Compression of multislice CT: 2D vs. 3D JPEG2000 and effects of slice thickness

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Compression of multi-slice CT: 2D vs. 3D JPEG 2000 and effects of slice thickness

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ABSTRACT

The widespread use of multi-detector CT scanners has been associated with a remarkable increase in the number of CT slices as well as a substantial decrease in the average thickness of individual slices. This increased number of thinner slices has created a marked increase in archival and network bandwidth requirements associated with storage and transmission of these studies. We demonstrate that although compression can be used to decrease the size of these image files, thinner CT slices are less compressible than thicker slices when measured by either a visual discrimination model (VDM) or the more traditional peak signal to noise ratio. The former technique (VDM) suggests that the discrepancy in compressibility between thin and thick slices becomes greater at greater compression levels while the latter technique (PSNR), suggests that this is not the case. Previous studies that we and others have performed suggest that the VDM model probably corresponds more closely with human observers than does the PSNR model. Additionally we demonstrated that the poor relative compressibility of thin sections can be substantially negated by the use of JPEG 2000 3D compression which yields superior image quality at a given level of compression in comparison with 2D compression. Additionally, thin and thick sections are approximately equally compressible for 3D compression with little change with increasing levels of compression.

Keywords: compression, 2D, 3D, DICOM, JPEG 2000, VDM, JND, PSNR, MSCT, CT

1. INTRODUCTION

With the advent of multi-detector computed tomography (MDCT) scanners and the routine use of thin slice image acquisition, the amount of image data generated can be enormous. This exacerbates limitations and challenges that already exist in image transmission and storage. The use of lossy image compression has been shown to have minimal if any deleterious impact on diagnostic image quality when used at acceptable ratios[1-4]. The use of lossy compression has been suggested[5] as a potential means to help address these very large datasets to make network transmission and image archival more efficient by ameliorating the negative impact of the larger number of uncompressed thinner section CT images that are now routinely acquired.

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However, these thinner sections are, in general, noisier and depict more high spatial frequency information than do thicker CT sections (figure 1). The JPEG 2000 compression standard is increasingly being adopted by industry as a preferred "standard" method for 2D image compression. We are not aware of any other studies that have been performed to date that investigate whether the thinner sections associated with MDCT are as compressible as thicker slices when using the JPEG 2000 compression standard, nor are we aware of any that quantify the compressibility of CT images using JPEG 2000 with varying slice thickness.

Additionally, 3D JPEG 2000 compression has been promoted commercially as a means to improve CT image compressibility in comparison to 2D JPEG 2000 compression. However, we are not aware of any previous studies that have attempted to quantify the degree to which 3D methods might be more suitable for thin slice CT datasets. The objective of our study was to determine the impact of varying slice thicknesses on compressibility of CT images of the thorax and upper abdomen when using 2D JPEG compression and to assess the impact of the use of 3D JPEG 2000 compression to improve compressibility of thin slice CT images.

2. METHODOLOGY

After investigational review board approval was obtained, five thoracic CT studies from the Baltimore VA Medical were identified. These studies were originally acquired utilizing 0.75 millimeter collimation and were reconstructed from a raw CT spiral dataset at 0.75 mm, 1.5 mm, 3.0 mm, 6.0 mm, and 10.0 mm. Using JPEG 2000 2D and 3D compression algorithms, images were compressed at ratios of 4, 6, 8, 12, 16, 32, and 64:1. Window width/center settings were set at 350/50 Hounsfield units (mediastinal settings) and 1500/-600 Hounsfield units (lung settings) respectively. A visual discrimination model (VDM) that simulates the physiological responses of the human eye and visual cortex to patterns of light from still images or video was selected. This model predicts the discriminability of two images or sequences in standardized psychophysical units known as "Just Noticeable Differences" (JND)[7]. A JND difference of 1 corresponds to a difference in two images such that 75% of observers will be able to discern a difference between the reference (uncompressed image) and the compressed image. A JND difference of 2 and 3 correspond to a 94% and 98% probability that an observer can tell that two images are different, respectively. The currently popular method of comparison of a compressed and uncompressed image, peak signal to noise ratio, was determined for each slice thickness and each level of compression. The overall JND difference was determined for each of the slice thicknesses (0.75 mm through 10 mm) with comparison made between an uncompressed image and images compressed at between 4:1 and 64:1 for both the JPEG 2000 2D and 3D algorithms.

