Journal of Digital Imaging

Evaluation of the Effect of Varying MPEG-2 Compression Ratios on Digital Coronary Angiographic Assessment of Stenosis Severity

Yasuhiko Okura, MS, Yasushi Matsumura, MD, PhD, Kuniyuki Hidaka, BSc, Hiromichi Yokoyama, Hiroshi Inada, PhD, Hajime Harauchi, BSc, Hiroko Kou, MS, and Kiyonari Inamura, PhD

The purpose of this study is to evaluate the influence of MPEG-2 compression scheme on coronary angiography and to search the highest compression ratio at which no significant effect to accuracy of assessment of stenosis severity occurs. Forty-Four digital cine angiographies were used. Three cardiologists participated in a subjective study in which they read both uncompressed images and compressed images. Furthermore, an objective study was carried out to measure vessel stenosis ratio by using software. The influence of compression was evaluated by kappa statistics in case of subjective study and by both systematic error and random error in case of objective study. Kappa statistics between uncompressed image and compressed image at a ratio of 80:1 was significantly lower than that of other compression ratios such as 40:1. Similar results were obtained in objective evaluation. In this report, the authors provide the baseline for further studies on observer performance for motion images.

KEY WORDS: Compression, motion picture, MPEG, coronary angiography, cardiology, kappa statistics, picture archiving and communication system

DIGITAL IMAGING TECHNOLOGY brings several benefits into catheterization laboratories. Immediate reviewing of studied images, quantitative analysis, and image delivery to remote site often have been discussed as benefits in articles.[1] However, motion image data size generated from such digital system is very large. Therefore, several problems such as long time for transferring image data through network and high cost for long-term storage arise in the clinical environment.

An approach to resolve these problems is to use an image data compression technique that reduces the size of digital image data. Image compression techniques can be classified into two categories: lossless (reversible) compression method and lossy (irreversible) compression method. Although lossless compression method can allow complete data reconstruction from compressed data, it can accomplish only lower compression ratio of 2:1 or 3:1.[2] However, because the lossy compression method generally reduces the high-frequency component or image noise in the image, it can provide higher compression ratio than the lossless compression method. However, deterious effects to image quality occur. Therefore, lossy compression should be applied carefully to the medical image so that diagnostic accuracy is maintained.

MPEG-2 is the standardized compression method for motion image by ISO (The International Organization for Standardization) and is easy to use in a clinical environment because much inexpensive encoding/decoding software is available. However, since MPEG-2 is a lossy compression method, the highest compression ratio with maintaining high-image quality for diagnosis should be discovered.

Joan et al[3] reported the effects of JPEG data compression on the quantitative assessment of the degree of stenosis and Kirk et al[4] have reported effects of MPEG compression on the quality and diagnostic accuracy of digital

From the Graduate School of Medicine, Course of Health Sciences, Osaka University, Osaka, Japan.

Correspondence to: Yasuhiko Okura, MS, Inamura Lab., 1–7 Yamadaoka, Suita, Osaka, 565-0871, Japan; tel: +81-6-6879-2570; fax: +81-6-6879-2570; e-mail: ookura@sahs.med.osaka-u.ac.jp.

Online publication 6 November 2002

doi: 10.1007/s10278-002-0013-8

echocardiography studies. However, there are few articles reporting the application of MPEG-2 to coronary motion images.

The purpose of this study is to evaluate the influence of MPEG-2 on coronary angiographic study and to provide useful baseline of MPEG-2 compression ratio for coronary motion images.

MATERIALS AND METHODS

Image Acquisition and Selection

We screened out motion image data of clinical digital cine angiography that were acquired routinely by the digital cine angiography system (KXO-100G, DFP-2000A/A4, Toshiba Corp., Tokyo, Japan) in the NCVC (National Cardiovascular Center, Suita, Japan). All of the angiograms were recorded immediately on DICOM-CD with uncompressed file format. Because image sequences, which have low contrast vessel images, were not suitable for clinical use, those image sequences were eliminated from this study. Image sequences, including total occlusion, catheter, or stent images also were excluded from this study. Furthermore, we chose image sequence groups for this study so that a wide range of degree of stenosis severity was included. Consequently, an image sequence group used in this study consisted of 44 image sequences that have various stenosis severities.

Frame rates of selected sequences were 30 frames per second, and image matrix was 512 × 512 with 8-bit depth. Therefore, the bit rate of these original motion images were 62.9 Mbit/sec.

Data Compression

We stored motion image data of angiograms from DICOM-CD to a hard disk of a personal computer (Pentium-III 500 MHz) with uncompressed file format (Microsoft AVI file format) using motion image editor, "Ulead Media Studio" (Ulead Systems, Inc., Taipei, Taiwan). According to encoder limitation, we transferred images of image format of 512 × 512 pixels with 8-bit depth monochromatic into that of 720 × 480 pixels with 24-bit depth of color that is defined as MP@ML (Main Profile at Main Level) in the MPEG-2 coding scheme. The position of 512 × 512 angiogram in each transferred 720 × 480 format was fixed to fit its left edge, and the rest area of each frame was filled by zero pixel value. The bottom area of 32 (512-480) pixels height of original image was truncated by means of this transformation. However, this truncation did not affect the assessment of vessel stenosis, because the truncated area did not include any information for diagnosis.

