Detection of discrete white matter lesions after irreversible compression of MR images.

D A Clunie, P J Mitchell, J Howieson, S Roman-Goldstein and J Szumowski

AJNR Am J Neuroradiol 1995, 16 (7) 1435-1440
http://www.ajnr.org/content/16/7/1435

Detection of Discrete White Matter Lesions after Irreversible Compression of MR Images

D. A. Clunie, P. J. Mitchell, J. Howieson, S. Roman-Goldstein, and J. Szumowski

PURPOSE: To validate the use of techniques of irreversible compression of images, which can be performed using a block-based discrete cosine transform technique as defined by the Joint Photographic Experts Group, before they can be used in clinical applications, by evaluating the effect of compression on the ability of observers to detect discrete white matter lesions on MR images of the brain. **METHODS:** Sixty T2- and intermediate-weighted spin-echo images were compressed with varying degrees of coefficient quantization with compression ratios from 1:1 to more than 40:1, randomized, and evaluated by three observers blinded to the degree of compression. **RESULTS:** No significant difference in the number of lesions detected was apparent until compression ratios reached 40:1, despite a significant subjective loss in perceived image quality at 20:1. Only small (≤5-mm) lesions were missed at the highest degree of compression. No significant differences were observed in the detection of confluent periventricular white matter disease at any degree of compression tested. **CONCLUSIONS:** The use of high degrees of irreversible compression of MR images may be acceptable for diagnostic tasks.

Index terms: Images; Magnetic resonance, tissue characterization

AJNR Am J Neuroradiol 16:1435–1440, August 1995

Much attention has been directed recently to the compression of images for the purposes of archiving and transmission. The recent effort by the American College of Radiologists and the National Electrical Manufacturers Association to define a workable standard for the interaction of medical imaging equipment has highlighted the need for effective evaluation of compression techniques included in such standards. The Joint Photographic Experts Group (JPEG) has defined a standard that includes an irreversible compression technique using the discrete cosine transform, which has already been widely applied outside the medical imaging community.

Reversible compression techniques do not discard information during compression and rely on the presence of redundancy within an image that can be removed without loss. Irreversible compression techniques deliberately discard information that is considered less important to the fidelity of the image, introducing additional redundancy that can be exploited by subsequent encoding steps to provide greater compression. Irreversible compression techniques potentially allow for more effective use of storage and transmission bandwidths than reversible compression methods. Before such methods can be adopted for medical applications, both the fidelity of the reconstructed images and the effect of any information loss on diagnostic accuracy must be evaluated.

Magnetic resonance (MR) images are somewhat different from other forms of radiologic images in their spatial and contrast resolution and noise characteristics. Although individual images are small, they are acquired in ever-increasing volumes as faster acquisition techniques proliferate; hence, the need for effective compression techniques is increasing. The different nature of MR images requires that evalu-

Received September 25, 1994; accepted after revision March 2, 1995.

From the Department of Diagnostic Imaging, King Khaled Eye Specialist Hospital, Riyadh, Saudi Arabia (D.A.C.); the Department of Radiology, Royal Melbourne Hospital, Parkville, Australia (P.J.M.); and the Department of Radiology, Oregon Health Sciences University, Portland (J.H., S.R.-G., J.S.).

Address reprint requests to D. A. Clunie, MBBS, FRACR, Department of Diagnostic Imaging, King Khaled Eye Specialist Hospital, PO Box 7191, Riyadh 11462, Saudi Arabia.

AJNR 16:1435–1440, Aug 1995 0195-6108/95/1607–1435

ations of irreversible compression be specifically directed, rather than drawing conclusions about effectiveness and accuracy from studies of other modalities.

In this study, brain MR images of differing contrast are compressed using one of the JPEG algorithms at varying degrees of compression and evaluated by a team of neuroradiologists for a specific diagnostic task involving the detection and enumeration of discrete white matter lesions. The purpose is to determine whether the JPEG algorithm is suitable for this application and what degree of compression can be achieved before diagnostic accuracy suffers. These results will be used to plan a larger, more rigorous study.