3. RESULTS

The main results of the study were that MSCT compressibility decreased for thinner sections using 2D JPEG 2000 compression and the use of 3D JPEG 2000 image compression resulted in improved quality or compressibility of thinner section CT images in comparison to 2D JPEG 2000 compression. As shown in figure 2, for mediastinal window/level settings, the thinner slice images were less compressible than the thicker ones at a given compression ratio. This difference between compressibility of thin and thicker slices was found to increase with higher compression ratios. At a compression ratio of 64:1, for example, there was a difference of approximately 2 JND units between the 0.75 mm and 10 mm slices. This suggests substantially greater image degradation for thin slices at a given compression ratio than for thinner slices. Figure 3 demonstrates greater degradation in peak signal to noise ratios for thinner slices than for thicker slices although, interestingly, unlike the case with the visual discrimination model (JND) this discrepancy between compressibility of thin and thicker sections did not become more pronounced at higher compression ratios. The lower compressibility of thin sections when using JPEG 2000 2D compression was also evident for lung settings although the absolute JND differences between the uncompressed and compressed images was lower as shown in figure 4 suggesting that thoracic CT images are more compressible in general at lung than at mediastinal settings.

With regard to the differences between compressibility of 2D and 3D images, the 3D method resulted in greater compressibility for thinner sections at all, but especially at higher compression ratios. The JND and PSNR estimates differed in their prediction of the dependence of compressibility on slice thickness for 3D compression. The JND model predicted very little dependence (unlike it's prediction for 2D JPEG 2000 compression) on slice thickness for 3D JPEG 2000 compression while PSNR suggests that thin slices are less compressible just as it does for 2D JPEG compression. Figure 5 demonstrates that the VDM predicts that there is very little variation in compressibility between thin and thick slices when using 3D compression.

4. CONCLUSION

As the average slice thickness decreases with the advent of multi-slice 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. Current literature and accepted practice suggest that compression ratios as high as 8:1 for CT can be achieved without visually perceptible loss of image quality. Our research suggests that compression of MSCT at this ratio for thin (e.g. 0.75 mm) slices would likely result in substantially greater (potentially clinically significant) perceptible degradation of image quality and that a lower compression ratio might be more appropriate when using 2D JPEG 2000 compression for these thin slices. Clinical ROC observer studies should be conducted to verify the predictions for image distortion and compressibility derived from our assessment of JND and PSNR metrics. 3D compression, which has been suggested as a technique to achieve acceptable levels of compression for thin section CT does indeed seem to offer a substantial increase in compressibility in comparison to 2D JPEG 2000 compression according to the JND metric. This suggests that the use of 3D compression could result in better image quality at similar compression ratios or comparable image quality with higher compression ratios in comparison to 2D JPEG 2000 compression. The elimination of the difference in compressibility as suggested by the JND metric may be due to the fact that the redundancy of image data from one thin slice to the next one is high in comparison to that of one thick slice to the next and counterbalances the difficulties in encoding the increased anatomic detail and noise associated with the thin CT slices. An important limitation of these studies is the fact that the ability to discern a difference between a compressed and an uncompressed image as predicted by the JND metric may be different than the ability of the radiologist to make a clinical diagnosis from the two images. Hence validation studies should be conducted correlating JND differences and loss of diagnostic accuracy with the use of compression.

