Optimum Value of Scale and Threshold for Compression of 99mTc-MDP Bone Scan Images using *Haar* Wavelet Transform

Abstract

Introduction: Wavelet transforms of an image result in set of wavelet coefficients. Thresholding eliminates insignificant coefficients while retaining the significant ones (resulting in matrix having few nonzero elements that need to be stored). The compressed image is reconstructed by applying inverse wavelet transform. The quality of compressed image deteriorates with increase in compression. Hence, finding optimum value of scale and threshold is a challenging task. The objective of the study was to find the optimum value of scale and threshold for compressing 99mTc-methylene diphosphonate (99 mTc-MDP) bone scan images using *Haar* wavelet transform. **Materials and Methods:** Haar wavelet transform at scale 1–8 was applied on 106 99 mTc-MDP whole-body bone scan images, and wavelet coefficients were threshold at 90, 95, 97, and 99 percentiles, followed by inverse wavelet transform to get 3392 compressed images. Nuclear medicine physician (NMP) compared compressed image with its corresponding input to label it as acceptable or unacceptable. The values of scale and threshold that resulted in majority of acceptable images were considered to be optimum. The quality of compressed image was also evaluated using perception image quality evaluator (PIQE) image quality metrics. Compression ratio was calculated by dividing the number of nonzero elements after thresholding wavelet coefficients by the number of nonzero elements in *Haar* decomposed matrix. **Results:** NMP found quality of compressed images (obtained at scale 2 and 90 percentile threshold) identical to the quality of the corresponding input images. As per *PIQE* score, quality of compressed images was perceptually better than that of the corresponding input images. **Conclusions:** The optimum values of scale and threshold were determined to be 2 and 90 percentiles, respectively.

Keywords: *99mTc-methylene diphosphonate bone scan image compression, Haar wavelet transform, image compression*

Anil Kumar Pandey, Jagrati Chaudhary, Akshima Sharma, Hemakshi Chetan Patel[1], Param Dev Sharma[2], Vivek Baghel, Rakesh Kumar

Department of Nuclear Medicine, All India Institute of Medical Sciences, [1]Department of Mathematics, University of Delhi, [2]Department of Computer Science, SGTB Khalsa College, University of Delhi, New Delhi, India

Introduction

Nuclear medicine has become an indispensable diagnostic tool in clinical practice. It has proven its utility as a diagnostic tool in almost all spheres of medicine (decision in treatment of oncology patients and other benign and functional disorders of various organs).[1] As a result, there is a surge in number of studies being performed every day. This poses a challenge in saving the huge amount of data which needs large amount of storage space. Earlier the data used to be saved on CDs/DVDs but presently, in most of the hospitals, Picture Archiving and Communication Systems (PACS) handle the short term and long-term storage of data.[2-4] The storage of such large amount of data either in CDs/DVDs or PACS raises the need for nuclear medicine image compression because the storage capacity is always limited.[5] The motivation for compression is that it requires less storage space or, if it is being transmitted over a communication link, it takes less time and cost to send. Compression techniques may be lossless and lossy. Lossless compression techniques provide complete recovery of original image without any loss. Such techniques typically reduce the amount of data just by a factor of 1.5–3.0.[6-8]

Lossy techniques may reduce the amount of data by a factor of ten or more but with these techniques, the compressed image may present some distortion relative to original due to the loss of some data during the compression. In nuclear medicine, the image data comprise some amount of noise due to the physical and technical factors, which even if removed from the image data, does not affect the information contained in

Address for correspondence:
Dr. Anil Kumar Pandey,
Department Nuclear Medicine,
All India Institute of Medical Sciences, New Delhi - 110 029, India.
E-mail: akpandeyaiims@gmail.com

Access this article online

Website: www.ijnm.in

DOI: 10.4103/ijnm.ijnm_170_21

Quick Response Code:

the data. In such a case, lossy compression techniques can work as low pass filters which remove the noisy data from the image, thereby reducing the amount of data without any significant loss.[9]

Lossless or lossy, both the techniques are not without limitations, but lossy techniques are preferred when higher amount of compression is required. When using lossy techniques for compression, the problem is to find a trade-off between the amount of compression and amount of image data loss since the target is to reduce the amount of data while keeping all the information required for image interpretation. Over compression can lead to artifacts due to loss of data.

In the present study, we have used lossy compression technique, "*Haar* wavelet transform" for image compression of whole-body 99mTc-methylene diphosphonate (99 mTc-MDP) bone scans. The choice of scale on which image is to be transformed/decomposed is a challenging task and so is the choice of threshold because these choices affect the quality of compressed images and hence the amount of compression achievable. We have optimized the scale on which the image should be transformed and also the threshold based on the feedback received from nuclear medicine physician (NMP) after comparative evaluation of compressed image with its input image.

Materials and Methods

A digital image is an array of pixel values, which one can think of as a list of numbers. The compression problem consists of two main parts: encoding and decoding. Encoding represents the original list of numbers in a different way so that the encoded information requires less storage space than the original list. Decoding tries to recover the original image from encoded information.

