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Improved compressibility of multislice CT datasets using 3D JPEG2000 compression

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Abstract. This study evaluated the compressibility of multislice CT (MSCT) datasets and its dependence on (1) slice thickness and (2) the use of three-dimensional (3D) vs. 2D JPEG2000 compression methods. Five thoracic CT datasets were obtained using a 16-detector MSCT scanner with a collimation of 0.75 mm (120 kVp, 90 mAs) and reconstructed at five slice thicknesses from 0.75 to 10.0 mm. These datasets were irreversibly compressed using a standard 2D JPEG2000 encoder and a developmental 3D JPEG2000 algorithm based on Part 2 of the JPEG2000 standard. Compression ratios ranged from 4:1 to 64:1. Image distortion was computed utilizing peak signal-to-noise ratio (PSNR) and the Sarnoff JNDmetrix visual discrimination model. For 2D compression, the thinnest sections were substantially less compressible than thicker sections for the same level of image quality, particularly at higher compression ratios. Applying 3D compression yielded consistently higher image quality in most cases compared to 2D compression at the same ratios. The advantage of 3D compression increased for thinner slices and higher compression ratios. These results indicate that 3D JPEG2000 (Part 2) compression offers substantial advantages over the current 2D JPEG2000 standard, yielding better quantitative image quality at similar compression ratios or comparable image quality at higher compression ratios.

Keywords: Image compression; Multislice CT; JPEG2000; Visual discrimination model; Just noticeable difference (JND); Slice thickness; 3D compression

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1. Introduction

Digital technology has revolutionized the medical imaging industry. All facets of medical imaging industry are advancing towards a filmless environment [1]. This filmless environment creates its unique challenges predominantly due to the sheer amount of digital data that has to be managed. This challenge has been realized in the past, but with the advent of multislice scanners and routine submillimeter image acquisition, the amount of CT data generated can be enormous and can exacerbate the challenges that already exist in image transmission and storage [2].

Multiple-image compression techniques have been utilized to address this challenge of image transmission and storage and each of these techniques have had their limitations [3]. To address these limitations and to standardize compression methodology the Joint Photographic Experts Group (JPEG) developed the original JPEG standard [4,5]. The key weakness of the original JPEG standard was its lack of architectural flexibility when integrated into imaging applications. Hence, in 1997, the JPEG committee started work on the JPEG2000 standard to address the limitations and to add a range of possible features, which were impossible or impractical to achieve with the previous definition of JPEG standard [6].

JPEG2000 compression standard is increasingly being adopted by industry as a preferred "standard" method for 2D image compression [7–10]. Three-dimensional (3D) discrete cosine transform (DCT) based image compression has been proposed as a preferred technique for volumetric coding of data for lossless coding, but the weakness of such systems is that they hardly meet the requirements imposed by the well-known scalability paradigm [11,12]. These 3D compression techniques in the past have been applied uniformly to all volumetric datasets without considering dependencies enforced by multitude of other factors, such as detector collimation, dose and image acquisition technique for example [13,14].

Surprisingly, no studies have been performed to date that investigate whether the thinner slices associated with MSCT are as compressible as thicker slices using the JPEG2000 compression standard, or whether 3D compression algorithms might be more suitable for compression of thin-slice, volumetric datasets. Work on the development of a 3D JPEG2000 compression standard is still in progress and will be addressed in part 10 of JPEG2000 standard [15].

The purpose of this study was to compare compression efficiency using the 2D JPEG2000 standard to the proposed 3D compression following guidelines described in Part 2 of the JPEG2000 standard for multicomponent images and to examine the compressibility of the data using both techniques at various slice thicknesses.

2. Methods

For this study, five thoracic CT data sets obtained using a 16-detector MSCT scanner with a collimation of 0.75 mm (120 kVp, 90 mAs) were reconstructed at various slice thicknesses: 0.75, 1.5, 3.0, 6.0 and 10.0 mm. These datasets were irreversibly compressed using a standard 2D JPEG2000 encoder and a developmental 3D JPEG2000 algorithm based on Part 2 of the JPEG2000 standard. Compression ratios were 4:1, 6:1, 8:1, 12:1, 16:1, 32:1, and 64:1. Image distortion was computed utilizing peak signal-to-noise ratio (PSNR) and the

Sarnoff JNDmetrix visual discrimination model (VDM) for both mediastinal (350/50 HU) and lung (1500/ – 600 HU) window width/center settings [16,17].