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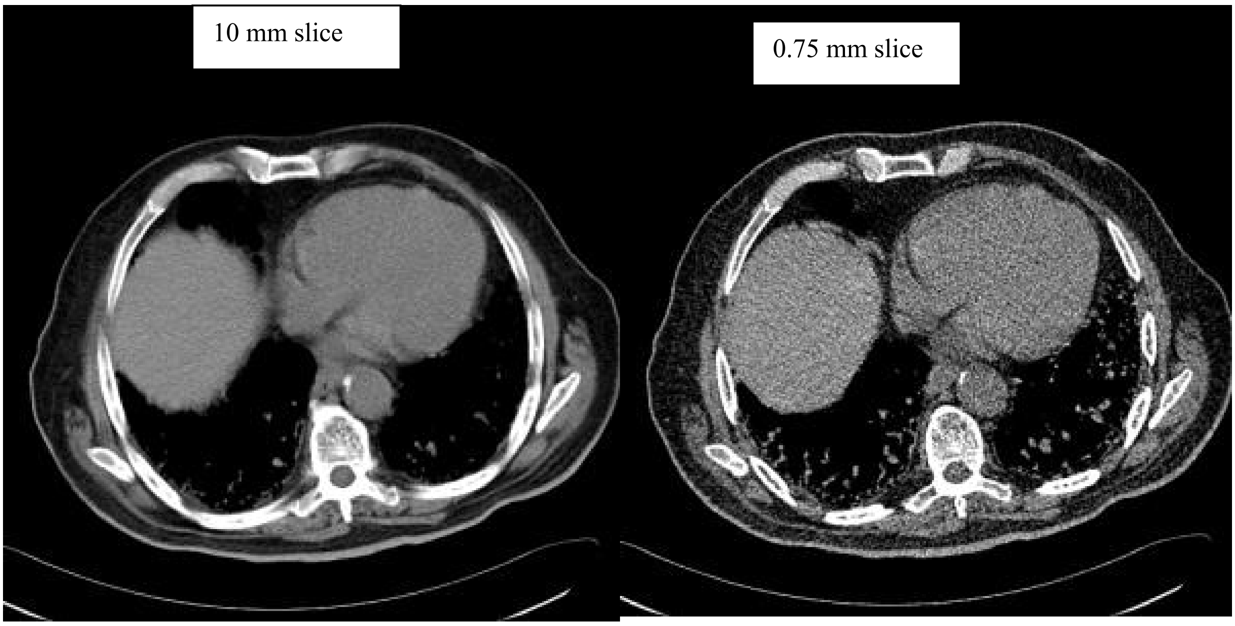

Figure 1. Increased anatomic detail and noise associated with thinner CT slices suggests that they may be less compressible than thicker slices. Both PSNR and the JND techniques support this.