We can compress the data represented by a list of numbers by making the list shorter (i.e., it consists of fewer numbers). In this study, we have followed the same concept to compress 99 mTc-MDP bone scan images.

The different wavelet families make different trade-offs between how compactly the basic functions are localized in space and how smooth they are. Daubechies, Haar, Coiflets, Symlets (least asymmetric) are some of the Wavelet families frequently used in data processing.[10-12] Due to relatively low computational requirement involved in *Haar* wavelet transform,[12] we decided to use *Haar* wavelet. Within each family of wavelets are wavelet subclasses distinguished by the number of coefficients and by the level of iteration. Wavelets are classified within a family most often by the *number of vanishing moments*. This is an extra set of mathematical relationships for the coefficients that must be satisfied and is directly related to the number of coefficients.

A Haar wavelet is the simplest type of wavelet. In discrete form, Haar wavelets are related to a mathematical operation called the Haar transform.

A Haar function is defined by:

$$\text{har har } (i, j, \theta) = \begin{cases} \sqrt{2^i}, & \dfrac{j-1}{2^i} \leq \theta \leq \dfrac{j-\frac{1}{2}}{2^i} \\[3mm] -\sqrt{2^i}, & \dfrac{j-\frac{1}{2}}{2^i} \leq \theta \leq \dfrac{j}{2^i} \\[3mm] 0, & \text{otherwise} \end{cases} \quad , i = 0,\ 1,\ 2.,; \ j = 1.,\ .,2^i$$

$(0, 0, \theta) = 1,\ 0 \leq \theta \leq 1,$

Haar transform analyses discrete signals. A discrete signal is a function of time with values occurring at discrete instants. The Haar transform decomposes a discrete signal into two sub-signals of half of its length. One subsignal is a running average or trend; the other subsignal is a running difference or fluctuation [Figure 1a shows graph of Haar function, Haar scale function representing a running average, Haar wavelet function representing a running difference or fluctuation]. Wavelet transform divides the information of an image into approximation and detail sub signals [Figure 1b Top left: approximation sub-signal, Top right, bottom left, and bottom right: detail sub signal]. The approximation sub-signal shows the general trend of pixel values and other three detail sub-signals show the vertical, horizontal, and diagonal details or changes in the images. If these details are very small, then they can be set to zero (threshold) without significantly changing the image. The greater the number of zeros the greater the compression ratio.

The Haar transform is performed in several stages, or levels. The first level is the mapping H_1 (level-1) defined by:

$$\text{f}\ \underline{H}_1(a^1 \,|\, d^1\,)..$$

From a discrete signal f to its first trend $a^{[1]}$ and first fluctuation d^1.

The mapping H^1 has an inverse. Its inverse maps the transform signal $\left(a^1 \,|\, d^1\right)$ back to the signal f.

The magnitudes of the values of the fluctuation subsignal are often significantly smaller than the magnitudes of the values of the original signal. *Haar* wavelet transform and explanation of how *Haar* wavelet filters decomposes the image into wavelet coefficients at various level/scale of transformation are explained in:[10-13]

The application of Haar wavelet transform at a particular scale to the 99 mTc-MDP bone scan image results in a list of wavelet coefficients (the number of elements in the list is equal to the number of elements in original list of image, that is, the number of pixels in the image) having large proportions of wavelet coefficients less than
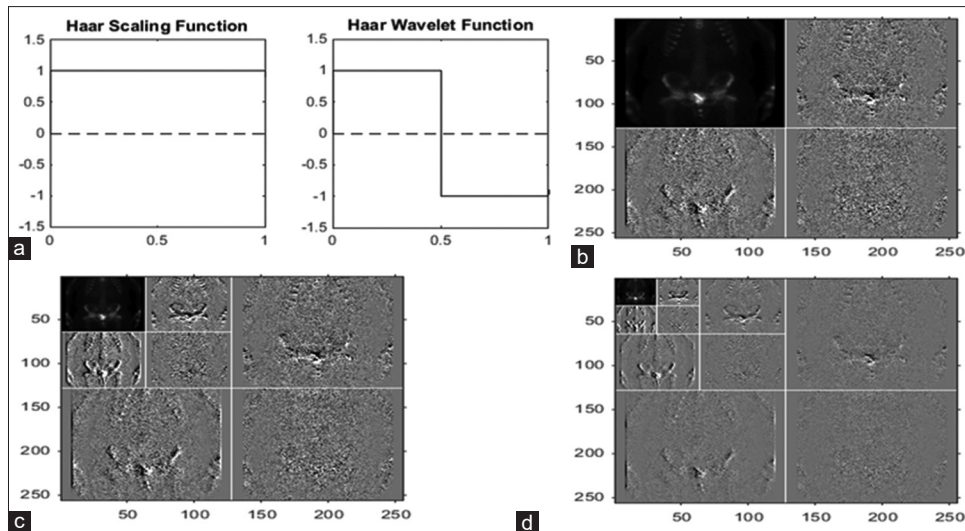
Figure 1: (a) Graph of scaling and wavelet function, (b) First level of decomposition (Top left: LL sub band, top right: LH sub band, bottom left: HL sub band, Bottom right: HH sub band), (c) Second level of decomposition, (d) Third level of decomposition

or equal to zero. Further, the number of elements in the list can be reduced by truncating the wavelet coefficients at an appropriate level of threshold so that a decoded image would still be reasonably identical to the original image.

