Original Article

Compression of ^{99m}Tc Methylene Diphosphonate Bone Scan Images using Discrete Cosine Transformation

Abstract

Aims and Objectives: The objective of this study was to find the optimum value of threshold for compression of ^{99m}Tc-methylene diphosphonate (MDP) bone scan images using discrete cosine transformation (DCT). **Materials and Methods:** DCT was applied to 51 ^{99m}Tc-MDP bone scan images and then the image of logarithmic value of DCT coefficients was inspected to determine the threshold. After inspecting the number of images of DCT coefficients, we estimated the appropriate value of the threshold to be 10. After the application of threshold = 10, compressed image was reconstructed by applying the inverse DCT. Compression factor was calculated by dividing the nonzero element after thresholding to the nonzero element before thresholding DCT coefficients. Nuclear medicine physicians compared the compressed images with its input images and labeled them as acceptable or unacceptable. During comparison of input and compressed images, we considered points such as smoothening, blocking artifacts, body contour, gap between closely placed lesions, and detectability of lesion. **Results:** Forty-four compressed images (out of 51 images) obtained at threshold 10 were acceptable to Nuclear Medicine Physician (NMP). Compressed images were less noisy compared to its input image. Compression factor was found to be 13.03 ± (minimum = 2.71, maximum = 42.92). **Conclusion:** The optimum value of threshold for compression of ^{99m}Tc-MDP bone scan images was found to be 10, and the average compression factor achieved was equal to 13.03 (92.30%).

Keywords: *Discrete cosine transformation, image compression, methylene diphosphonate bone scan images*

Anil Kumar Pandey, Priya Yadav, Jagrati Chaudhary, Param Dev Sharma[1], Jasim Jaleel, Chetan Patel, Chandra Sekhar Bal, Rakesh Kumar

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

Introduction

The number of investigations performed in nuclear medicine (NM) facility is increasing day by day and so is the data generated by these studies. The data need to be stored for comparison of studies acquired at different time points to comment on the progression or remission of the disease. The digital representation of images depending on its size might be of small to very large number of bits. With increase in number of bits, the image to be transferred from one location to another through network takes transmission time proportionately. The Picture Archiving and Communication System (PACS) is used for storage and communication of data from one location to another. However, the storage space of PACS is also limited; purchase of additional storage space and also transferring a large number of bits over the network involve cost and time and thus have raised the issue of compression in NM images to save both storage space and time.[1]

Image compression is a type of data compression applied to digital images to minimize the size in bytes of an image file without degrading the quality of image to an unacceptable level. It involves the minimization of the number of information carrying unit pixel (i.e., reducing spatial redundancy). Reduction in file size allows a number of images to be stored in a limited storage space and also reduces time required for image to be sent over network. Two types of compression techniques exist, lossy and lossless.[2] In lossy image compression scheme, certain amount of information is discarded (that is some data are lost), and hence, image cannot be decompressed 100% with originality. In lossless image compression, no data is lost and thus this method of image compression allows the original image to be perfectly reconstructed from the compressed data. We choose to work on the lossy image compression techniques with hope that we will get a very good compression without loss of clinical details for NM images.

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

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Although there are many image transforms that can be utilized for compressing NM images, we selected discrete cosine transform (DCT). The motivation behind using DCT is as follows: (a) DCT is a unitary image transform meaning it preserves signal's energy and has tendency to pack a large fraction of the average energy of the image into a relatively few components of the transform coefficients. Since the total energy is preserved, this means many of the transform coefficients will contain very little energy. The DCT coefficient with very little energy can be safely discarded to achieve the compression. (b) The DCT has excellent energy compaction for highly correlated data, and (c) it is a fast transform (that is, it takes very less time for computation of DCT coefficients).[3]

Several authors have used DCT for compression of medical images.[4-7] However, compression of NM images using DCT has not gained much attention. In this pilot study, we have performed the compression of ^{99m}Tc methylene diphosphonate (MDP) bone scan images using DCT. We have evaluated the amount of compression achieved without loss of clinical details. The compressed image quality was evaluated both subjectively and objectively. In this manuscript, we report the result of this investigation.