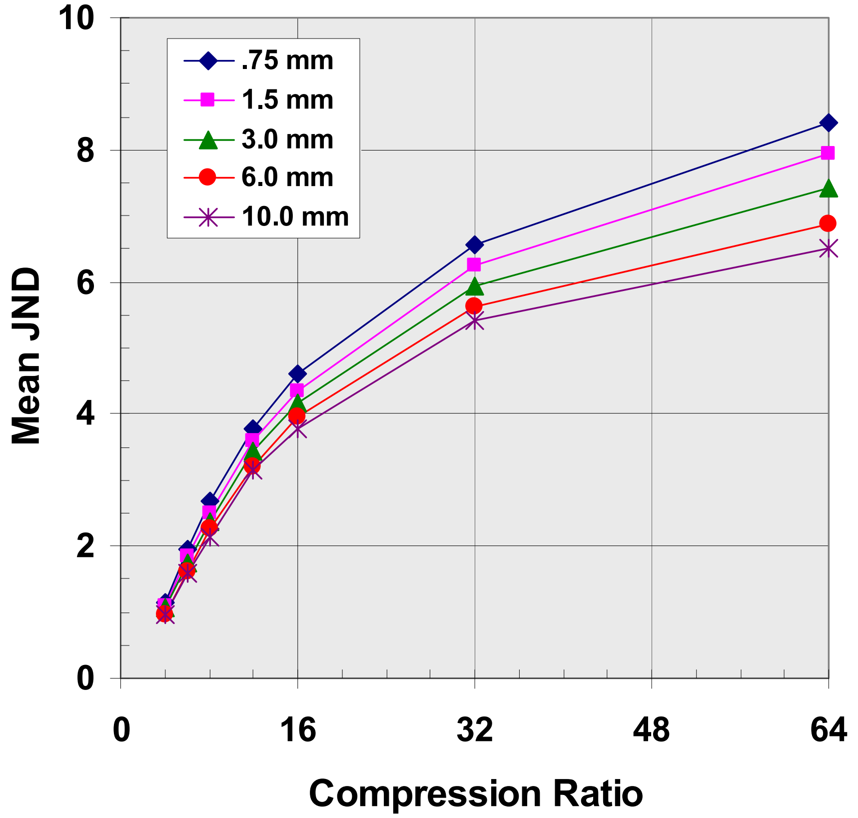

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Figure 2. At a given compression ratio using the 2D JPEG 2000 standard, thin slices of the thorax at mediastinal settings have a greater degree of distortion as measured by mean JND units than do thicker slices. The difference in degree of relative distortion between thin and thicker slices as measured by JND increases with greater compression ratios.

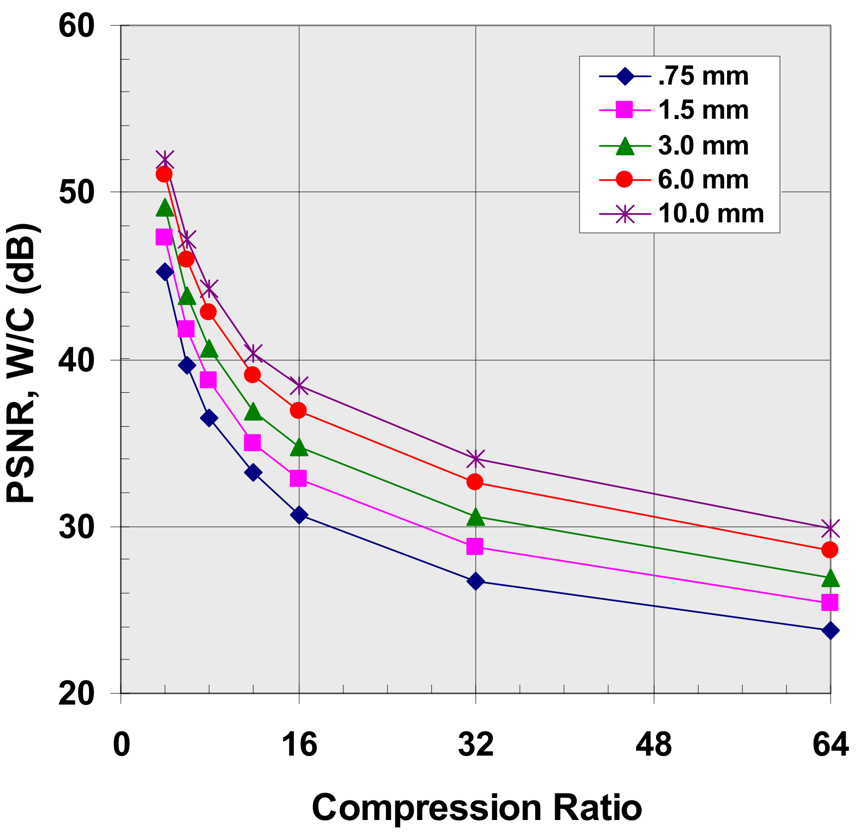

Figure 3. Thinner CT slices result in a lower peak signal to noise ratio at a given level of compression. This also suggests a greater level of distortion of thin slices and thus a lower level of compressibility than thicker slices. Unlike the JND curve in figure 2, there is not a substantial increase in the difference between the thin and thicker sections for high levels of compression in comparison to lower levels.

