Clinical Evaluation of Irreversible Data Compression for Computed Radiography of the Chest

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Efficient data compression is essential for practical daily operation of computed radiography (CR) systems. In this study the clinical applicability of type III irreversible high data compression using an FCR 9501 chest unit (Fuji Photo Film, Tokyo, Japan) was evaluated. Sixty-eight normal and 93 various abnormal cases, with an additional 15 cases of lung cancers with solitary lung nodules, were selected from the file. A pair of hard copies of original images and images reconstructed using type III compression was made for each case. Six radiologists evaluated the image quality by visual rating and receiver operating characteristic (ROC) curve analysis. For all five anatomic regions of normal cases, "original equal to compressed" was the most common response, followed by "original significantly better than compressed." When abnormal cases were evaluated for diagnostic information, there was no significant difference between the compressed and original images. ROC curve analysis on lung nodules with lung cancer showed no significant difference between the two. Compressed CR images using the type III irreversible technique are clinically applicable and acceptable despite slight degradation of image quality.

KEY WORDS: computed radiography, data compression, chest.

PHOTOSTIMULABLE storage phosphor computed radiography (CR) is currently one of the most widely used digital radiography systems.[1-5] Digital CR images are superior to conventional screen-film systems not only for providing a stable image under a wide range of x-ray exposure settings, but also for image transfer and storage. However, one CR image usually requires 4 to 6 Mb of information storage capacity, and the routine use of raw data is not practical. For daily operation of the system, some type of data compression is used, particularly for image storage. High data compression that does not affect diagnostic capability is preferable. A compression ratio of at least 20:1 is currently available and in use. Although studies on the clinical applicability of high data compression have been reported for radiography of the chest,[6-10] gastrointestinal tract,[11] urinary tract,[12] and bone,[13] additional studies confirming its usefulness are necessary for this technique to be widely accepted. In this study we evaluated the usefulness of high data compression, of type III, for a new FCR chest unit (Fuji Photo Film) on various repiratory diseases. This type III data compression technique is based on prediction and Huffman coding. The prediction method indicates a difference in density between the preceding and the present point, and it takes advantage of the fact that the density of the x-ray image does not change rapidly. Huffman coding is a compacting method that depends on occurrence frequency. The more frequently occurring bit sequence is assigned to the shorter bit sequence; this improves the average coding efficiency. The type III technique achieves a 20:1 to 25:1 compression ratio for the chest image.[9]

MATERIALS AND METHODS

The CR system used is a dedicated chest unit for erect radiographs, the FCR 9501 (Fuji Photo Film). The imaging plate was ST-V (35 cm × 43 cm, 1,770 × 2,150 matrix, 10 bits, 200-μm pixel size). Image reading and processing were performed using an automatic mode with an exposure data recognizer and dynamic range control processing in a single image format. Hard copy images of 23.5 cm × 28.5 cm (67% reduction) were produced using a laser printer (FL-IMD, Fuji Photo Film).

For all radiographic exposures, an x-ray apparatus with an x-ray tube having a focal size of 1.2 mm × 1.2 mm (Toshiba, Tokyo, Japan), and a 0.1 mm copper filter backed with 1.0 mm aluminum and a moving grid with a 10:1 ratio (40 lines/cm) were used. Posteroanterior erect views were obtained. The exposure factors were 120 kV and 500 mA with a phototimer, and the focus-imaging plate distance was 2 m.

Evaluation of the diagnostic quality of the images was performed for both normal and abnormal cases by visual rating and on malignant lung nodules by receiver operating characteristic (ROC) curve analysis.

Visual Rating

Sixty-eight normal and 93 abnormal cases were selected from the chest radiographs obtained at the Department of Radiology, University of Occupational Health Hospital, from July 1995 to April 1996. The patients selected included a wide range of normal cases of various ages and also included patients with

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Table 1. Characteristics of Abnormal Cases for Visual Rating

	No. of Cases (Lesions)			
Abnormality	Tuberculosis	Other Benign Nodule	Lung Cancer	Metastatic Tumor
Lung nodule				
0-9 mm	(6)	(2)	(0)	(3)
10-19 mm	(6)	(6)	(4)	(3)
20-29 mm	(4)	(1)	(5)	(4)
Bulla	9			
Bronchiectasis	8			
Consolidation	10			
Pneumoconiosis	12			
Carcinomatous lymphangitis	6			
Interstitial pneumonia	14			
Rheumatoid arthritis		6		
Idiopathic interstitial pneumonia		5		
Progressive systemic sclerosis		3		

various common respiratory diseases. The abnormalities were confirmed by computed tomography (CT) and were detectable at least on the original CR chest radiographs. The age of normal cases ranged from 16 to 93 years (mean, 48). The abnormal cases consisted of 34 with lung nodules (44 lesions), 27 with other localized lesions, and 32 with diffuse lung diseases (Table 1).