Methods

Sixty intermediate-weighted and T2-weighted images were selected by one neuroradiologist from a group of patients undergoing routine MR examination of the brain. Only patients with normal images or images showing evidence of white matter disease were included. Those with space-occupying lesions were excluded. All images were acquired on a 1.5-T magnet with conventional multiplanar spin-echo acquisition parameters of 2800/30,80/2 (repetition time/echo time/excitations) for intermediate-weighted and T2-weighted images, a section thickness of 4 mm, a matrix size of 256, and a field of view of 200 mm, resulting in an in-plane resolution of 0.78 mm per pixel.

Image data were transferred to a SparcStation IPC (Sun Microsystems, Mountain View, Calif) for processing. The code from the independent JPEG group version 2b was modified to read and write 12-bit images and used to compress each image at five different degrees of compression. The compressed images were then decompressed, converted back into images acceptable to the MR host, and pooled to form a total of 360 images. The order of images in this series was then randomized to prevent observers from correlating the same image at different degrees of compression.

The images were then transferred to an MR diagnostic console for evaluation. All observations were made at the console. No images were printed. The observers had access to the limited imaging functions on the console, which included adjustment of window level and width and magnification but no form of filtration.

Three neuroradiologists experienced in reading brain MR images and blinded to the degree of compression then evaluated the entire series independently. Each was asked to determine for each image the number of discrete white matter lesions in size categories of less than 2 mm, 2 to 5 mm, and more than 5 mm and the presence or absence of confluent periventricular white matter changes. Each observer was also asked to make a subjective assessment of image quality on a scale of one to five.

The degree of compression and its effect on image quality, the number of lesions stratified by size, and the presence of periventricular disease were evaluated using the noncompressed image as a reference standard. A comparison was performed using the nonparametric Wilcoxon's matched-pairs signed rank test for lesion detection and the McNemar test for matched pairs of dichotomous values for periventricular changes. Significant differences were regarded as present when the two-tailed probability of a difference was less than 5%. A two-tailed test was chosen, because the compression process could conceivably alter the image in a manner that improved lesion detection.

Results

The extent of compression achieved at each coefficient quantization level selected, and the effect of the compression ratio on normalized and root mean squared error rates are graphically depicted in Figures 1 through 3. There is a wide variation in the effectiveness of compression for a chosen quantization level as a consequence of the variation in noise between images. The noise in each reconstructed image increases as the quantization level is increased (fewer bits are used to encode each coefficient).

Table 1 demonstrates the effect of compression on the total number of lesions detected in each size category. Most of the lesions are in the 2- to 5-mm size category. Table 2 describes the impact of varying degrees of compression on the detection of confluent periventricular disease, the mean number of lesions per image in each size group, and the effect on subjective assessment of image quality. Although these tables show mean values and totals averaged among the three observers, all significance levels quoted pertain to nonparametric comparisons of matched pairs of discrete observations, not parametric comparisons of means or totals.

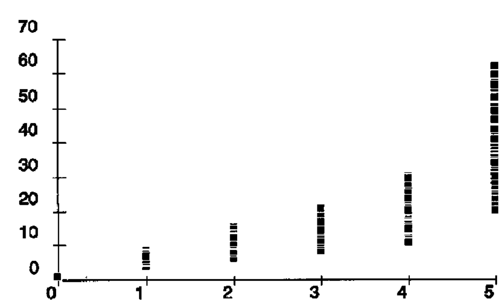


Fig 1. Compression ratio compared with level of coefficient quantization.

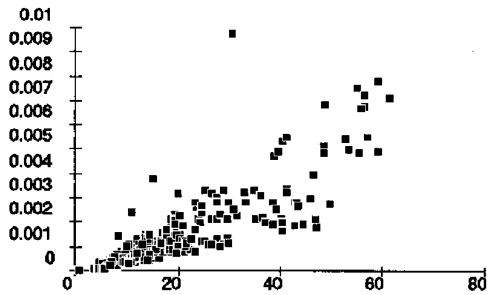


Fig 2. Normalized mean squared error compared with compression ratio.