Thus, we apply a Haar wavelet transform to an image and then remove some of the coefficient data from the transformed image. The compressed image is reconstructed by applying inverse transform.

Most images contain some amount of redundant and irrelevant data depending on how much correlation between neighboring pixels exists in the image. Furthermore, the human eye is insensitive to a wide variety of information loss, so removing redundant and irrelevant data may lead to useful compression. If highly redundant data in the image can be identified and removed, the data can be greatly compressed. In wavelet transform domain, it is easy to identify the high-detail (redundant) data that may safely be deleted. This enables the discarding of an appreciable amount of data content with no or little loss of image quality to human eye.

For application of wavelet transform in computing (Discrete Wavelet Transform [DWT]), the image data matrix is decomposed into four sub-bands LL-low pass horizontal and vertical filter, LH-low pass vertical and high pass horizontal filter, HH-high pass vertical and horizontal filter, and HL-high pass vertical and low pass horizontal filter. These sub-bands (also known as four distinct sets of coefficients) give an approximation of the image at a lower resolution (LL sub-band), and three details with orientations in the horizontal (LH-sub-band), vertical (HL-sub-band), and diagonal directions (HH-sub-band). This decomposition is the first level of DWT [Figure 1b Top left: LL sub band, top right: LH sub band, bottom left: HL sub band, Bottom right: HH sub band]. The approximation coefficients of the first level are again decomposed into four sets of

coefficients to obtain a second level 2D DWT [Figure 1c]. This procedure is continued till the desired level is achieved [Figure 1d shows third level of decomposition of bone scan image]. The number of levels of DWT to be used is flexible and depends on the application. The higher the scale of decomposition, the higher is the percentage of zeros obtained with no thresholding.[14] Evidently, the computational load increases with the number of scales though not proportionately because the sub-band size decreases with levels.[14]

In thresholding operation, we decide which wavelet coefficients can be neglected. In order that there is minimal effect on the quality of compressed image, one can truncate the insignificant coefficients since the amount of information obtained from them is negligible. The threshold value is chosen in a manner such that it gives good perceptual quality of the image along with good compression ratio (no loss of clinical details in case of scintigraphic images).

To calculate *compression ratio (compression factor)*, the number of nonzero elements in *Haar* decomposed matrix (i.e., wavelet coefficient) was divided by the number of nonzero elements after thresholding wavelet coefficients.

Image processing software

Imager package consists of collection of image processing functions, especially developed for R users.[15] The two functions, namely *Haar* and *threshold* of the *imager* package were used in this experiment for image compression. The *Haar* function was used for both forward and inverse wavelet transform of image at different level/scale using *Haar* wavelet filter. The function *threshold* was for thresholding wavelet coefficient at different percentiles.

All experiments were performed on personal computer in R programming environment.[16]

99mTc-methylene diphosphonate whole-body bone scan acquisition protocol

A total of 106 99 mTc-MDP whole-body bone scan images were retrospectively included in the study.

All bone scan images included in the study were acquired using dual head single-photon emission computed tomography gamma camera (Symbia E, Siemens Medical Solutions USA, Inc.) equipped with low-energy high-resolution collimator. Before the administration of 99 mTc-MDP, patients were instructed to drink at least one to two liters of water and void their bladder frequently to reduce the radiation burden in the body. 7–11 MBq 99 mTc-MDP per kg body weight was administered intravenously. After a waiting period of 3–4 h, the whole-body bone scan was acquired with both anterior and posterior view with a table speed of approximately 1.66×10^{-3} m/sec, zoom 1.0, and resolution of 1024×256 pixels.

Image data analysis

One hundred six 99 mTc-MDP bone scan images were exported in Digital Imaging and Communications in Medicine (DICOM) format from nuclear medicine workstation. Haar wavelet transform at a scale (from scale 1–8) was applied to each image and the resulting wavelet coefficients were threshold at 90, 95, 97, and 99 percentiles, and finally, inverse *haar* transform was applied to obtain the compressed image.

In this way, for one image, 32 compressed images (8 image [one for each level] × 4 image [one image at each threshold] = 32 images) and therefore for 106 images, a total of 3392 compressed images (106 × 32 = 3392) were obtained. These images were converted to 8-bit pixel depth enabling them to be properly displayed on the monitor.