A pair of hard copies of original images and images reconstructed using type III compression was made for each case. The paired images were presented in tandem on a view box to six certified radiologists (H.W., K.U., K.N., Y.I., K.H., R.Y.). They were not told which of the pair was the original or compressed image and were asked to compare the diagnostic quality of the paired images. In normal cases the following were evaluated: (1) margin of the right clavicle and upper ribs, (2) peripheral pulmonary vessels and lower thoracic spine overlying the heart, (3) margin of carina and main bronchus, (4) peripheral pulmonary vessels overlying the right diaphragm, and (5) peripheral pulmonary vessels in the right lower lung field above the diaphragm. In abnormal cases, the diagnostic features of the individual lung opacities were evaluated. The observers were allowed to freely rearrange the pairs of the images for comparison, and the observation time was limited to within 1 minute per pair. Each observer reviewed the cases individually. The results were rated as follows: 1 = original much better than compressed image; 2 = original better than compressed image, 3 = original equal to compressed image; 4 = compressed better than original image; and 5 = compressed much better than original image (Figs 1-3). Statistical evaluation was performed using the χ^2 test.

ROC Curve Analysis

Next ROC curve analysis was performed in cases of lung cancer with solitary lung nodules. Fifteen cases of peripheral adenocarcinomas of less than 26 mm in size were selected from August 1995 to July 1996. Only relatively small adenocarcinomas were included because they are very important targets in chest radiography. They were histologically proven and confirmed by CT (Table 2). The ages and sexes of 15 normal cases were matched to those of lung cancers. The absence of abnormality was confirmed by CT.

The same six radiologists participated in this study. First, the observations were made for the series of compressed images; 1 month later the original images were examined. The observers were informed of the nature of the lung lesions and the proportion of normal and abnormal cases. For each image, the

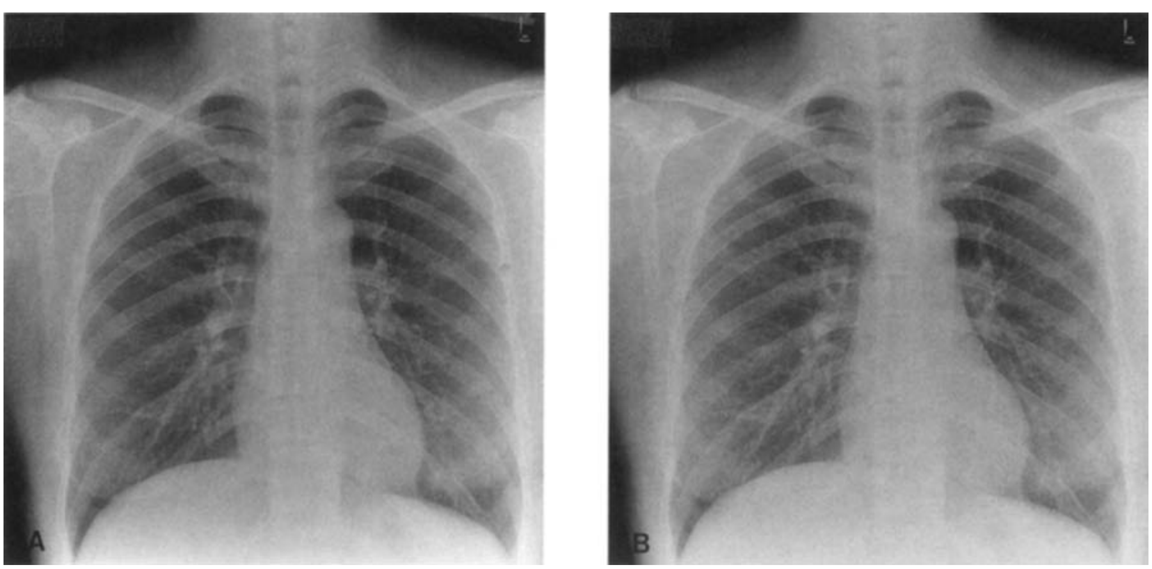

Fig 1. Normal case (43-year-old woman). (A) Original image. (B) Compressed image (compression ratio of 25:1). The pulmonary vessel and spine overlying the heart, and the pulmonary vessel above the right diaphragm were rated as "original better than compressed" by three of the six observers. Other anatomic regions were rated as "original equal to compressed" by at least four of the six observers.