Materials and Methods

Image data acquisition

All bone scan images included in the study were acquired using dual-head SPECT gamma camera (Symbia E, Siemens Medical Solutions USA, Inc.) equipped with low-energy high-resolution collimator. Before the administration of ^{99m}Tc MDP, patients were instructed to drink at least one to 2 L of water and void their bladder frequently in order to reduce the radiation burden in the body. 7–11 MBq ^{99m}Tc 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 views with a table speed of approximately 20 cm/s zoom 1.0 and resolution of 1024 × 256 pixels.

Discrete cosine transform and idea behind the image compression

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

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

where

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

Similarly,

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

The 2D inverse DCT is given by

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

The application of DCT on an image result in DCT coefficients corresponding to each pixel (left column, Figure 1a-d) displays input image, the results of DCT on input image, the effect of thresholding DCT coefficients and reconstructed compressed image (shown in the left column) and its corresponding intensity values (in the right column, Figure 1a-d). It can be seen that large fraction of the average energy of the image is concentrated into a relatively few components of the transform coefficients (as shown in Figure 1b left column, in yellow color).

Larger DCT coefficients contain significant information of the image while smaller coefficients contain the least significant information of the image, which can be discarded (reader can notice that the clinical details in the compressed image and input image are same). The compressed image was reconstructed with larger DCT coefficients above 10 (by retaining only larger DCT coefficients and discarding all other DCT coefficients ≤10).

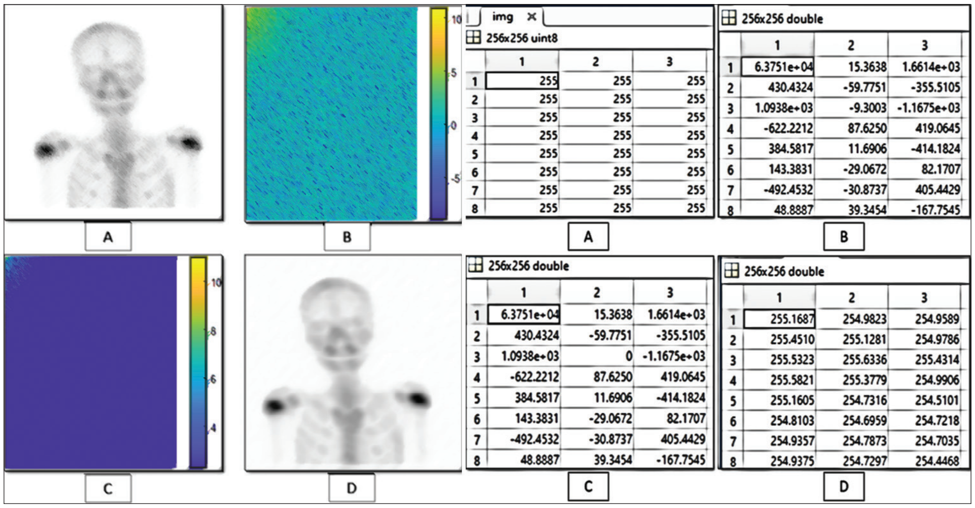
Image data analysis

Fifty-one ^{99m}Tc MDP bone scan images were exported from NM processing workstation in *DICOM* format. After this, all other experiments were performed on a 3.30 GHz i3-2120 CPU with 2 GB RAM, running 64-bit Microsoft Windows operating system. A personal computer program was written in *Matlab R2020b* (The MathWorks, Inc. 3 Apple Hill Drive Natick, MA 01760–2098), to read and compress *DICOM* images using DCT.

After inspecting the number of images of DCT coefficients, we estimated that the appropriate value of the threshold might be 10 and all the DCT coefficients which were less than this threshold were made equal to zero and then inverse DCT was applied to get back the compressed image in spatial domain.