Each bone scan image along with its output compressed images was arranged on power point slides [Figure 2 shows a representative slide]. After arranging the input and output images on slides, the quality of images were evaluated subjectively by visual inspection. The quality of input and compressed images were also evaluated objectively using perception image quality evaluator (PIQE) score. The PIQE is a no-reference image quality metrics.[17]

Subjective/qualitative analysis of images

The visual assessment of such a large number of images is practically difficult for NMPs due to their busy schedules. Therefore, the visual assessment was done in two steps. In first step, NMP set criteria for visual assessment which focused on two characteristics in output images as compared to input image, namely, visually appreciable loss in sharpness, and induction of artifact in the output images after compression. Reasons of selecting these criteria by NMPs were:
1. Loss in sharpness or over-smoothening of images sometimes causes the blurring of structures which can result in wrong interpretations [Figure 3a and b]

2. The artifact induced using Haar wavelet transform causes the loss of edges of structures and also sometimes appears like lytic lesions [Figure 4].

For the above criteria, the visual images analysis was performed by students who were trained for the same and subsequently reviewed by the experienced physicians. The output images with presence of any of the above criterion were scored 0 (unacceptable) and output images which were visually of similar quality as input images were scored 1 (acceptable).

Objective/quantitative analysis

The quality of compressed images was also assessed using PIQE score. Lower the PIQE score, higher the quality of images and vice-versa. However, with PIQE score, it may happen that the score is low and quantitatively the quality of image seems to be good but visually it may not be acceptable to NMPs. Thus, we used PIQE score as an indicative quantitative parameter for image quality assessment but our final results are based on visual assessment results verified by NMP.

Results

The result of visual assessment is summarized in Table 1. All 106 compressed images obtained with 90 percentile threshold of wavelet coefficients at scales 2–8 were acceptable to NMPs. In fact, they found it difficult to visually spot any difference between original and compressed image [i.e., original and compressed images looked identical, see Figure 5].

A portion of bone scan image and reconstructed compressed image at 90, 95, 97, and 99 percentile threshold is shown in Figure 6. It can be noted that the input image [Figure 6a] and the reconstructed compressed image at 90 percentile threshold [Figure 6b] look visually identical resulting in acceptable image. At 95, 97 and 99 percentiles thresholds, the reconstructed compressed image showed noticeable blockiness [a characteristic of using the Haar wavelet for compression, Figure 6c-e] resulting in unacceptable images.

Objective assessment supported the result of visual assessment. Based on PIQE score, it can be seen that at

Table 1: Compression ratio achieved at different scale of decomposition and threshold 90 percentile

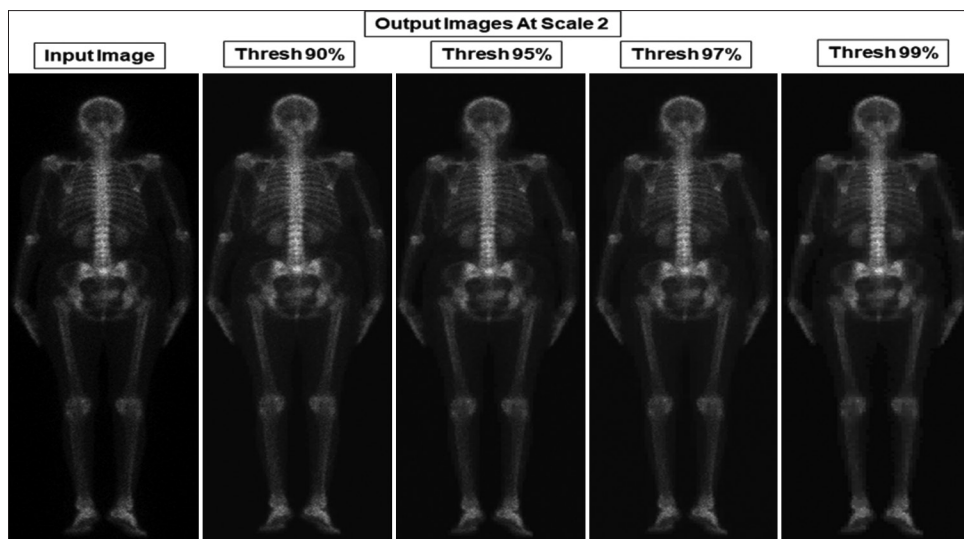| Decomposition	Mean	Median	SD	Maximum	Minimum
Scale_1	4.61	4.68	0.56	2.26	5.59
Scale_2	4.78	4.74	0.56	2.36	5.98
Scale_3	4.74	4.71	0.50	2.35	5.66
Scale_4	4.74	4.72	0.51	2.37	5.74
Scale_5	4.76	4.73	0.51	2.39	5.79
Scale_6	4.76	4.73	0.51	2.39	5.79
Scale_7	4.77	4.73	0.52	2.41	6.01
Scale_8	4.79	4.80	0.51	2.41	6.01

