Journal of Digital Imaging

Clinical Evaluation of Compression Ratios using JPEG2000 on Computed Radiography Chest Images

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The efficient compression of radiographic images is of importance for improved storage and network utilization in support of picture archiving and communication systems (PACS) applications. The DICOM Working Group 4 adopted JPEG2000 as an additional compression standard in Supplement 61 over the existing JPEG. The wavelet-based JPEG2000 can achieve higher compression ratios with less distortion than the Discrete Cosine Transform (DCT)-based JPEG algorithm. However, the degradation of JPEG2000-compressed computed radiography (CR) chest images has not been tested comprehensively clinically. The authors evaluated the diagnostic quality of JPEG2000-compressed CR chest images with compression ratios from 5:1 to 200:1. An ROC (receiver operating characteristic analysis) and *t* test were performed to ascertain clinical performance using the JPEG2000-compressed images. The authors found that compression ratios as high as 20:1 can be utilized without affecting lesion detectability. Significant differences between the original and the compressed CR images were not recognized up to compression ratio of 50:1 within a confidence level of 99%.

KEY WORDS: JPEG2000, receiver operating characteristic analysis, *t* test, computed radiography

MEDICAL IMAGES such as computed radiography (CR) and digital mammography require large storage facilities and long transmission times. Therefore, reduction in the implementation costs associated with a Picture Archival and Communications System (PACS) requires use of image compression to decrease image transmission time and to save disk space. This is true despite the recent rapid advances made in storage and transmission technology.[1] The size of each CR chest image is about 7-10 MB (megabytes). Given the number of CR chest images archived per day at Yonsei University Medical Center (YUMC), the daily storage requirement for CR is about 4.5 GB (gigabytes). Currently, YUMC archives 7 to 8 GB of digital images per day in a partial PACS. This is expected to reach 20 to 30 GB when a full PACS system is installed in 2002. The envisaged YUMC PACS facility will require an efficient method to reduce the amount of data stored, which are likely to be mainly radiographs, either from scanned film or direct digital acquisition. These images must be high quality to be clinically useful.

Medical image compression can be described as the process of discarding some information while maintaining relevant diagnostic information. Lossless compression allows exact recovery of the original image and is an obvious initial choice for medical imaging applications because it does not affect image quality. However, it achieves only very modest compression ratios, typically from 1.5:1 to 3:1. However, the lossy compression method does not allow exact recovery after compression, although it does allow much higher compression ratios. Generally, higher degrees of lossy compression can be

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Online publication 26 September 2002
doi: 10.1007/s10278-002-0007-6

obtained at the expense of greater image degradation.

The digital images reconstructed from the compressed images must be very close to the originals in quality and must preserve all the significant information of the original images for clinical diagnostic applications. However, it is important to obtain high compression efficiency.[2]

The DICOM (digital imaging and communications in medicine) standard for medical images provides lossy/lossless compression mechanisms to support the use of JPEG, Run-Length-Encoding (RLE), and JPEG-lossless image compression.[3] The JPEG standard includes both lossy and lossless compression techniques, but the former has been used mainly in medical imaging applications. The RLE method for lossless compression takes advantage of uniform areas (such as often are present in ultrasound images) to achieve simple and efficient compression. A new lossless technique called JPEG-lossless has been defined that can outperform previous lossless techniques. In particular, the JPEG standard is the primary compression technology within DICOM for high-compression efficiency.[4] However, it has been recognized that the current lossy JPEG standard has certain limitations, such as the presence of objectionable blocking artifacts that can occur at high compression ratios, and limitations in terms of the types of input images caused by the maximum bit depth of 12bit/pixel.[5] Therefore, the DICOM subcommittee, Working Group 4 (WG4), which is responsible for image compression, reviewed JPEG2000 and adopted it as the DICOM standard in Supplement 61: (JPEG2000 Transfer Syntaxes).[6] JPEG2000, which provides a new compression algorithm based on the use of a wavelet technique, can provide significantly higher compression efficiency than the lossy JPEG technique with less degradation and distortion. JPEG2000 also provides various features, which may be advantageous for medical imaging applications, including integrated lossy/lossless compression, region-of-interest (ROI) encoding, inherent multiresolution capability, progressive decoding, and security techniques.[7]