No significant difference in number of lesions detected was apparent until compression ratios reached 40:1 ($z = -6.63$; $P < .0001$). This was despite a highly significant difference in subjective assessment of image quality observed at compression ratios of 20:1 ($z = -6.22$; $P < .0001$). However, even at the highest level of compression, significant differences were observed only for small (≤5 mm) lesions. No significant differences were observed in the detection of confluent periventricular white matter disease at any level of compression tested. The same results were obtained when intermediate-weighted images and T2-weighted images were considered separately.

The images in Figure 4 demonstrate the subjective effects of the irreversible compression. This T2-weighted spin-echo image contains discrete white matter lesions and confluent periventricular disease. The whole image is shown, together with a magnified region of interest containing a discrete lesion and a "difference image" obtained by subtracting the reconstructed compressed image from the original noncompressed image and enhancing the contrast by a factor of 32. In the 1:9 compressed image there is very little structure in the difference image, either at large boundaries, such as

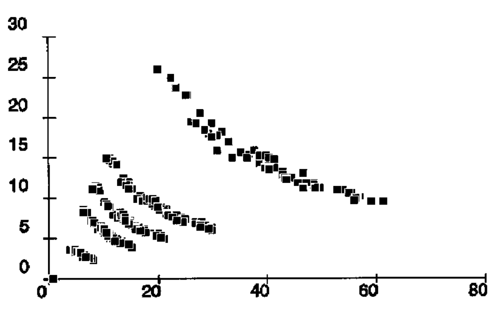


Fig 3. Root mean squared error compared with compression ratio.

TABLE 1: Total number of white matter lesions of each size compared with mean compression ratio

Mean Compression Ratio	Number of <2-mm Lesions	Number of 2- to 5-mm Lesions	Number of >5-mm Lesions	**Total Number of All Lesions**
1:1	63	173	36	**272**
1:5.89	85	169	36	**290**
1:10.5	67	179	36	**282**
1:14.2	61	170	36	**267**
1:19.8	59	173	32	**264**
1:40.2	20*	137†	35	**192‡**

* Wilcoxon's matched pairs signed-rank, $z = -5.40$, $P < .0001$.
† Wilcoxon's matched pairs signed-rank, $z = -3.92$, $P < .0001$.
‡ Wilcoxon's matched pairs signed-rank, $z = -6.63$, $P < .0001$.

around the ventricles or around focal lesions. With a higher degree of compression of 1:24, high-frequency differences are apparent. The block artifact caused by applying the transform to 8 × 8 blocks rather than the entire images is only barely perceptible, even at 1:24 compression. No cross-block smoothing was applied to these images. Also apparent at 1:24 is the slight reduction in contrast of the magnified lesion relative to the surrounding white matter.

Discussion

The costs of archival storage media and transmission bandwidths remain relatively high despite recent advances in technology. The increasing volume of digitally acquired medical image data is driving the search for more effective compression techniques. Reversible techniques have been applied to the compression of MR images, but even with techniques especially chosen to handle such images, compression ratios of at most 3.05:1 have been attained (1). A ratio of 2:1 is more typical (2). The effectiveness of compression is limited by the relatively high level of noise (2) and the high contrast resolution and low spatial resolution (1) compared with other modalities.

A family of irreversible compression algorithms has developed using the principle of transformation into the frequency domain to decorrelate components of an image to facilitate more effective encoding. The discrete cosine transform is usually chosen, because, inasmuch as algorithms are known for fast discrete implementation, it closely approximates more ideal transforms for decorrelation and has only real components in the frequency domain, unlike the Fourier transform.

