceptable images
Threshold=5	242	0
Threshold=10	236	6
Threshold=15	204	38
Threshold=20	172	70

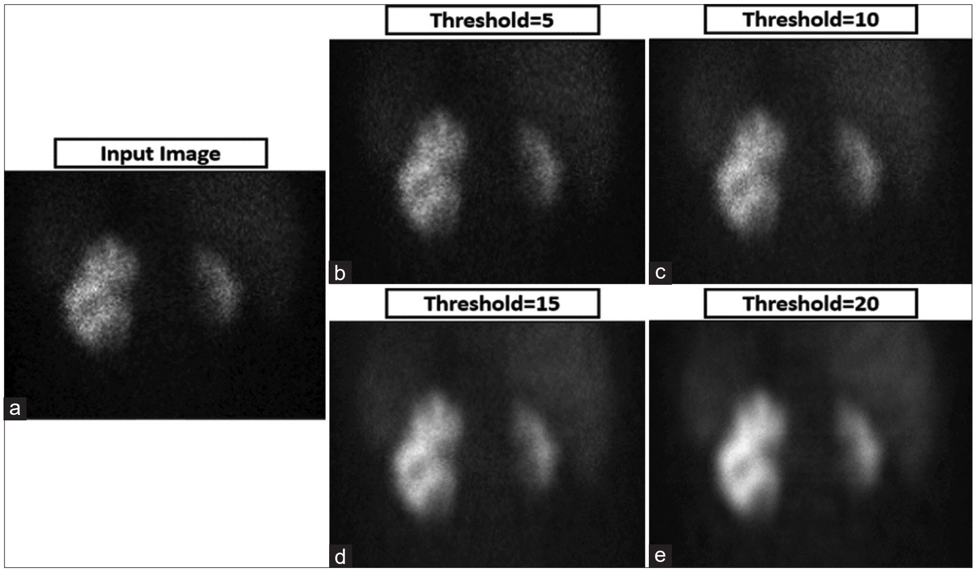

Figure 1: Input image and acceptable compressed images: (a) Input image, (b) Compressed image at threshold 5, (c) Compressed image at threshold 10, (d) Compressed image at threshold 15, and (e) compressed image at threshold 20

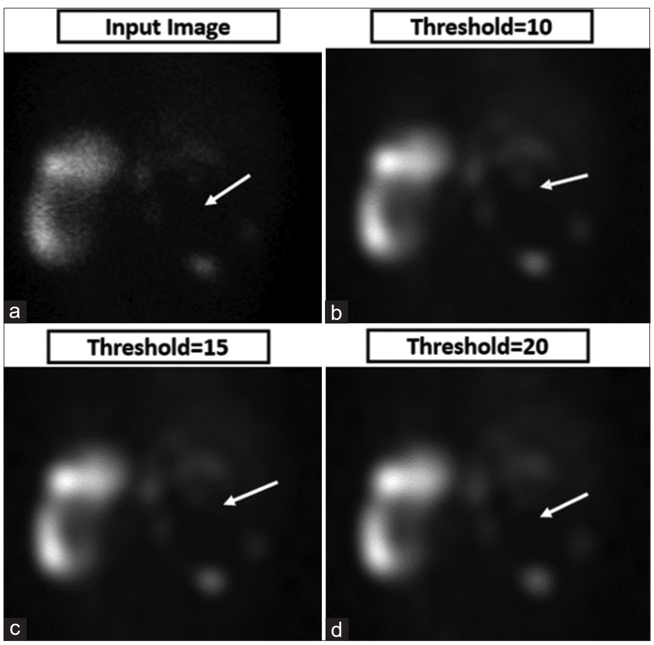

Figure 2: Example image of small scar in input image appeared as large scar in the compressed image. (a) Input image, (b) Compressed image at threshold 10, (c) Compressed image at threshold 15, (d) compressed image at threshold 20