The American College of Radiology and the National Electrical Manufacturing Association (ACR/NEMA) standard report defines a compression scheme to be a form of information preservation if the resulting image retains all of the significant information of the original image. The related term for lossy compression used by ACR/NEMA is information preserving. Both information preserving and visually lossless are subjective definitions, and great caution should be taken in their interpretation.[8]

We report the results of a study to determine the compression ratios that can be achieved with JPEG2000 while maintaining the criteria that they remain information preserving for clinical diagnostic applications on CR chest images.

MATERIALS AND METHODS

Sixty CR chest images were selected at YUMC; 31 with abnormal lesions and 29 normal images. Two radiologists experienced in thoracic imaging selected chest radiographs that contained specific subtle abnormalities (but were otherwise normal) that they believed might be difficult to detect if the images were degraded. These included small nodules, subtle and focal "fibro-streaky" densities, and mild blunting of the costophrenic angle. They were obtained with a pixel dimension of $1,760 \times 2,140$ and a bit depth of 10 from a FUJI FCR 9501HG CR system (FUJI PHOTO FILM Co, Tokyo, Japan) CR system. Window width and level were set at 783 and 1,023, respectively for display. The computer platform used for this study was an IBM (IBM, Co, White Plains, NY) with Intel PIII-860, 512 MB RAM and 32 MB of video RAM. The 60 images were compressed using JJ2000 public domain software, as recommended by the Joint Photographic Expert Group. The compression ratios relative to output file size applied for the studies were: 5:1, 7:1, 10:1, 15:1, 20:1, 25:1, 30:1, 35:1, 40:1, 45:1, 50:1, 55:1, 60:1, 65:1, 70:1, 75:1, 80:1, 90:1, 100:1,120:1, 140:1, and 200:1.

With JPEG2000 compression, an image can be divided into rectangular nonoverlapping equal size blocks (tiles). Each tile is decomposed in different resolution levels, and compression then can be performed independently. This tiling reduces memory requirements and enables one to decode specific parts of an image, but it can reduce overall image quality. In this study, all original images were untiled to enhance image quality. The untiled images were decomposed to the fifth level.

The original and reconstructed images were displayed in random order, approximately 10 seconds per image, on a viewing monitor and evaluated by 3 radiologists including 2 radiologists experienced in thoracic radiology and one general radiologist. Observation more than 10 seconds or adjustment of the level and window by the radiologists was not allowed because observation time or image manipulation could affect detectability, and they might be confusing factors. All images were displayed using a TOTOKU MDL2102A Monochrome LCD 1.5K Monitor (TOTOKU Electric Co, Nagano, Japan), which is one of the monitors used for the PACS at Yongdong Severance Hospital (YSD), in conjunction with an IrfanView v3.61 image viewing program (Irfan Skiljan, Graduate of Vienna University of Technology, Austria). The pixel dimension of the monitor was set to 1,536 × 2,048.

To evaluate lesion detectability relative to image quality, we performed an ROC analysis. For all images, 3 radiologists were asked independently to give an ROC confidence rating on a scale of 1 to 5, corresponding to the likelihood of lesion presence, with 5 indicating definite presence and 1 definite absence. Confidence values 4 and 2 indicated that the lesion was probably present and probably absent, respectively. A confidence value of 3 indicated that the lesion presence was equivocal or indeterminate. ROC analysis used the uncompressed images, which were ranked 1 or 5 as a gold standard.

To evaluate the image quality relative to compression ratio, we used a paired sample *t* test. Three radiologists also were asked independently to provide a subjective assessment from 1 to 5 of the quality of each image for lesion detectability. Confidence values 5 and 1 indicated that the image quality was definitely acceptable and definitely unacceptable for diagnosis, respectively, 4 and 2 that it was probably acceptable and probably unacceptable, respectively, and 3 indicated equivocal or indeterminate quality. The *t* test also used the original images as a gold standard.