TABLE 2: Confluent white matter disease, lesion size, and subjective image quality compared with mean compression ratio

Mean Compression Ratio	Confluent Periventricular Disease, %	Mean Number of <2-mm Lesions	Mean Number of 2- to 5-mm Lesions	Mean Number of >5-mm Lesions	Subjective Image Quality
1:1	29.4	1.04	2.89	0.594	2.67
1:5.89	28.8	1.41	2.82	0.606	2.78
1:10.5	27.8	1.11	2.98	0.606	2.62
1:14.2	29.4	1.01	2.83	0.600	2.57
1:19.8	31.1	0.989	2.89	0.528	2.20*
1:40.2	28.3	0.333	2.28	0.583	1.30†

* Wilcoxon's matched pairs signed-rank, $z = -6.22$, $P < .0001$.
† Wilcoxon's matched pairs signed-rank, $z = -10.6$, $P < .0001$.

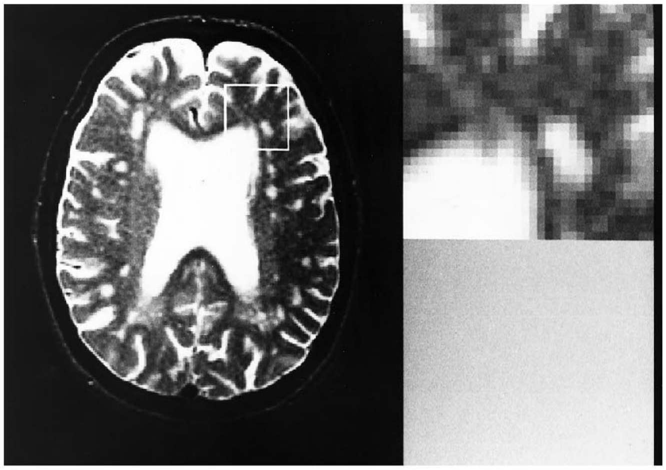
Greater compression can be achieved by selectively reducing the number of bits per value (performing quantization) of the frequency components that carry information of less importance to the diagnostic process, such as the higher-frequency coefficients that carry edge rather than contrast information. It is the selection of the quantization parameters that primarily dictates the effectiveness of compression and the degree of information loss. A subsequent reversible encoding step such as Huffman encoding takes advantage of the additional redundancy introduced.

What distinguishes variations on this theme are whether the image is transformed as an entire image (3, 4) or split into smaller blocks, whether adaptive techniques are used on a regional basis to optimize the quantization process locally (5, 6), and whether special techniques such as bit allocation are used to handle images containing significant edge and contrast information (7–9). The JPEG process chosen (extended sequential discrete cosine transform–based mode with Huffman coding and 12-bit sample precision) (10) splits an image into 8 × 8-pixel blocks and uses the same quantization algorithm for the entire image and in some ways represents the worst member of such a family for this application. It is, however, computationally the simplest, amenable to commercial hardware implementation (most of which are for 8-bit-deep data only, however) and well understood. A well-tested and freely available software implementation that runs on almost any processor was available for this project. The entire family of reversible, irreversible, and hierarchical compression techniques described in the JPEG standard has been incorporated as the basis for compression in the new American College of Radiologists–National Electrical Manufacturer's Association DICOM (Digital Image Communication in Medicine) standard version 3.0 and hence is destined to be the focus of considerable attention.

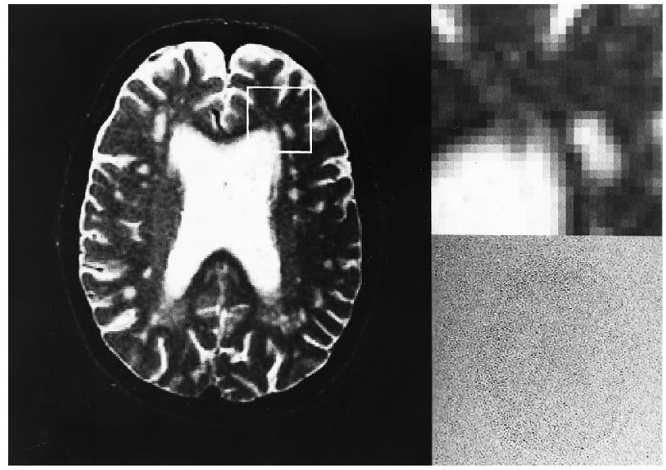
The application of these irreversible techniques to medical images has received scrutiny before. High-resolution (4096 × 4096) scanned radiographs of the hand compressed with a full-frame technique were found to retain diagnostic information up to a ratio of 28:1 for the difficult task of detection of subperiosteal resorption (3). Digitized chest radiographs have been compressed with adaptive block-based techniques, achieving compression ratios of 25:1 (6) and 20:1 (5) before loss of diagnostic accuracy. Application to MR images has been described, but without evaluation of the effect on loss of diagnostic information (8, 11).