SD: Standard deviation

Figure 2: Input and compressed images obtained after decomposition at scale 2 and then thresholding wavelet coefficients at threshold 90%, 95%, 97%, and 99%, respectively (from left to right)
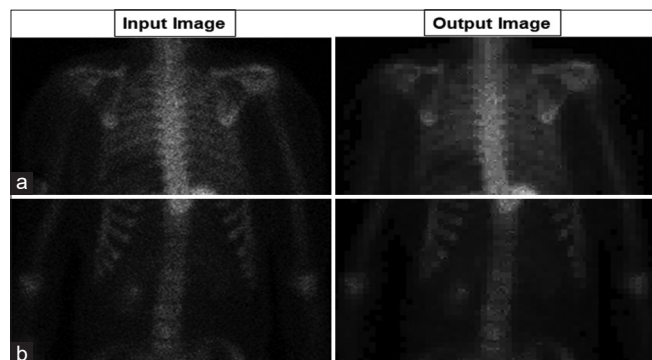

Figure 3: Presence of blockiness artifacts and loss of sharpness. (a) Input image: Posterior view, output image: compressed image obtained at scale 2 and threshold 97 percentile. (b) Output image: Anterior view, output image: compressed image obtained at scale 2 and threshold 97 percentile
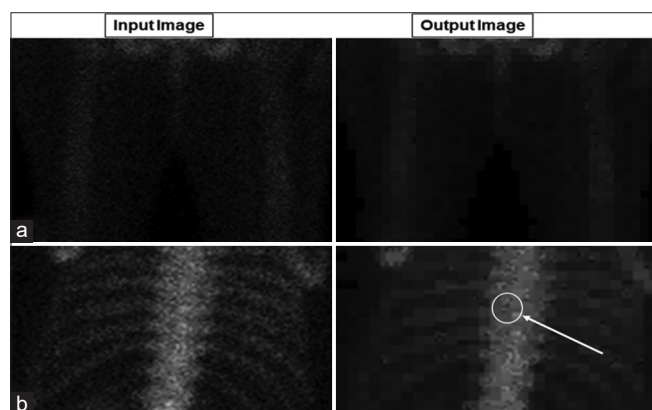

Figure 4: Noticeable blockiness artifacts (a characteristic features of using Haar wavelet). Arrow indicates the presence of blockiness artifacts, which appears as lytic lesion

all scales, the compressed images obtained at 90 percentile threshold were perceptually better than its input image [the median PIQE score of compressed image is much smaller than that of input image, Figures 7 and 8].

Based on PIQE score, the perceptual quality of compressed image obtained at scale 1 and 90 percentile threshold [Figure 9] was found to be the best, however, NMP had labeled majority of these images as unacceptable. The compressed images obtained with scale 2 and 90 percentile threshold were the perceptually second-best series of compressed image (based on PIQE score) and NMP had also labeled these series of all 106 images as acceptable. NMP had also labeled all 106 images acceptable which were obtained at scale 3 to scale 8 [Table 2] with 90 percentile threshold. Since the computational load involved in decomposition of image scale 2 is minimum compared to all other scales >2, therefore considering computation load and both visual and objective assessment of compressed image, the optimum value of scale and threshold should to be 2 and 90 percentiles for the compression of 99 mTc-MDP bone scan images.

Discussion

In this study, we have explored Haar Wavelet Transform, a lossy image compression technique for the compression of whole-body 99 mTc-MDP bone scans. The technique comprises three steps: first, we decompose the image at scale 2 using Haar wavelet resulting image into wavelet coefficients, second, we apply the 90 percentile threshold on wavelet coefficients, and in third step, we apply inverse transform on thresholded wavelet coefficient to get the compressed image. The technique is very simple yet we have achieved a good average compression ratio of 4.78:1.