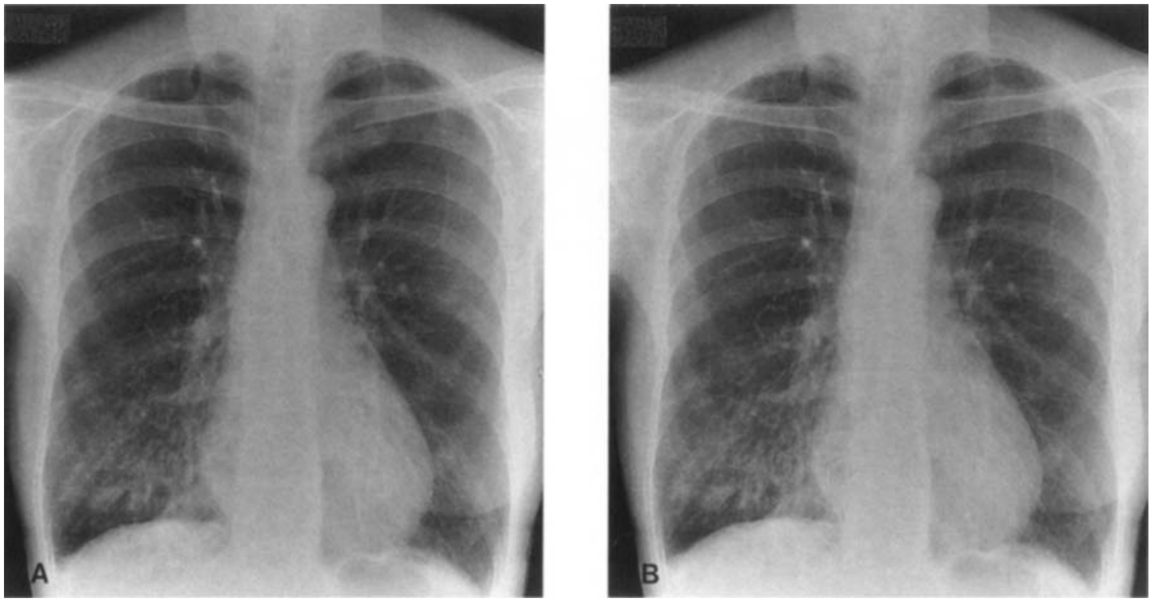

Fig 2. Bronchiectasis (67-year-old woman). There are strand opacities in the right lower lung field. (A) Original image. (B) Compressed image (compression ratio of 25:1). All six observers rated these images as "original equal to compressed."

observers indicated the presence or absence of the abnormality on continuously distributed data, from 0 to 100, with 0 indicating a definite absence and 100 representing definite presence. A maximum of 1 minute was allowed for the viewing of each CR image (Figs 4 and 5). The area under the ROC curves (A_z) was calculated from each ROC curve using LABROC software (Metz CE, University of Chicago, IL), and statistical evaluations were performed using the paired *t* test.[14,15]

RESULTS

Visual Rating

The results of the visual rating of normal anatomic structures are shown in Table 3. The rating "original equal to compressed" was the most common, followed by "original better than com-