In several image sequences, because there were plural stenosis portions, a small white arrow was superimposed near a stenosis portion to indicate the portion for assessment using the motion image editor "Ulead Video Paint."

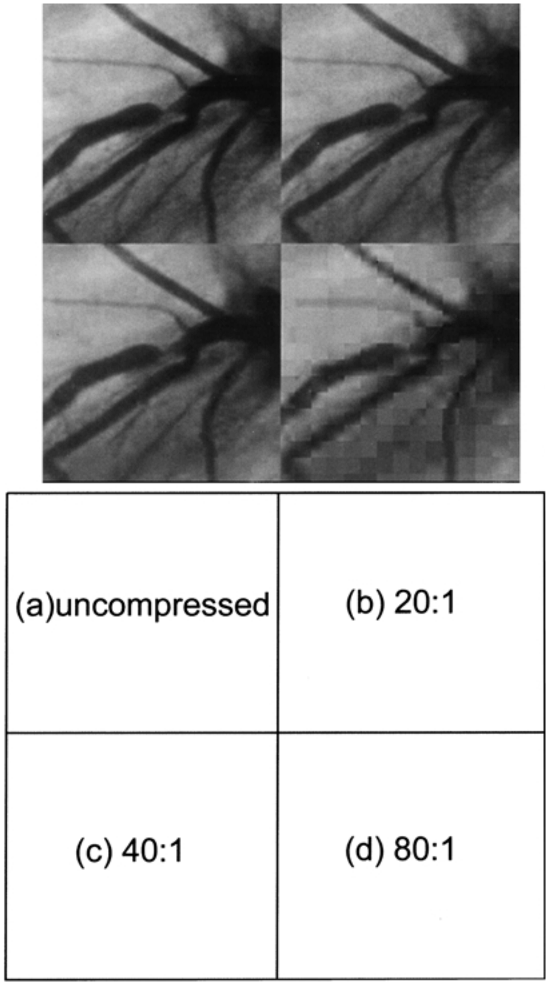

Fig 1. An example of representative image series of digital coronary angiography. (a) uncompressed image, (b) 20:1 compressed image, (c) 40:1 compressed image, (d) 80:1 compressed image. Block artifact was appeared especially in (d).

Using the MPEG-2 software encoder, "Ligos MPEG Encode" (Ligos Technology Corp., San Francisco, CA), we compressed digital cine angiography image sequences. Bit rates for compressed images were adjusted to 0.75 Mbps, 1.5 Mbp, and 3.0 Mbps. Corresponding compression ratio compared with original motion image (monochromatic image) was 80, 40, and 20, respectively (Fig 1).

Three types of picture are defined in MPEG coding scheme; I-picture, P-picture, and B-picture. Decoded frame from P-picture or B-picture includes a slight error in the frame. Therefore, when the compressed file includes many P-pictures or B-pictures in the image sequence, image quality will be decreased, whereas a higher compression ratio will be realized.[5]

The picture sequence of MPEG-2 file in this study was "IBBPBBPBBPBBI..," and this was defined in MPEG-2 encoder.

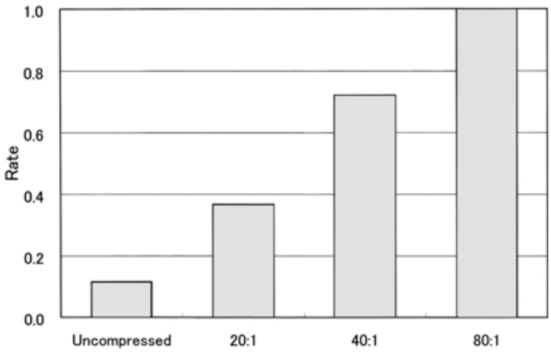

Fig 2. Rate of cases recognized as compressed image to all cases displayed on CRT monitor. At a compression ratio of 80:1, all cases were recognized as compressed by all observers.

Subjective Study

First, we subjectively evaluated the compressed image by using the MPEG compression method. An image sequence set for viewing consisted 2 uncompressed image sequence groups and 3 compressed image sequence groups with different levels of bit rate. Because each image sequence group includes 44 image sequences, the number of image sequence in a final image sequence set was 220, $(2 + 3) \times 44$. The viewing order was randomized according to random number generator. Images were displayed on a 19-inch color monitor (FlexScan E67T, Nanao Corp., Ishikawa, Japan). Ambient light in the viewing room was fixed during the viewing session at dark level.