The JNDmetrix VDM is a computational, just noticeable difference (JND) model that simulates known physiological mechanisms in the human visual system, including the luminance and contrast sensitivity of the eye, and spatial frequency and orientation responses of the visual cortex. The VDM takes two luminance images as input and returns an accurate and robust estimate of their visual discriminability. When these input images represent uncompressed and irreversibly compressed versions of the same image, the model can be used to predict the visibility of compression artifacts or distortions. JNDmetrix VDM predictions have been found to correlate very well with observer performance in a variety of medical and nonmedical visual detection and rating tasks, including the perceptibility of distortions in compressed images. Traditional metrics of image quality, such as MSE and PSNR, often have not correlated as well with subjective image quality ratings or observer task performance. Higher JND values indicate that a human observer would be more likely to notice a significant difference between a compressed and uncompressed image [18–21].

3. Results

Using 2D JPEG2000 compression, the thinnest (0.75 mm) sections were substantially less compressible than thicker (up to 10 mm) sections for the same level of image quality (i.e., constant JND or PSNR value), particularly at higher compression ratios. For images evaluated with the mediastinal window settings, 0.75 mm sections compressed at ratios of 6:1 and 12:1 had distortion levels comparable to the 10 mm sections compressed to higher ratios of 8:1 and 16:1, respectively (corresponding to constant JND levels of approximately 2 and 4, respectively). Increasing the 2D compression ratios of the 0.75 mm sections from 6:1 to 8:1 and 12:1 to 16:1 raised their distortion levels significantly above those of the 10 mm sections by as much as 1 JND or 8 dB in PSNR ($p < 0.001$).

Applying 3D JPEG2000 compression yielded consistently higher image quality (i.e., lower JND and higher PSNR values) in most cases compared to 2D compression at the same ratios (Fig. 1A and B).

For 3D compression of 0.75 mm sections, image quality based on JND levels was comparable to that of the 10 mm sections at all compression levels. The reduction in image distortion between 2D and 3D compression of 0.75 mm sections at ratios of 8:1 and 16:1 was 0.5 and 1.0 JND, respectively, or 1 to 3 dB in PSNR.

Results for the "lung" window settings showed similar trends in the dependence of image compressibility on section thickness and compression method (2D vs. 3D). Distortion levels, however, were generally much lower than for the mediastinal window settings at the same compression levels by up to 1.5 JND or 10 dB in PSNR.

Overall, the advantage of 3D compression over the current 2D JPEG2000 standard was greater for thinner slices and higher compression ratios. The additional degree of compression that could be achieved using 3D compression without loss of image quality is shown in Fig. 2 as a function of 2D compression ratio for the 0.75 mm (minimum)

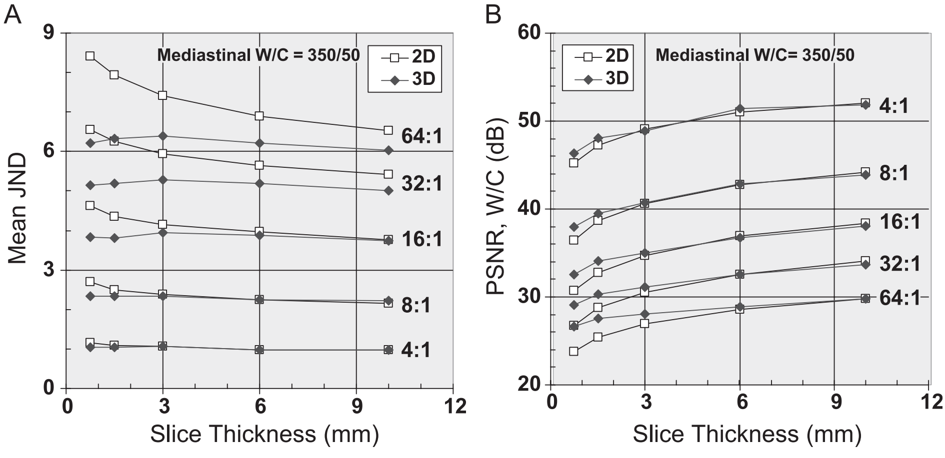

Fig. 1. Effect of slice thickness on 2D and 3D JPEG 2000 compression at mediastinal window settings—distortions measured in JNDs (A) and PSNR (B).

and 10.0 mm (maximum) slice thicknesses. For the 0.75 mm slices, 3D JPEG2000 enhanced image compressibility over the entire range of compression ratio in a manner that was qualitatively similar for both JND and PSNR metrics. For the 10.0 mm slices, however, the JND metric predicted significant advantages for 3D compression only at ratios above 20:1, while PSNR predicted no significant advantages over the entire range of compression.