The diagnostic task chosen in this study to compare the effect of compression is one that entails detection of both small and large lesions in relatively high (T2-weighted images) and low (intermediate-weighted images) contrast conditions. The lesions are common enough that a sufficient number of cases could be acquired, and the task has clinical relevance in that the number of lesions is regarded as being of prognostic significance, particularly in the setting of demyelinating disease. Each lesion represents a discrete signal that is either present or absent, reducing the ambiguity in the observer's mind.

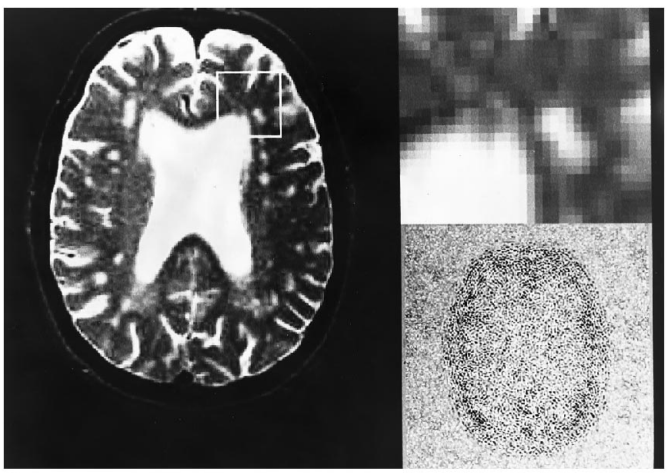
The technique of analysis was chosen to provide a mechanism for determining the probability of a significant difference between images. Many similar studies use the receiver operating characteristic method for this purpose. That technique was thought unsuitable for the present task, which involves counting lesions, rather than assessing a degree of confidence in their presence or absence. Although it is fash-



A



B



C

Fig 4. T2-weighted spin-echo image with discrete white matter lesions and confluent periventricular disease. Full image, magnified region of interest, and difference image, contrast enhanced by a factor of 32. *A*, Noncompressed; *B*, compressed 1:9; *C*, compressed 1:24. Note the lack of structure in the difference image in *B*, compared with the appearance of high-frequency differences at the higher level of compression in *C*. Note also the perceptible 8 × 8 block artifact appearing in *C*, as well as the slight reduction in contrast of the magnified lesion relative to the surrounding white matter.

ionable to quote sensitivity and specificity in such situations, without a meaningful standard of reference, these parameters have little meaning outside a single study. Rather than recast the problem into one suitable for receiver operating characteristic analysis, a nonparametric comparison of lesion counts considering matched pairs maximizes the use of the available data.

The findings suggest that for the specific task of detecting and counting discrete white matter lesions and detecting the presence of periventricular changes, high degrees of compression can be tolerated. Interestingly, the subjective assessment of image quality reduced significantly at lesser degrees of compression. For this kind of image, it would seem that compression of at least 10:1 can be tolerated before there is a perceptible loss of quality, and of 20:1 before there is a loss of diagnostic accuracy. Contrast-enhanced difference images between the noncompressed original image and the compressed image seem to contain very little anatomic structure. With a greater degree of compression, more structure is apparent. Although artifacts attributable to the block-based algorithm used are perceptible with higher degrees of compression, these are neither particularly prominent nor objectionable. No difference was seen when T2-weighted images and intermediate-weighted images were considered separately, presumably reflecting the fact that these lesions have a high contrast with the white matter on both types of images.