The reconstructed images were quantitatively evaluated by performing an ROC analysis and a *t* test using the results of the 3 radiologists' evaluations of lesion detectability and diagnostic accuracy, comparing the reconstructed with the original images.

The results of ROC and *t* test were analyzed using SPSS 9.0 statistics software (SPSS Inc, Chicago, IL).

RESULTS

1. ROC analysis

ROC analysis measures the difference between lesion detectability of the original and reconstructed images.[9] The area under the (ROC) curve (AUC), which can range from 0 to 1, is used commonly as a performance measurement. A higher AUC indicates a greater probability of making a correct decision. Table 1 shows the results of the ROC analysis and includes estimates of the area, the standard error of the area, and the confidence limits of the area. The area and standard error have values near 1 and 0, respectively, which indicate that the degree of lesion detectability with reconstructed images is almost always close to that of the original images. The results of AUC (Fig 1) for evaluating lesion detectability showed that there was almost no difference for compression ratios up to 10:1 (AUC $\approx$ 0.986), at a 99% confidence level, and that lesion detectability was very close to that of the original images even for compression ratios up to 50:1 (AUC $\approx$ 0.946 ~ 0.954). Therefore, compressions of up to 50:1 may be acceptable for clinical diagnostic applications, because the AUC for lesion detectability differed only marginally between the reconstructed and original images.

2. *t*-test

The paired samples *t* test for evaluating image quality was used to compare the quality of the original and reconstructed images and to compute the differences between the mean values of the original and the reconstructed image quality assessment.

Table 1. Results of ROC Analysis for Various Compression Ratios at a Confidence Level of 99%

				Asymptotic 99% Confidence Interval	
Compression Ratio	Area	Standard Error	Asymptotic Sig.	Lower Bound	Upper Bound
5:1 ~ 10:1	0.986	0.010	0.000	0.959	1.012
15:1	0.954	0.017	0.000	0.909	0.999
20:1	0.946	0.017	0.000	0.903	0.988
25:1	0.947	0.019	0.000	0.899	0.995
30:1	0.952	0.018	0.000	0.905	0.999
35:1	0.954	0.016	0.000	0.911	0.996
40:1	0.951	0.016	0.000	0.909	0.992
50:1	0.946	0.017	0.000	0.903	0.989
60:1	0.907	0.024	0.000	0.845	0.969
70:1	0.894	0.025	0.000	0.829	0.960
80:1	0.899	0.025	0.000	0.834	0.965
100:1	0.895	0.026	0.000	0.829	0.961
140:1	0.901	0.025	0.000	0.837	0.965

NOTE: The standard errors were negligible.

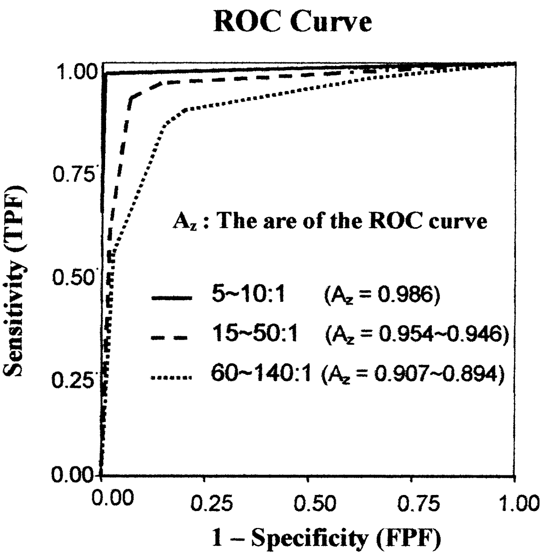

Fig 1. Graph of ROC curve for various compression ratios at a confidence level of 99%.

Table 2 shows the results of the paired sample *t* test obtained in the evaluation of image quality. These results indicated that the *t* value ($\approx$ 1.09) was relatively small at a compression ratio of ~15:1 and that no differences were found between the quality of the original and reconstructed images below a 20:1 compression ratio, at the 99% confidence level (P value $>$.01). The *t* test established that at a compression ratio of ~20:1 there was a significant difference between the original and reconstructed images (P value $<$.01). These results suggested that image degradation or distortion may not affect perception of diagnostic quality at compression ratios up to ~20:1, and that such CR chest images were truly "visually lossless" or "information preserving."