We optimized the value of scale of decomposition and threshold for compressing 99 mTc-MDP bone scan images by conducting experiment on 106 images, where each image was converted into wavelet coefficients using Haar wavelet at scale 1–8, followed by thresholding the wavelet coefficients at 90, 95, 97, 99 percentiles. After thresholding
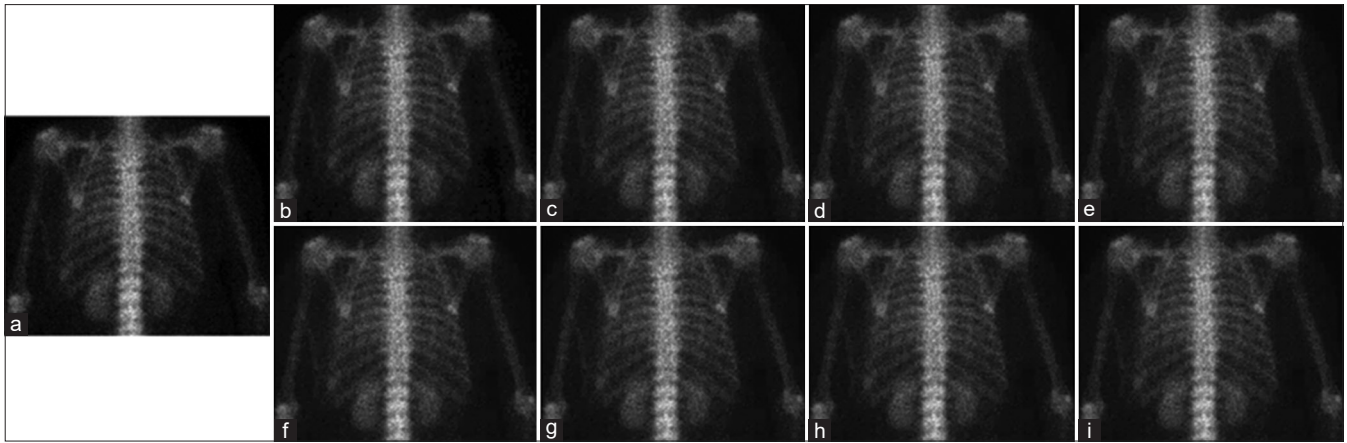
Figure 5: (a) Input image, b to i (compressed image at scale 1, scale 2, scale 3, scale 4, scale 5, scale 6, scale 7, and scale 8, respectively). Thresholding used was 90 percentiles at scales of decomposition
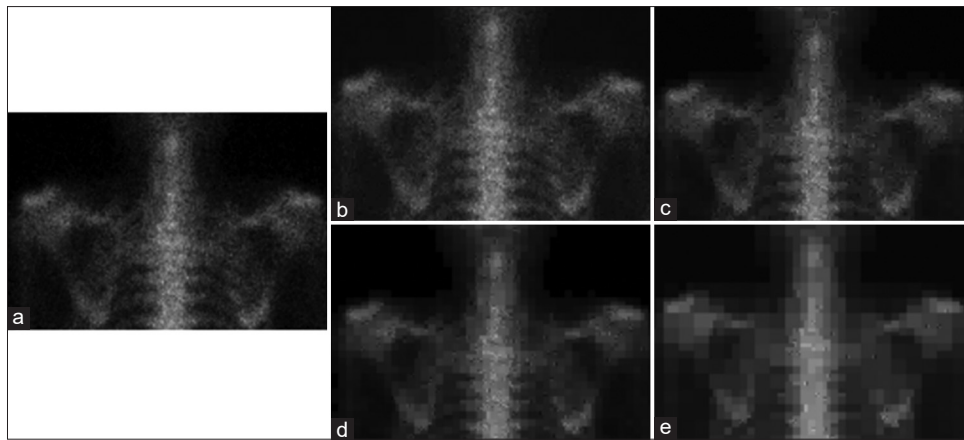

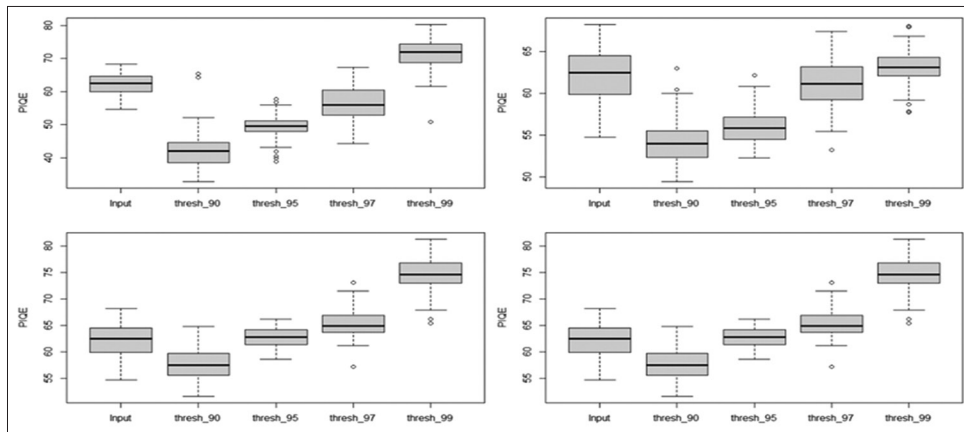**Figure 6: Scale 3, (a) original, (b) 90 percentile, (c) 95, (d) 97, and (e) 99 percentile**

Figure 7: Boxplot of perception image quality evaluator score of input and compressed images obtained at scale 1 (Top-left), scale 2 (Top right), scale 3 (bottom left) and scale 4 (bottom right)

the wavelet coefficients, inverse Haar wavelet transform was applied to reconstruct the compressed image. The quality of the compressed image was compared with its corresponding input image by NMP and categorized as acceptable or not acceptable. Considering the result of both subjective and objective assessment, the optimized value of scale and threshold was determined to be 2 and 90 percentiles, respectively.