Qualitative/objective assessment

NM physicians compared the compressed images with its input images and labeled them as acceptable or unacceptable. During comparison of input and compressed images, we considered some points such as smoothening, blocking artifacts, body contour, gap between closely placed lesions, and detectability of lesion – smoothing (if image is so smooth, but



A

	1	2	3
1	255	255	255
2	255	255	255
3	255	255	255
4	255	255	255
5	255	255	255
6	255	255	255
7	255	255	255
8	255	255	255

B

	1	2	3
1	6.3751e+04	15.3638	1.6614e+03
2	430.4324	-59.7751	-355.5105
3	1.0938e+03	-9.3003	-1.1675e+03
4	-622.2212	87.6250	419.0645
5	384.5817	11.6906	-414.1824
6	143.3831	-29.0672	82.1707
7	-492.4532	-30.8737	405.4429
8	48.8887	39.3454	-167.7545

C

	1	2	3
1	6.3751e+04	15.3638	1.6614e+03
2	430.4324	-59.7751	-355.5105
3	1.0938e+03	0	-1.1675e+03
4	-622.2212	87.6250	419.0645
5	384.5817	11.6906	-414.1824
6	143.3831	-29.0672	82.1707
7	-492.4532	-30.8737	405.4429
8	48.8887	39.3454	-167.7545

D

	1	2	3
1	255.1687	254.9823	254.9589
2	255.4510	255.1281	254.9786
3	255.5323	255.6336	255.4314
4	255.5821	255.3779	254.9906
5	255.1605	254.7316	254.5101
6	254.8103	254.6959	254.7218
7	254.9357	254.7873	254.7035
8	254.9375	254.7297	254.4468

Figure 1: On left side: (a) Bone scan image, (b) Image of DCT coefficients displayed in left side Figure a, (c) DCT coefficients image after thresholding. (d) Reconstructed bone scan image. On right side: (a) Pixel values of a portion of Figure a left side, (b) Value of DCT coefficients corresponding to the pixel value in Figure A right side. (c) DCT coefficient after thresholding applied on DCT coefficient in Figure b right side, (d) Pixel value of the compressed image. DCT: Discrete cosine transformation

the diagnostic information is lost in it, the image is unacceptable), gap between closely placed lesions (If closely placed lesions appears as separate lesions in input image but seems to be as a one fused lesion in compressed image, then the image is unacceptable), body contour (if the lesion is too close to the body contour and the body contour is not clearly visualized, the image is unacceptable), and detectability of lesion (if the body contour and the background of the image are having approximately same intensity still lesion is visualized, the image is acceptable).

Quantitative/subjective assessment

The quality of compressed image was also assessed using peak signal-to-noise ratio (PSNR), structural similarity index measure (SSIM), and Joint Photographic Export Group (*JPEG) image quality score*. PSNR is an indicator of PSNR, i.e., the higher the PSNR, the better the quality of compressed image. SSIM is an indicator of SSIM, i.e., the higher the SSIM, the well-defined the structure of the compressed image. The *JPEG image quality score* typically has a value between 1 and 10 (10 represents the best quality and 1 the worst), i.e., the higher the value of *JPEG image quality score*, the better is the quality of image.[9]

Results

Forty-four out of 51 ^{99m}Tc MDP bone scan compressed images were found to be acceptable to the NM physician. In fact, they found it difficult to visually spot any difference between original and compressed images [i.e., original and compressed images looked identical, Figure 2]. The compression factor was found to be 13.03 ± (min = 2.71 and max = 42.92).

Qualitative/objective analysis of images

Figure 2 shows four example images which were acceptable to the NMP; in each quadrant, the left side image is an input image and the right side is the compressed image. The compressed image is just identical to the input image with no loss of clinical information. Reader can notice that there is no blocking artifact in the compressed image. We can see that the lesions are well defined and easily differentiated in the compressed images as compared to the input images. The compressed images are smoother than the input images with no loss of structural details as we can easily differentiate between the background and body contour.