The results of this study suggest that the use of the irreversible compression technique tested may be feasible for such tasks. A larger study with more rigorous methods is indicated before such a technique can be widely applied. Other more difficult tasks that involve the detection of lesions requiring very high spatial resolution or subtle changes in image contrast also need to be specifically assessed.

Irreversible techniques are already finding wide application for teleradiology, in which primary reading is not the objective, and access to the original image is ultimately available. Considerable debate has ensued as to the applicability of irreversible techniques to long-term archival storage, and more controversially, to images for primary reading. Medicolegal factors related to the implications of deliberately discarding information, however meaningless, will undoubtedly play a role in determining the future applicability of irreversible compression, perhaps beyond what is scientifically sound.

Studies using methods similar to ours have recently compared fast spin-echo with conventional spin-echo for the detection of white matter disease in patients with human immunodeficiency virus infection (12). All modern digital acquisition methods, including MR imaging, computed tomography, and computed radiography, involve a conscious decision to limit spatial and contrast resolution according to cost and time and patient discomfort and motion. Such new techniques as fast spin-echo, GRASE (gradient- and spin-echo), and keyhole dynamic imaging entail even more deliberate decisions to sacrifice information content to achieve a specific goal and yet are readily accepted by the imaging community once the artifacts involved are well understood. Compression techniques that alter images in similar ways do not seem to be received with the same liberal attitude in the present litigious climate.

Acknowledgments

Patrice Manley and her team of technologists kindly performed the MR examinations. Tom Lane, coordinator of the independent JPEG group, provided the code to perform the JPEG compression.

References

1. Li CC, Gokmen M, Hirschman AD, Wang Y. Information preserving image compression for archiving NMR images. *Comput Med Imaging Graphics* 1991;15:277–283
2. Rabbani M, Jones PW. Image compression techniques for medical diagnostic imaging systems. *J Digital Imaging* 1991;4:65–78
3. Bramble JM, Cook LT, Murphey MD, Martin NL, Anderson WH, Hensley KS. Image data compression: magnification hand radiographs. *Radiology* 1989;170:133–136.
4. Siegel EL, et al. Image data compression using a new floating-point digital signal processor. *J Digital Imaging* 1991;4:188–195
5. Ishigaki T, Sakuma S, Ikeda M, Itoh Y, Suzuki M, Iwai S. Clinical evaluation of irreversible image compression: analysis of chest imaging with computed radiography. *Radiology* 1990;175:739–743
6. MacMahon H, Doi K, Sanada S, et al. Data compression: effect on diagnostic accuracy in digital chest radiography. *Radiology* 1991;178:175–179
7. Chan KK, Lou SL, Huang HK. Radiological image compression using full-frame cosine transform with adaptive bit-allocation. *Comput Med Imaging Graphics* 1989;13:153–159
8. Chan KK, Lou SL, Huang HK. Full-frame cosine transform compression of CT and MR images. *Radiology* 1989;171:847–851
9. Ho BKT, Chao J, Zhu P, Huang HK. Design and implementation of full-frame, bit-allocation image compression hardware module. *Radiology* 1991;179:563–567
10. ISO Draft International Standard 10918-1. Digital compression and coding of continuous-tone still images. In: Pennebaker WB, Mitchell JL, eds. *Joint Photographic Experts Group Still Image Data Compression Standard*. New York: Van Nostrand Reinhold, 1993:335–543
11. Howe FA. Implementation and evaluation of data compression of MR images. *Magn Reson Imaging* 1989;7:127–132
12. Olson EM, Healy JF, Wong WHM, Youmans DC, Hesselink JR. MR detection of white matter disease of the brain in patients with HIV infection: fast spin-echo vs conventional spin-echo pulse sequences. *AJR Am J Roentgenol* 1994;162:1199–1204