Figure 2 presents the reconstructed images for various compression ratios.

DISCUSSION

We evaluated the clinical diagnostic performance radiologists reviewing JPEG2000-compressed CR chest images over a range of compression ratios. The advantage of the JPEG2000 technique is that it is more compression efficient than the lossy previous JPEG technique with less degradation and distortion.[10] Many other compression studies have been undertaken in medical imaging applications using the JPEG technique, which have indicated that it is possible to compress a radiographic image by a ratio of 10:1, or even higher, without any loss of diagnostic quality. Recent studies using wavelet transforms have shown the possibility of achieving compression ratios up to 20 to 30:1 in projection radiography without compromising image diagnostic quality.[11-15] The purpose of our study was to evaluate the visually lossless or information-preserving compression ratios of JPEG2000 for CR chest images. ROC analysis has been the

Table 2. Results of Paired Sample *t* Test By Comparing Reconstructed Images With Original Images at a Confidence Level of 99%

		Paired Difference						
					99% Confidence Interval of the Difference			
	Mean	Mean	Standard Deviation	Standard Error Mean	Lower	Upper	*t*	*P* value
5.1	4.300 4.308	−8.33e-03	9.13e-02	8.33e-03	−3.01e-02	1.35e-02	−1.0	.319
7:1	4.300 4.250	5.00e-02	0.483	4.4e-02	−6.53e-02	0.165	1.14	.259
10:1	4.300 4.217	8.33e-02	0.656	5.98e-02	−7.34e-02	0.240	1.39	.166
15:1	4.300 4.233	6.67e-02	0.670	6.12e-02	−9.35e-02	0.227	1.09	.278
20:1	4.300 4.142	0.158	0.722	6.59e-02	−1.41e-02	0.331	2.40	.018
25:1	4.300 4.108	0.192	0.639	5.83e-02	3.89e-02	0.344	3.29	.001
30:1	4.300 4.067	0.233	0.645	5.88e-02	7.93e-02	0.387	3.96	.000