Quantitative/subjective analysis of images

Our quantitative analysis supported the result of visual analysis. The median value of PSNR, SSIM, and JPEG image quality was found to be 24.13, 0.86, and 12.34, respectively [Figure 3 shows boxplots of SSIM, PSNR, and *JPEG image quality score* of compressed images]. The median value (24.13) of PSNR indicates good image quality. The SSIM indicates that compressed image was 86% structurally similar to the input image not affecting the clinical details in the image. The median value of JPEG image quality metric equal to 12.34 indicates the good quality of image.

Discussion

A noncompressed digitized image contains an enormous amount of data that may affect the storage capacities and transmission.[10] There are several methods available for the image compression. This study focuses on determining the optimum amount of compression that can be used for transmitting and storing ^{99m}Tc MDP bone scan images used for clinical purpose in NM using DCT. When DCT is applied to an image, it results in DCT coefficients. The DCT coefficients smaller than 10 were discarded and then inverse DCT was applied to obtain the compressed image. NM physicians compared compressed image with its original image, and 44 out 51 images were found to be acceptable. The compression factor achieved was found to be 13.03 (that is 92.30%).

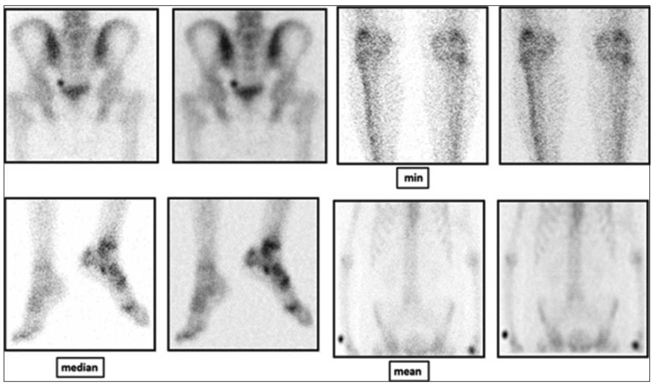


Figure 2: In each quadrant, the left side image is a portion of original ^{99m}Tc MDP bone scan image and right-side image is compressed image. Top right: The original-compressed image in which minimum compression factor (2.72) was achieved, bottom left: The original-compressed image in which median level of compression factor (7.63) was achieved, and bottom right: The original-compressed image in which mean level of compression factor (13.01) was achieved. It is to be noted that there is no loss of clinical details in compressed image compared to its original image. MDP: Methylene diphosphonate

There were seven compressed images (threshold = 10) that were unacceptable to NM physicians [original and its compressed images at threshold = 5 and threshold = 10 are shown in Figure 4]. Thus, we can say that the threshold = 10 was not optimum for the compression of all the 51 bone scan images included in this study. Lowering the threshold (from threshold = 10 to threshold = 5) resulted in these seven compressed images into an acceptable category. It can be verified that the compressed image at threshold = 5 looks identical to its original image [Figure 4]. However, the compression factor achieved at threshold = 5 is much smaller than that of threshold = 10 [Table 1].

We could not find a single threshold value for truncating DCT coefficients that can result in all the 51 original bone scan images into acceptable compressed images (only 86.27% of images [44 out of 51 images] were acceptable at threshold = 10). This is the expected results because every image is a unique image (with respect to the counts at each pixel location and how the pixel counts are distributed spatially in the image) and thus a single threshold for all the images might not produce an acceptable compressed image.

The result of objective assessment supports the visual assessment made by NM physicians. The median PSNR value of compression images above 24 indicates good image quality of compressed images. The median value of SSIM equal to 0.86 indicates that compressed image was