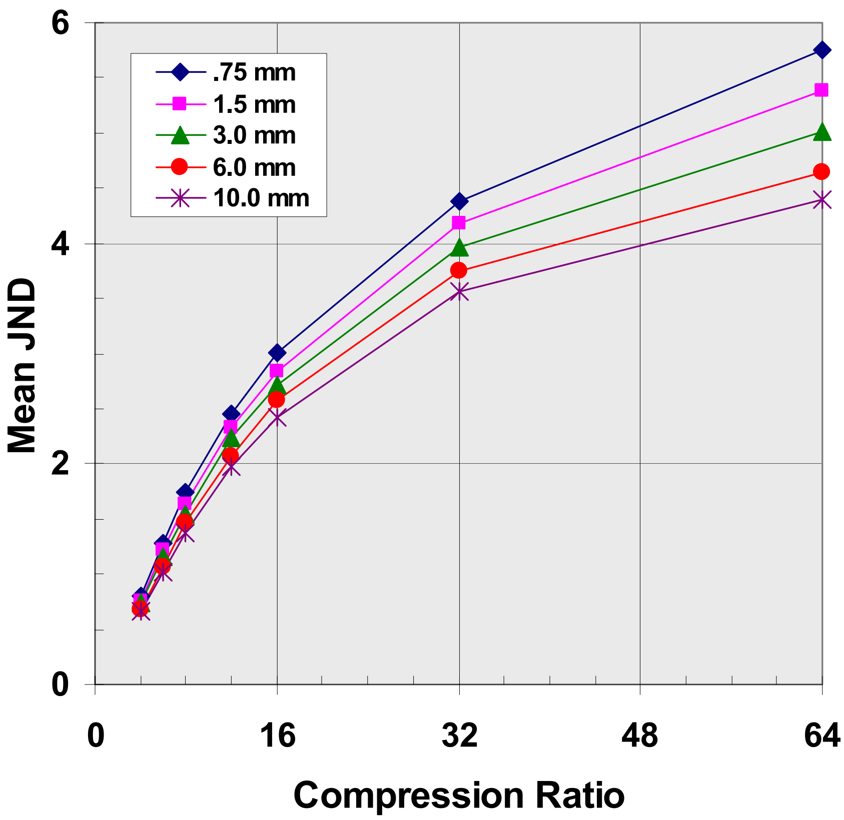

Figure 4. At a given compression ratio using the 2D JPEG 2000 standard, thin slices of the thorax at lung settings have a greater degree of distortion as measured by mean JND units than do thicker slices. At a given compression ratio, the JND is less than for mediastinal settings (figure 2). The difference in degree of relative distortion between thin and thicker slices as measured by JND increases with greater compression ratios just as it does for mediastinal settings..