Fig. 3 shows example images that illustrate (1) the increased anatomical structure and noise that are characteristic of the 0.75 mm slices and reduce their compressibility, and

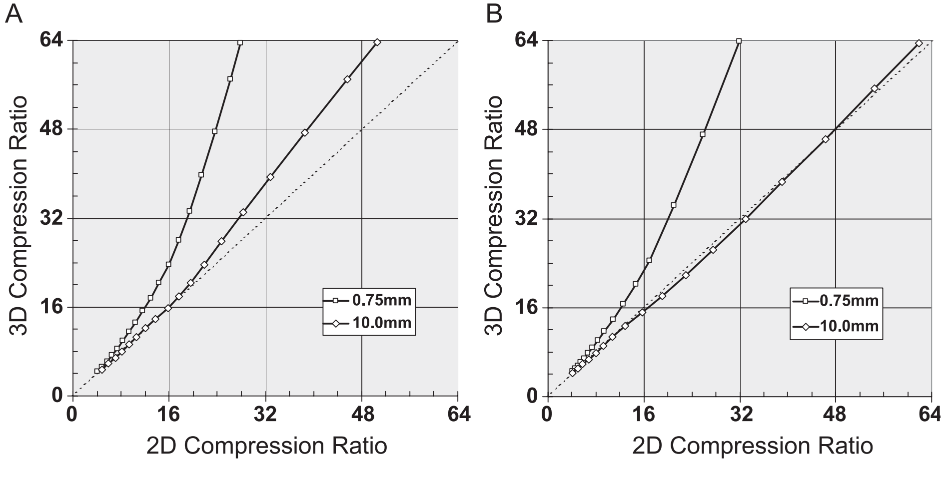

Fig. 2. Relationship between 2D and 3D JPEG2000 compression ratios for equal image distortion measured in JNDs (A) and PSNR (B).

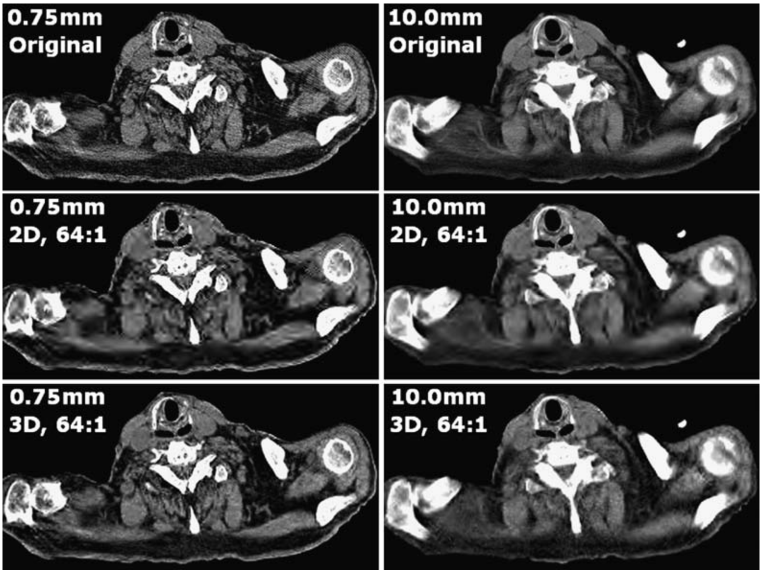

Fig. 3. Examples of original and 64:1 2D/3D compressed slices at 0.75 and 10.0 mm slice thicknesses.

(2) the relative impact of 3D vs. 2D compression on image distortion at 64:1 for 0.75 and 10.0 mm slices

4. Discussion

As the average slice thickness decreases with the advent of multislice CT, the degree of image compression achievable with standard 2D compression decreases resulting in an increase in required archival space greater than would be expected from merely counting the number of images. 3D JPEG2000 (Part 2) compression offers substantial advantages over 2D JPEG2000 compression especially for thinner submillimeter CT slices, yielding better quantitative image quality at similar compression ratios or comparable image quality at higher compression ratios. Current literature and accepted practice suggest that compression ratios using 2D JPEG2000 can be as high as 8:1 for CT without visually perceptible loss of image quality [9,12]. However, our research suggests that compression of MSCT thin (0.75 mm) slices at this ratio using 2D JPEG2000 would likely result in substantially greater and potentially clinically significant, perceptible degradation of image quality and that a lower compression ratio should be utilized for thinner slices. Our data also suggest that the use of 3D JPEG2000 compression will likely permit significantly higher compression ratios for thinner slices while maintaining acceptable image quality. The fact that the thinner slices are more compressible using the 3D algorithm suggests that the redundancy of image content across neighboring slices outweighs the difficulties of encoding the increased anatomical structure and noise associated with these slices. It is critical that vendors and the medical imaging community in general understand the potential for unexpected image degradation that may be associated with the compression of thin-slice MSCT studies when conventional 2D compression method and ratios are utilized.

Adoption of a 3D JPEG2000 compression standard by vendors and the rest of the medical imaging community would be likely to result in improved ratios of compression for large CT datasets and/or improved image quality at similar compression ratios. Clinical ROC observer performance studies should be conducted to verify the predictions for image distortion and compressibility derived from our assessment of JND and PSNR metrics.

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