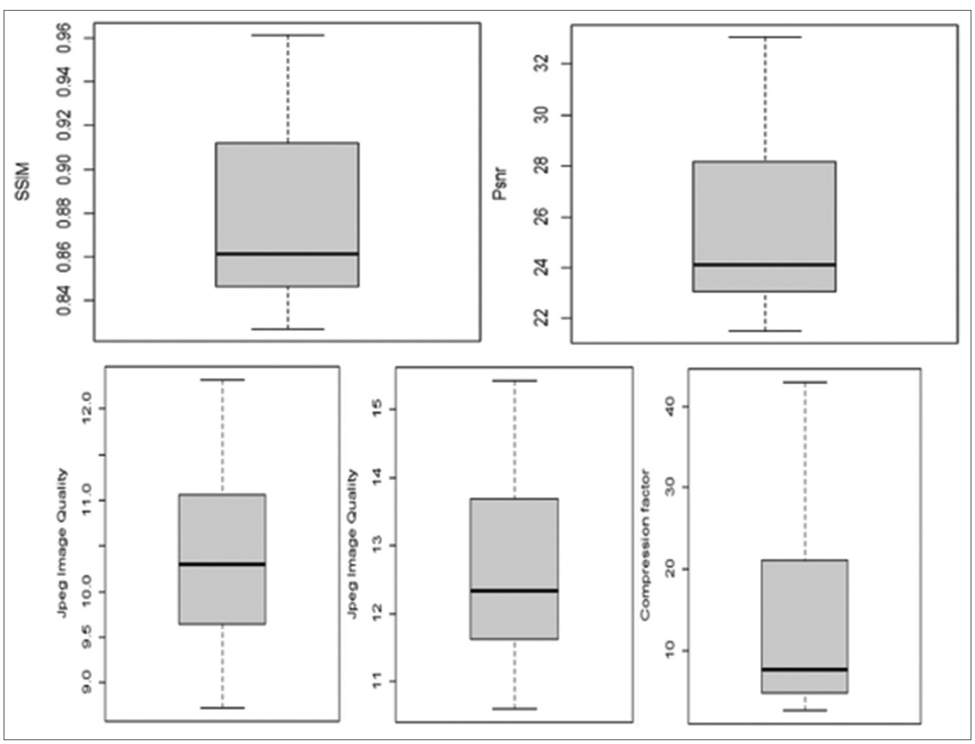


Figure 3: Top row (left side): boxplots of SSIM (median value: 0.86), top row (right side): PSNR (median value: 24.13), bottom row (left side): boxplot of JPEG image quality of original image (median value 10.29), bottom row (middle): boxplot of JPEG image quality of compressed image (median value: 12.34), and bottom row (right side): Boxplot of compression factor (median value: 7.63). SSIM: Structural similarity index measure, PSNR: Peak signal-to-noise ratio