compressed image at threshold 5 is lower than that of the input image which indicates the better perceptual quality of the compressed image. The median value of SSIM of the compressed image at threshold 5 is around 0.23 (which is greater than the median value of SSIM of the compressed image at thresholds 10, 15, and 20) indicates that the compressed image at threshold 5 was around 23% structurally similar to the input image. The median value of MS-SSIM at threshold 5 is 0.57 (which is the largest among the median value of the MS-SSIM of the compressed image at thresholds 10.15 and 20) indicates that at MS the compressed image at threshold 5 is structurally closer to the input image compared with the compressed image at different thresholds. Similarly, the median value of FSIM, GCF, CPP, and brightness of the compressed image at threshold 5 is greater than that of the compressed image at thresholds 10.15 and 20 indicating compressed image at threshold 5 had best feature, similarity, best contrast, best CPP, and was brightest. The median value of blur of the compressed image at threshold 5 is the smallest among median values of blur of compressed images at thresholds 10.15 and 20. After inspecting the image, it was confirmed that the amount of blur was optimum.

Statistical analysis

The quality of the compressed image at threshold 5 was significantly better than that of the input image as the value of image quality metrics (PIQE, SSIM, MS-SSIM, FSIM, blur, GCF, CPP, and brightness) of compressed images at threshold 5, 10, 15, and 20 were significantly different than the image quality metrics of its input images at the level of significance alpha = 0.05. All the images were acceptable at threshold 5, however, some of the compressed images were unacceptable at thresholds 10.15 and 20.

Discussion

NM images need to be efficiently compressed before transmission and storage, due to the limited storage capacity and limited bandwidth issues. An ideal image compression system must yield a high CR with good-quality compressed images. There are many compression techniques exists.[1-3] Among those image compression techniques, we have explored DCT-based image compression technique. We investigated the compression of Tc-99 m DMSA scan images on different thresholds (5, 10, 15, and 20) to find the optimized

Table 2: Summary statics of perception-based Image quality evaluator, structural similarity index measure, multiscale structural similarity index measure, feature similarity indexing method, blur, and global contrast factor

	Threshold=5	Threshold=10	Threshold=15	Threshold=20
PIQE				
Minimum	67.49	30.44	22.55	19.37
1st quartile	74.28	55.33	41.57	38.67
Median	75.09	67.19	48.09	44.69
Mean	75.02	63.13	50.46	45.51
3rd quartile	75.93	72.39	58.70	52.82
Maximum	77.58	77.18	78.10	74.11
SSIM				
Minimum	0.08	0.04	0.03	0.03
1st quartile	0.18	0.06	0.05	0.05
Median	0.23	0.08	0.06	0.05
Mean	0.25	0.11	0.07	0.06
3rd quartile	0.30	0.14	0.07	0.06
Maximum	0.60	0.43	0.30	0.19
Multiscale SSIM				
Minimum	0.40	0.32	0.28	0.25
1st quartile	0.50	0.38	0.34	0.31
Median	0.57	0.42	0.37	0.34
Mean	0.58	0.44	0.38	0.35
3rd quartile	0.63	0.48	0.40	0.37
Maximum	0.90	0.78	0.67	0.59
FSIM				
Minimum	0.92	0.89	0.84	0.79
1st quartile	0.95	0.90	0.87	0.85
Median	0.95	0.92	0.89	0.87
Mean	0.95	0.92	0.89	0.86
3rd quartile	0.96	0.92	0.90	0.88
Maximum	0.99	0.93	0.92	0.91
Blur				
Minimum	0.13	0.14	0.15	0.18
1st quartile	0.17	0.25	0.50	0.61
Median	0.19	0.36	0.59	0.64
Mean	0.19	0.36	0.54	0.61
3rd quartile	0.21	0.47	0.63	0.67
Maximum	0.38	0.66	0.72	0.75
GCF				
Minimum	343.3	351.3	374.1	381.7
1st quartile	634.5	613.0	621.9	633.8
Median	767.0	753.1	749.0	758.9
Mean	784.8	794.4	788.3	799.0
3rd quartile	903.5	938.5	915.5	918.5
Maximum	1470.8	1551.0	1708.9	1776.4

PIQE: Perception-based image quality evaluator, SSIM: Structural similarity index measure, FSIM: Feature similarity indexing method, GCF: Global contrast factor

threshold value of compression for efficient transmission and storage. The DCT was applied on images, the resulted DCT coefficients which were less than the applied threshold values (5, 10, 15, and 20) were discarded and then inverse DCT is applied to get back the compressed images. Two NMPs compared the compressed images with the input images. They found that all the images which were compressed at threshold 5 were acceptable and looks identical to the input image with no loss of clinical information. The average compression factor at threshold 5 was found to be 7.20 (that is 80.03%). At thresholds 10, 15, and 20, the number of compressed images was unacceptable to NMPs because some images are providing false clinical information about the patients. The average percentage compression at thresholds 10, 15, and 20 were found to be 96.12%, 98.36%, and 98.86%,