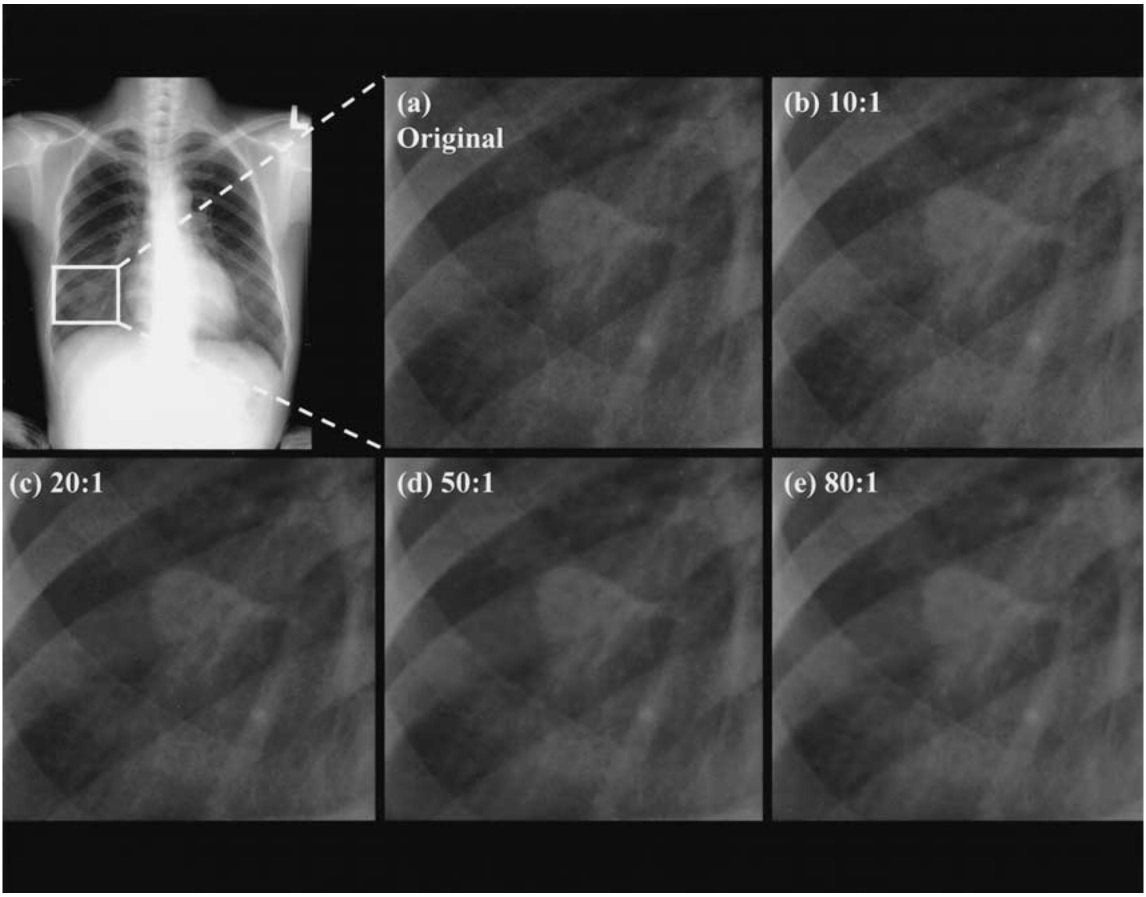

Fig 2. An example of comparisons made between reconstructed images and the original image, using the JPEG2000 image compression technique. Increased levels of compression result in greater image quality degradation

most common method for assessment of image quality or diagnostic accuracy of compressed images. Because the radiologists rated diagnostic usefulness rather than general appearance, edge patterns, or mere lines, the ROC study can be used to evaluate diagnostic efficacy at various compression levels. In this study, the results of the ROC analysis showed that there were no significant image degradation at compression ratios up to ~ 10:1, at a confidence level of 99%, and that lesion detectability was very close to that of the original image even for compression ratios up to 50:1.

The results of the paired sample *t* test suggest that there was no difference between the quality of the original and reconstructed images over the range 5 ~ 20:1, at the 99% confidence level (P value > 0.01). This suggests that the clinically acceptable compression ratio using JPEG2000 for CR chest images may be as high as ~20:1.

The results of the ROC analysis and *t* test suggest that visual loss did not occur at a 20:1 compression ratio, and that significant medical information was conserved with a confidence level of 99%.

However, rating the detectability of a lesion and image quality are subjective tasks. The results can be affected by radiologist attitude, degree of fatigue, and experience, as well as observation time and memory effect. Radiologists can easily memorize the location and shape of a lesion associated with other characteristics. Complete exclusion or control of these factors may be impossible. In particular, memory effect is a confounding factor that can be affected again by other factors such as attitude, degree of fatigue, and experience of radiologists. However, it could be reduced by controlling the environment and condition of reviewing as much as possible as well as by presenting the compressed images randomly. In addition, we believe that the memory effect is not a critical problem in rating of detectability of already recognized lesions by radiologists.

CONCLUSIONS

The use of image compression makes PACS a more economically viable alternative to analog film-based systems by reducing the bit size required to store and represent images while maintaining relevant diagnostic information. It also enables fast transmission over a PACS network and workstation display of large medical images for diagnostic and review purposes. The JPEG2000 compression algorithm, which has been adopted as the DICOM standard for medical images, provides higher compression efficiency than JPEG, RLE, and JPEG-lossless compression algorithms.

In this study, the results of the statistical tests performed showed that there was no significant difference between the original and reconstructed images for compression ratios up to 20:1, at a 99% of confidence level. Moreover, the results of ROC analysis suggested that compression ratios using JPEG2000 for CR chest images may be as high as ~50:1, without adverse effects on clinical diagnostic performance. Further studies will be needed before these findings can be applied to other imaging modalities and medical applications.

ACKNOWLEDGMENTS

This study was supported by a grant from the BK21 Project for Medical Sciences, Yonsei University, Seoul, Korea.

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