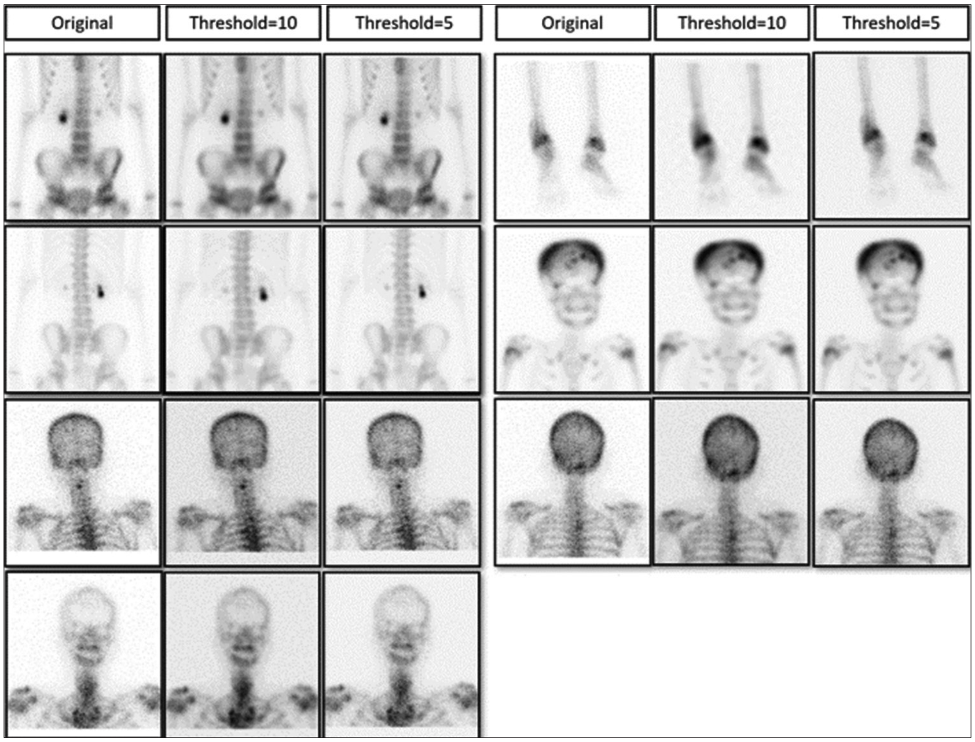


Figure 4: The original (all seven images whose corresponding compressed images at threshold = 10 were unacceptable) and its compressed images at threshold = 10 and at threshold = 5. It is to be noted that compressed image at threshold = 5 looks identical to the original image

Table 1: Compression factor achieved at threshold=5 and threshold=10

Original image of Figure 4	Compression factor of compressed image at threshold=5	Compression factor of compressed image at threshold=10
1st row 1st column	3.3829	15.8147
2nd row 1st column	14.1914	28.5436
3rd row 1st column	1.7347	3.6569
4th row 1st column	7.1460	40.0587
1st row 4th column	9.2136	28.8705
2nd row 4th column	1.9448	4.8491
3rd row 4th column	2.2956	7.6116

86% structurally similar to the input image (SSIM value of compressed image was above 0.80; no loss of clinical details in the compressed images as per NM physicians in 44 images out of 51 images). The median value of JPEG image quality metric is equal to 12.34 (JPEG image quality value was above 10; the median value of JPEG image quality metric was greater than that of original image), which indicates that the compressed image quality (visually appears less noisy, Figure 2) was better than the original images.

Many authors worked on the compression of NM images. Rebelo *et al*. have investigated the application of a lossy compression method by DCT on cardiac NM images. The DCT compression algorithm (with the threshold 10%, 20%, 30%, 40%, and 50% of the mean energy) was then applied to the group of 23 normal heart sequence images. The ejection fraction was computed before and after compression. As a result, 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.[11] Zhou *et al*. investigated the usefulness of JPEG2000 compression for NM image; normal and abnormal static images were compressed using a JPEG2000 plug-in. For lossless algorithm, the compressing ratio (CR) was calculated. For lossy algorithm, images were visually analyzed by NM physicians and ROC curves were generated. Comparison between the original and the compressed images revealed no significant difference for 10:1 CR but significant difference for bigger CRs. They have concluded that lossless compression has little usefulness for NM image because of very low CR. While lossy compression is used, the diagnostic quality of static NM images is preserved at CRs 50:1, 40:1, 30:1, 20:1 up to 10:1.[12]

The significance of this study is that the study provides guideline regarding the choice of threshold for truncating DCT coefficients in order to compress ^{99m}Tc MDP bone scan images using DCT. If compressed image at threshold=10 is acceptable then user can terminate the process else he/she can reconstruct the compressed image at threshold=5. At threshold = 5, if the compressed image is acceptable and the requirement is for the more compression, threshold >5 but <10 should experiment. At threshold = 5, if the compressed image is unacceptable, intuitively, threshold should be lowered further.

The limitation of this pilot study is the small sample size. In future, we would like to extend this study by including the large number of ^{99m}Tc MDP bone scan images.

Conclusion

The optimum value of threshold for compression of ^{99m}Tc MDP bone scan images was found to be 10, and the average compression factor achieved was equal to 13.03 (92.30%).

The threshold value equal to 10 results in a larger percentage (86.27%) of ^{99m}Tc MDP bone scan compressed images acceptable to NM physicians. The average compression factor achieved was equal to 13.03 (i.e., 92% compression).

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Conflicts of interest

There are no conflicts of interest.

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