Table 3: Summary statics of contrast per pixel, brightness, compression ratio, and percentage compression

	Threshold=5	Threshold=10	Threshold=15	Threshold=20
CPP				
Minimum	0.81	0.92	0.97	0.97
1st quartile	1.60	1.26	1.33	1.45
Median	1.82	1.55	1.53	1.68
Mean	1.87	1.81	1.72	1.77
3rd quartile	2.13	2.24	1.86	1.92
Maximum	2.25	3.16	4.48	5.50
Brightness				
Minimum	6.30	7.25	7.60	7.55
1st quartile	12.40	9.89	10.36	11.34
Median	14.11	12.13	12.01	13.13
Mean	14.47	14.09	13.44	13.82
3rd quartile	16.55	17.49	14.50	15.00
Maximum	24.83	34.75	41.77	42.73
Compression ratio				
Minimum	1.69	3.49	8.80	25.57
1st quartile	3.60	25.79	61.83	79.97
Median	5.87	42.49	71.62	92.43
Mean	7.20	40.33	70.97	93.09
3rd quartile	8.86	52.14	81.79	103.17
Maximum	29.83	122.27	155.67	179.06
Percentage compression*				
Minimum	40.79	71.38	88.64	96.09
1st quartile	72.25	96.12	98.38	98.75
Median	82.92	97.65	98.60	98.92
Mean	80.03	96.12	98.36	98.86
3rd quartile	88.71	98.08	98.78	99.03
Maximum	96.65	99.18	99.36	99.44

*Percent compression as: Minimum as 40.79 and Maximum as 96.65, that is an X-size image file will become approximately 0.59X in the worst case and approximately 0.03X in the best case at threshold=5

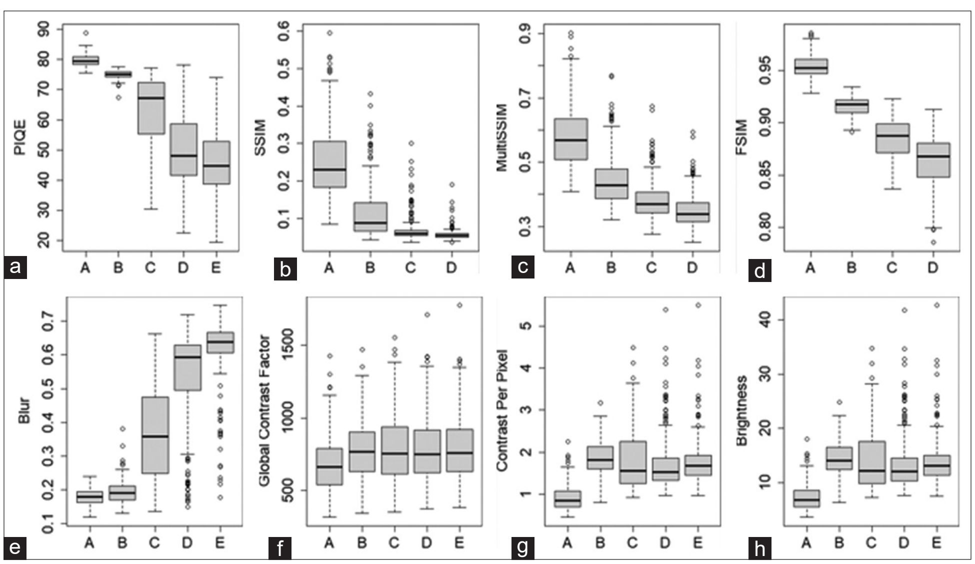

Figure 3: Boxplot of (a) PIQE, (b) SSIM, (c) MS-SSIM, (d) FSIM, (e) Blur, (f) GCF, (g) CPP, and (h) Brightness. PIQE: Perception-based image quality evaluator, SSIM: Structural similarity index measure, MS-SSIM: Multiscale-SSIM, FSIM: Feature similarity indexing method, GCF: Global contrast factor, CPP: Contrast per pixel

respectively. Although the percentage compression factor was found to be greater with higher thresholds, we have also found unacceptable compressed images at these thresholds (at threshold = 10: unacceptable images = 06,