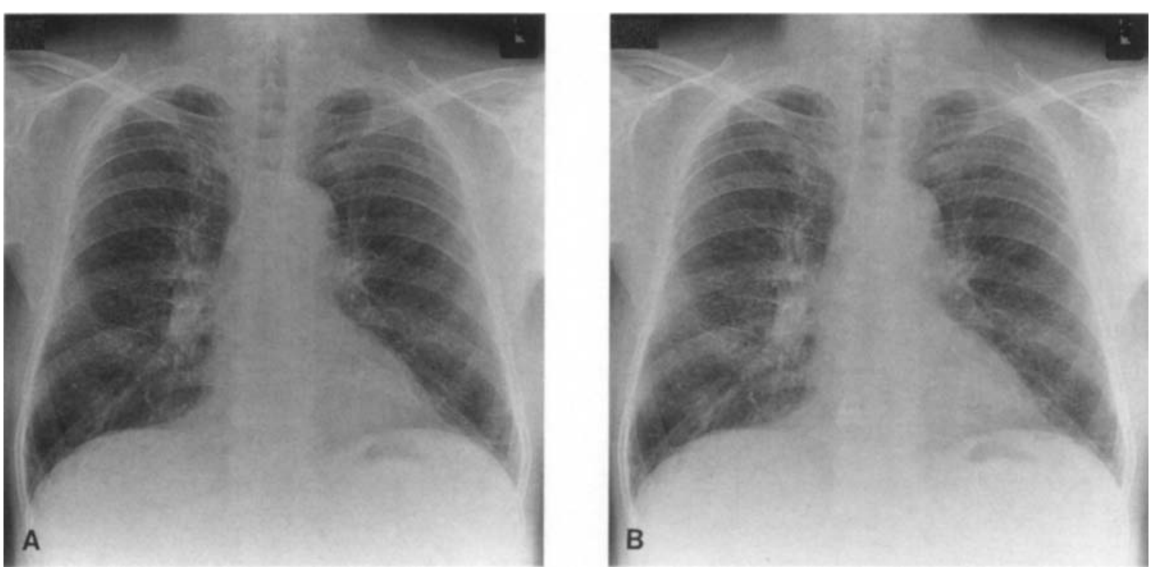

Fig 3. Pneumoconiosis (70-year-old man). There are diffuse small nodular opacities throughout both lungs. (A) Original image. (B) Compressed image (compression ratio of 25:1). Only one observer rated these images as "original better than compressed"; the other five noted "original equal to compressed."

Table 2. Characteristics of Cases of Lung Cancer for ROC Study

Characteristic	No. of Cases
Adenocarcinoma	
Well differentiated	6
Moderately differentiated	8
Poorly differentiated	1
CT Appearance	
Size	
11-15 mm	3
16-20 mm	9
21-25 mm	3
Margin of nodule	
Distinct	5
Indistinct	10
Air attentuation within nodule	
Present	7
Absent	8

pressed." The extremes of the scale (original much better, compressed much better) rarely were noted. However, the original image was considered significantly better than the compressed image in all anatomic regions at the .05 level.

When the abnormal cases were evaluated diagnostically, the results were different. "Original equal to compressed" was the most common, and there was no significant difference between compressed and original images at the .05 level (Table 4).

ROC Curve Analysis

ROC curves were obtained from all six observers for lung nodules with lung cancer. The A_z for each observer is shown in Table 5. The mean A_z for original and compressed images was 0.907 and 0.891, respectively. There was no significant difference between the two at the .05 level.

DISCUSSION

Previous reports state that a compression of digital data as high as 20:1 to 30:1 usually is permissible in chest digital images.[6-8] However, studies evaluating clinical cases have been scarce. We previously reported the clinical applicability of high data compression in chest CR images using the FCR 7000 system.[9] A posteroanterior view with this system consisted of a pair of one mildly processed simulating conventional screen-film radiograph and the other heavily processed. With the new FCR 9501 system, it has become possible to produce a single CR image combining both processing techniques. This combined method is now widely used. Therefore, it seemed necessary to evaluate the same compression technique on the chest CR images with the new single-image format.

The possible degradation of image quality by data compression was evaluated first. Five ana-

Fig 4. Well-differentiated papillary adenocarcinoma, 22 mm in diameter (63-year-old man). There is a poorly defined nodule overlying the right third anterior rib. (A) Original image. (B) Compressed image (compression ratio of 25:1). The visibility of the nodule is satisfactory on this image.

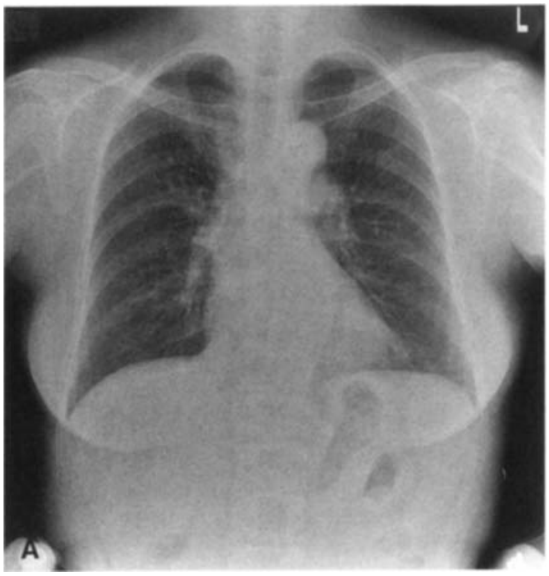
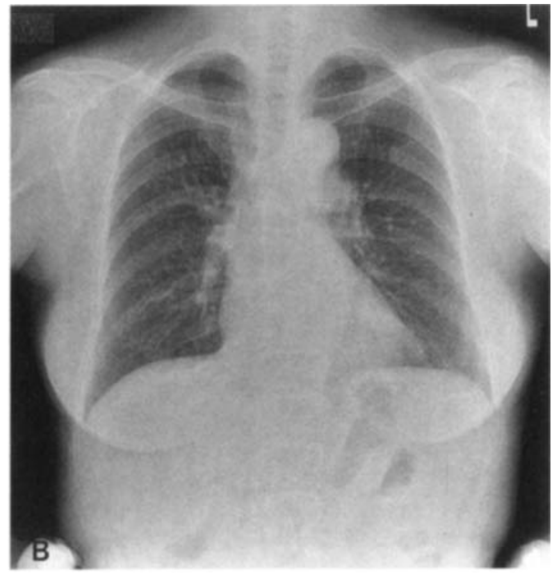