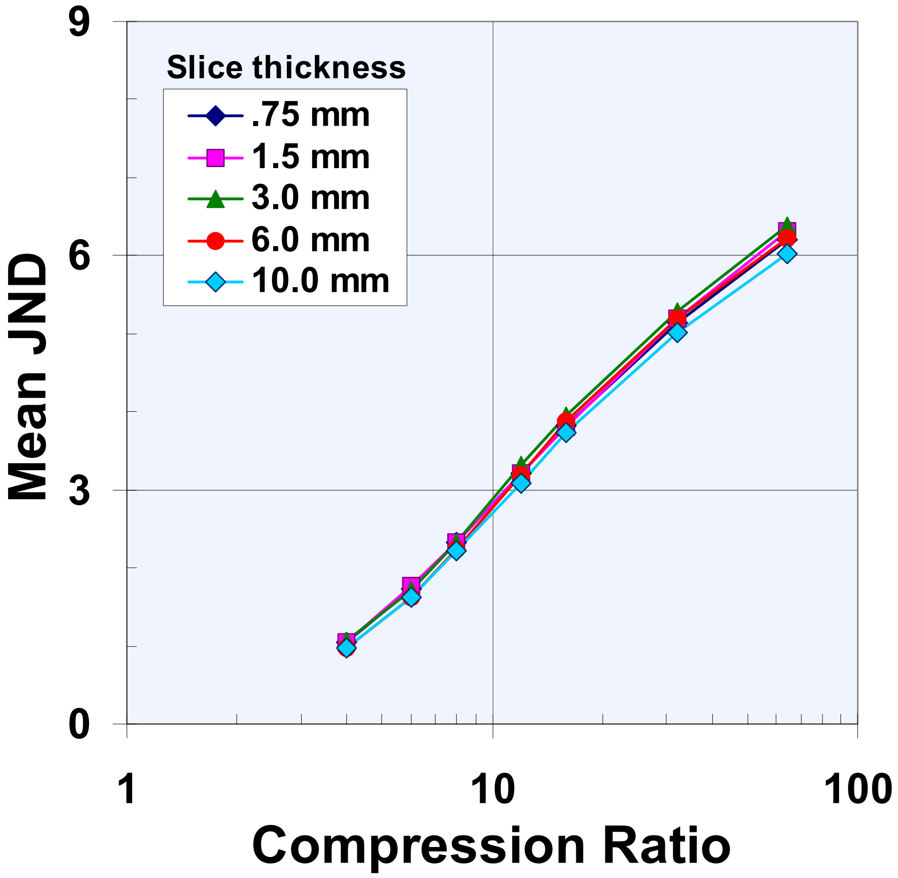

Figure 5. Unlike 2D compression, there is very little variability in compressibility using 3D compression with increasing compression ratios between thin and thick slices for CT of the thorax (mediastinal settings)

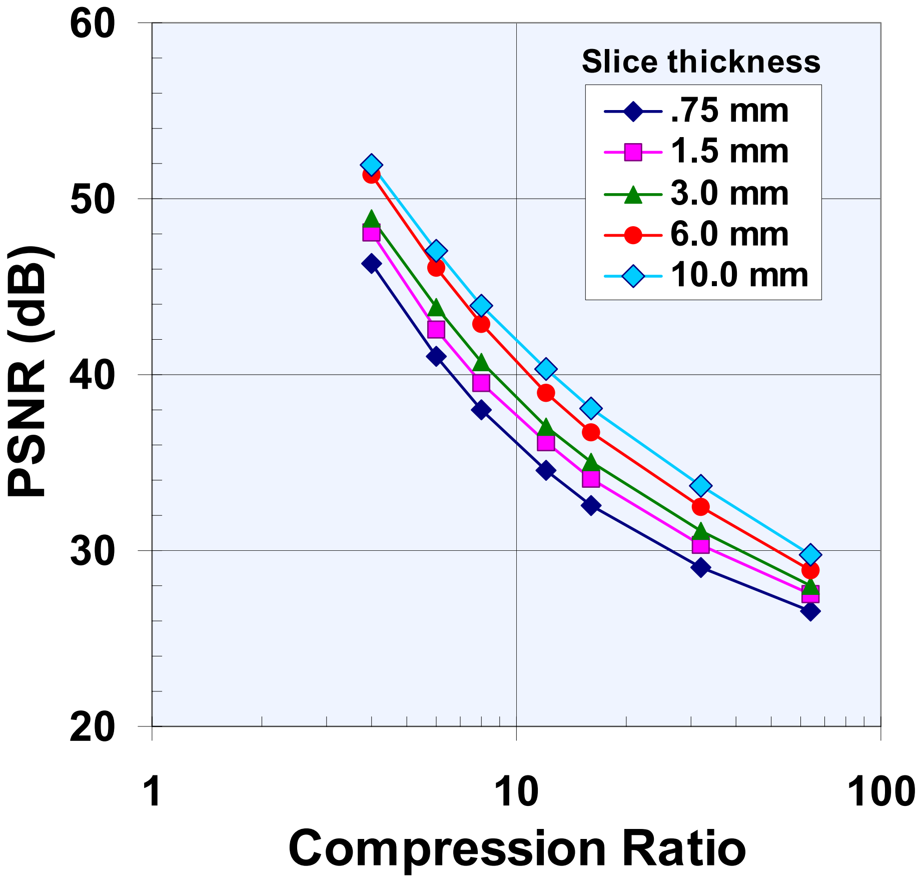

Figure 6. Unlike the prediction of the VDM (which probably corresponds more closely with human observers), the use of PSNR suggests substantially greater compressibility (or greater image quality at a given compression ratio) for thick in comparison to thin slices