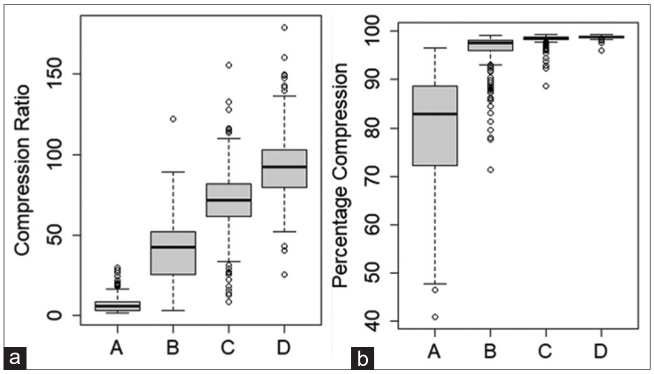

Figure 4: Boxplot of CR and Percentage compression, CR: Compression ratio A: at threshold=5, B: at threshold=10, C: at threshold=15, D: at threshold=20

at threshold = 15: unacceptable images = 38, and threshold = 20: unacceptable images = 70).

We have applied DCT on the entire image and not on the block of size 8 × 8 of the image as it is used in the JPEG standard. We did not observe blocking artifacts in our compressed image. The JPEG standards use multiple image compression techniques (8 × 8 blocks, quantization, and entropy coding) other than the steps we have used for compression. However, we have used only three steps: apply DCT, threshold DCT coefficients, and inverse DCT.

The compressed images at threshold 5 were perceptually better, smooth (reduced noise), and had improved target-to-background ratio. The average value of the FSIM = 0.95 shows that the feature of the input image was preserved in the compressed image. The average value of the SSIM was 0.23 and MS-SSIM was 0.57; although these values indicate that there might be loss of structural similarity in the compressed images, however, during visual comparison, we have not observed loss of clinical details in the compressed image. The loss of insignificant details (that is noise; the area of the image which does not contain clinical information/details) might be the reason for smaller values of SSIM and MS-SSIM structural details.

Few authors have used DCT-based image compression in NM, however, they have not included the Tc-99 m DMSA images in their studies. Chameroy and Di Paola presented an image compression technique for NM dynamic studies to achieve a very high CR as high as 100:1 without significant degradation. They performed the experiment on 70 images of first pass radionuclide angiocardiography series. Technique was implemented in two steps. In the first step, a principal component analysis of the image series is performed to extract the limited number of principal images. In the second step, an adaptive block quantization technique using 2D DCT was used to compress principal images. An inverse DCT is applied to obtain reconstructed images which were compared to the original image series. The reconstructed series gives a very similar result compared to the initial one in terms of time activity curves, extracted by the Region of interest (ROI) method, and FADS.[2] Rebelo *et al*. have investigated the application of a lossy compression method using DCT on cardiac NM images. A group of 23 normal heart sequence images were taken and then the DCT compression algorithm (with the threshold 10%, 20%, 30%, 40%, and 50% of the mean energy) was applied. The ejection fraction was computed before and after compression. They found that images compressed with a threshold up to 30% of the mean energy were considered reliable for visual inspection and no significant difference was found in the value of ejection fraction before and after compression.[3]

The limitation of this study is that the study has not evaluated the compression at thresholds 6, 7, 8, and 9. Anyone from the list of threshold values (6, 7, 8, and 9) could have resulted in better compression (and also the compressed image identical to the original image) compared to the compression obtained at threshold 5. In the future, we will continue working on the same image database to evaluate the effect of thresholds 6, 7, 8, and 9 on percentage compression and compressed image quality. Besides this, we will also evaluate this compression technique on parathyroid scan images.

Conclusions

The optimum value of the threshold at which all 242 Tc-99 m DMSA scan images were acceptable to both the NM Physicians was found to be 5. At an optimum threshold up to 96.65%, near-losses compression of Tc-99 m DMSA images was achieved. The compressed images look identical to the input image and having no loss of clinical details in them.

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Conflicts of interest

There are no conflicts of interest.

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