Wavelet transform is used in the Joint Photographic Experts Group(JPEG) 2000 compression standard. JPEG 2000 compression (lossless) has been recommended and adopted by DICOM standard. However, lossy compression
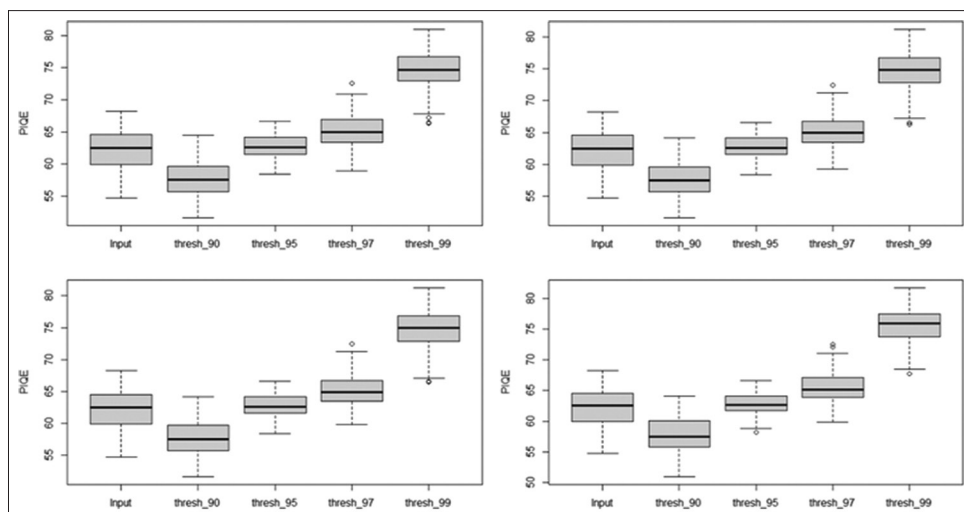
Figure 8: Boxplot of perception image quality evaluator score of input and compressed images obtained at scale 5 (Top-left), scale 6 (Top right), scale 7 (bottom left) and scale 8 (bottom right)
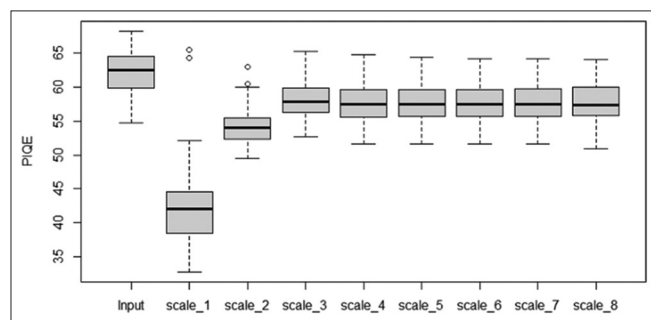

Figure 9: Box plot of perception image quality evaluator score of input, and compressed images obtained at scale 1, 2,3,4,5,6,7,8 with 90 percentile threshold

Table 2: Number of compressed images acceptable to nuclear medicine physician at different scale of decomposition and threshold

Scale of decomposition	Threshold			
	90%	95%	97%	99%
Scale 1	2	0	0	0
Scale 2	106	0	0	0
Scale 3	106	3	0	0
Scale 4	106	9	0	0
Scale 5	106	4	0	0
Scale 6	106	2	0	0
Scale 7	106	2	0	0
Scale 8	106	2	0	0

of scintigraphic images using wavelet transform has not been explored in general, and in particular, compression of 99 mTc-MDP bone scan image using Haar wavelet transform has not been investigated. However, there are plenty of articles available in the literature on compression of natural, ultrasound, and MRI images. Since there is no study similar to our's (i.e., compression of 99 mTc-MDP bone scan images), our results cannot be compared with the other studies.

Rebelo *et al*. have used discrete cosine transformation (lossy compression techniques) for compressing nuclear medicine images. On visual inspection, they have found the quality of compressed image reliable. Further, they have estimated some parameters on compressed image and have not found any discernible change in the result obtained from original uncompressed image.[9] Zhou *et al*. have studied the usefulness of JPEG2000 compression for nuclear medicine image. They have found lossless compression ratio as (1.34 ±). They have also applied lossy compression scheme and found that the diagnostic quality of static nuclear medicine images is preserved at compression ratios: 50:1, 40:1, 30:1,20:1 up to 10:1.[18]

Eising *et al*. in a pilot study have examined the value of JPEG format for most frequently used planar scintigraphic images (thyroid, bone, myocardium, lungs, and kidneys) at different amount of compression. They have found that relevant loss of clinical information did not occur up to compression factors of 0.75. They observed major decrease in image quality at compression factor >0.90. Their recommendation was JPEG format which may use to save costs of image transfer or archiving of standard planar scans for nuclear medicine evaluation.[19] Have studied the effect of JPEG2000 lossy compression of nuclear medicine images using line source and quadrant-bar phantom images acquired at various noise level. They compressed that the images at various compression level form 10:1 to 50:1 with a step of 10:1. They observed decrease in peak to total count ratio of line spread function of line source with increase in compression ratio. However, no significant change in the value of modulation transfer function and full width at half maximum was observed with increase in compression ratio.[20]

We have transformed image at different scales and then applied hard thresholding (threshold as percentile) and achieved 4.78:1 compression factor of 4.78. It is possible

to further compress the image by incorporating different steps (such as quantization and entropy coding) which we would like to include in our future studies on compression of scintigraphic images.