Fig 5. Moderately differentiated adenocarcinoma, 11 mm in diameter (67-year-old woman). There is a well-defined nodule overlying the left sixth posterior rib. (A) Original image. (B) Compressed image (compression ratio of 25:1). There is no visibility problem in the nodule on this image.

tomic structures in normal cases were chosen to keep constant the target of evaluation among observers. Although the equal rating was the most common, original images were considered significantly better than compressed images in all five anatomic structures. This recognition of degradation of image quality is understandable because the targets of observation were mostly the linear margins of bony structures, peripheral pulmonary vessels, and the proximal bronchial tree. A clinically important question is whether this subtle degradation affects the diagnostic decision in abnormal cases. This aspect was evaluated on various respiratory diseases commonly encountered in daily practice. They included lung nodule, consolidation, bulla, bronchiectasis, pneumoconiosis, carcinomatous lymphangitis, and interstitial pneumonia of various etiologies. The visual rating of image quality in these abnormal cases was performed in

Table 3. Comparison of Original and Compressed CR Chest Images in Normal Cases

	No. of Observations With Each Rating				
Anatomic Region	1	2	3	4	5
Rib, clavicle	9	171	220	8	0
Pulmonary vessel and spine overlying heart	8	130	265	5	0
Carina, main bronchi	0	97	301	10	0
Pulmonary vessel overlying right diaphragm	1	83	315	9	0
Pulmonary vessel above right diaphragm	4	139	260	5	0

NOTE. The total number of observations made by the six observers is 2,040.

Ratings: 1 = original much better than compressed; 2 = original better than compressed; 3 = original equal to compressed; 4 = compressed better than original; 5 = compressed much better than original. In all anatomic regions, the original image was significantly better than the compressed image at the .05 level.

Table 4. Comparison of Original and Compressed CR Chest Images in Abnormal Cases

	No. of Observations With Each Rating				
Abnormality	1	2	3	4	5
Nodule					
0-9 mm	0	3	63	0	0
10-19 mm	0	10	104	0	0
20-29 mm	0	13	71	0	0
Bulla	0	11	43	0	0
Bronchiectasis	0	3	45	0	0
Consolidation	0	1	59	0	0
Pneumoconiosis	0	6	66	0	0
Carcinomatous lymphangitis	0	3	33	0	0
Interstitial pneumonia	0	15	69	0	0

NOTE. The number of observations varies according to each abnormality.

Ratings: 1 = original much better than compressed; 2 = original better than compressed; 3 = original equal to compressed; 4 = compressed better than original; 5 = compressed much better than original. For all abnormalities, there was no significant difference between compressed and original images at the .05 level.

Table 5. A_z Values of Original and Compressed CR Chest Images for Lung Nodules With Lung Cancer

Observer	Original	Compressed
1	0.946	0.905
2	0.912	0.897
3	0.854	0.869
4	0.927	0.883
5	0.886	0.901
6	0.914	0.889
Mean ± SEM	0.907 ± 0.013	0.891 ± 0.005

NOTE. A_z refers to the area under the receiver operating characteristic curve. There was no significant difference between original and compressed images at the .05 level.

the context of diagnostic information. Equal ratings were found in about 80% to 90%, and no significant difference was noted between compressed and original images. This suggests that the slight degradation of image quality recognizable in normal anatomic structures is not a problem clinically. To further evaluate this, ROC analysis was performed on lung cancers with solitary lung nodules. Although they were relatively small in size and included ill-defined localized opacity, there was no significant difference between original and compressed images. This further confirms the results of the visual rating of abnormal cases.

The advantage of compression of data in digital imaging is in the storage and transfer of data. In light of the rapid progress in computer technology, in the future it may be possible to deal with original data directly and easily. Presently, however, an efficient and useful data compression technique is a necessity in terms of cost. We conclude that the type III compression technique is clinically acceptable and useful in chest CR with the new single-image format.

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