The choice of scale on which image to be transformed is a challenging task and also the choice threshold. Yet, there are different methods exists for the determination of optimal threshold, most commonly are hard thresholding, soft thresholding, universal thresholding, statistical based method of estimating threshold, and each method has its own merits and demerits. In this study, we used a heauristic for thresholding and investigated the impact on quality of compressed image obtained as a result of 90, 95, 97, and 99 percentile thresholding of wavelet coefficients. Certainly, the threshold is not tailored *a-priori* for the image data.

This study is unique in a sense that the compressed image quality of 99 mTc-MDP bone scan was evaluated by NMP following very stringent evaluation criteria. An image having slightest doubt whether should be acceptable or unacceptable was lebeled as unacceptable. It is very difficult to say whether the image is original or compressed, and yet, we have found a good compression factor of 4.78 [Figure 5].

In future, we would like to incorporate quantizer, and entropy encoding steps in image compression algorithm to see how much further compression can be achieved without degrading the quality of the image to unacceptable level for NMP.

The significance of this study is that the result of the study (i.e., transformation at scale 2 and threshold 90 percentile) can be used to compress 99 mTc-MDP bone scan images without degrading the quality of original image to unacceptable level. This may be a significant contribution to the nuclear medicine community as they can use the result for storage and transmission of the 99 mTc-MDP bone scan images. This is further easier to achieve since it uses open-source software R and on personal computer (i.e., no additional cost of proprietary software or hardware).

Conclusions

The 99 mTc-MDP bone scan images should be compressed by decomposing the image at scale 2 using Haar wavelet and thresholding the wavelet coefficients at 90 percentile threshold to achieve acceptable image quality and good compression (4.78:1).

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. O'Malley JP, Ziessman HA. Nuclear Medicine and Molecular Imaging: The Requisites E-Book. Philadelphia: Elsevier Health Sciences; 2020.
2. Huang HK. PACS: Picture Archiving and Communication Systems in Biomedical Imaging. Philadelphia: VCH Publishers; 1996.
3. Law MY, Zhou Z. New direction in PACS education and training. Comput Med Imaging Graph 2003;27:147-56.
4. Arora D, Mehta Y. Use of picture archiving and communication system for imaging of radiological films in cardiac surgical Intensive Care Unit. J Anaesthesiol Clin Pharmacol 2014;30:447-8.
5. Alhajeri M, Shah SG. Limitations in and solutions for improving the functionality of picture archiving and communication system: An exploratory study of PACS Professionals' perspectives. J Digit Imaging 2019;32:54-67.
6. Rabbani M, Jones PW. Digital Image Compression Techniques. Tutorial Texts TT07. Bellingham, Washington: SPIE Press; 1991.
7. Chen ZD, Chang RF, Kuo WJ. Adaptive predictive multiplicative autoregressive model for medical image compression. IEEE Trans Med Imaging 1999;18:181-4.
8. MacMahon H, Doi K, Sanada S, Montner SM, Giger ML, Metz CE, *et al.* Data compression: Effect on diagnostic accuracy in digital chest radiography. Radiology 1991;178:175-9.
9. Huang HK. PACS: Picture Archiving and Communication Systems in Biomedical Imaging, VCH Publishers; Inc.: New York. 1996.
10. Lepik Ü, Hein H. Haar Wavelets: With Applications. Switzerland: Springer International Publishing; 2014.
11. Van Fleet PJ. Discrete Wavelet Transformations: An Elementary Approach with Applications. 2nd ed. 111 River Street, Hoboken, NJ 07030, USA: John Wiley & Sons, Inc.; 2019.
12. Stanković RS, Falkowski BJ. The Haar wavelet transform: Its status and achievements. Comput Electr Eng 2003;29:25-44.
13. Castleman KR. Digital Image Processing. Englewood Cliffs: Prentice-Hall, Inc.; 1996. p. 475-8.
14. Thyagarajan KS. Still Image and Video Compression with MATLAB. New Jersey: John Wiley & Sons; 2011.
15. Barthelmé S, Tschumperlé D. Imager: An R package for image processing based on CImg. J Open Source Softw 2019;4:1012.
16. Marina S Rebelo, Sergio S. Furuie, Agda C. L. Munhoz, Lincoln Moura, Candido P. Melo: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing; 2018. Available from: https://www.R-project.org/.
17. Venkatanath N, Praneeth D, Bh MC, Channappayya SS, Medasani SS. Blind Image Quality Evaluation Using Perception Based Features. In 2015 Twenty First National Conference on Communications (NCC). IEEE; February 27, 2015. p. 1-6.
18. Zhou L, Su X, Qin W, Li L, Kuang A, Mo T. Application study of JPEG2000 image compression in nuclear medicine. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi 2006;23:52-5.
19. Eising EG, Jentzen W, Görges R, Freudenberg L, Bockisch A. Economic image compression of output documentation of the most frequent examinations in nuclear medicine. Acad Radiol 2007;14:967-73.
20. Zhou L, Su X, Kuang A, Li L, Chai L. Objective and quantitative study on the effect of lossy JPEG2000 compression of nuclear medicine image. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi 2007;24:1027-30, 1044.