Three cardiologists who were blinded to compression ratio reviewed individually 220 image sequences using "Microsoft Media Player ver 6" as a decoder and viewer. By using this viewer, cardiologists could stop or reverse motion images by mouse operation. Viewing time and viewing distance were not limited. In the viewing session, each cardiologist was asked to classify vessel stenosis severity of coronary segment, which was indicated by a small arrow in the image, according to modified American Heart Association (AHA) recommended stenosis classification (0%, 25%, 50%, 75%, 90%, 99%, and 100%). In addition, they are asked whether the image was compressed. To avoid memory effect, observers were asked to assess stenosis severities only by the displayed image independently, which was viewed in the display at that time without utilizing their memorized stenosis severity that was assessed previously on the same case at a different compression ratio.

In this study, kappa statistics between two uncompressed image sequences were used to determine whether results of the assessment were influenced by compression scheme.

Namely, kappa statistics that indicate the agreement between two categorical data sets were used. Kappa statistics are defined as kappa = (observer agreement − chance agreement)/(1 − chance agreement). As noted by Landis and Koch,[6] kappa = 0 to 0.20 suggests slight agreement, kappa = 0.21 to 0.40 suggests fair agreement, kappa = 0.41 to 0.60 suggests moderate agreement, kappa = 0.61 to 0.80 suggests substantial agreement, and kappa = 0.81 to 1.0 suggests almost perfect agreement.

Objective Study

To assess the influence to quantitative coronary measurement, another evaluation was carried out. We selected still images representing coronary stenosis in each image sequence and used these selected images for measuring coronary stenosis ratio by obtaining density profile curve using the coronary analysis software, "CAW-2000" (ELK Corp., Osaka, Japan). In this procedure, an operator points out one stenosis portion together with two normal portions located on both sides before and after the stenosis region of the vessel. The coordinates indicated in the uncompressed image was registered and used in the measurement in the compressed image for matching anatomic positions.

To establish the criteria for comparison and followed statistical analysis, we first calculated mean differences between the first and second measurements in uncompressed images. And then mean differences between measured vessel stenosis ratios of uncompressed image and that of each compressed image also was figured out to express systematic errors. Furthermore, variances of differences were calculated to show random errors. To identify significant differences, paired *t* test and F test were carried out for systematic errors and random errors, respectively. Statistical significance was defined as a *P* value less than .01 for both tests. We used SPSS version 8.0.1 for all statistical analyses.

RESULTS

An example of representative still images from uncompressed and compressed images is shown in Fig 1.

Figure 2 shows the rate of number of cases that were recognized by cardiologists as a compressed image to total number of cases displayed on a CRT monitor. When a compressed image at a compression ratio of 80:1 was displayed, all observers recognized that the displayed image was compressed in all cases.

Figures 3A-C show kappa statistics obtained by observer A, B, and C, respectively in a subjective study using AHA classification. In the case of observer A and B, the kappa statistics between 2 uncompressed image sequences showed substantial agreement as shown in Fig 3A and Fig 3B, namely, 0.616 and 0.768, respectively. The kappa statistics of 20:1 and 40:1 were rather close to those of uncompressed images. However, kappa statistics of 80:1 compressed image were significantly lower than

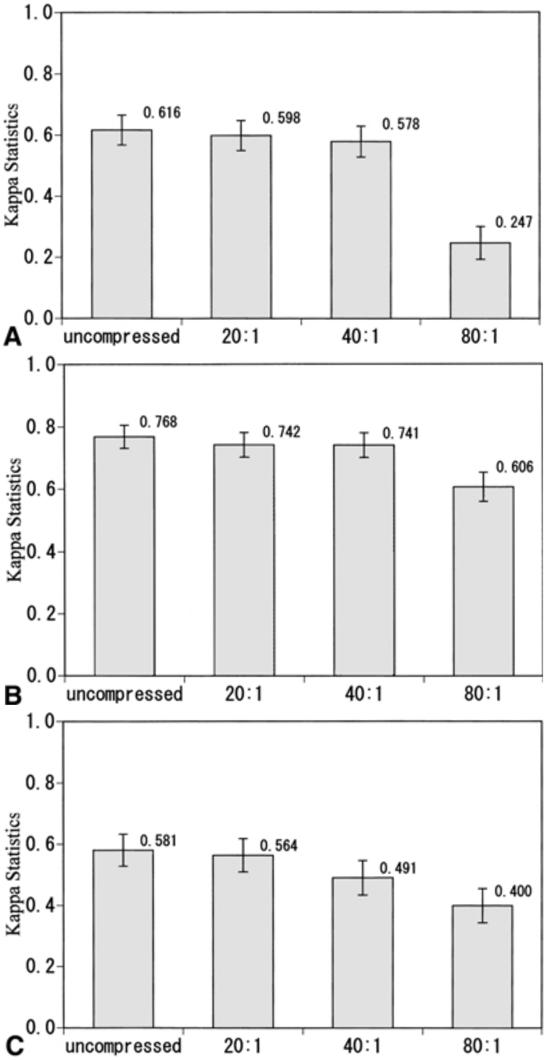

Fig 3. Value of κ statistics at various compression ratios. At a compression ratio of 80:1, its κ statistics were lowered significantly than that of others.

others. In particular, kappa statistics of 80:1 compressed image of observer A showed fair agreement (0.247). In case of observer B, these trends were similar to the results of observer A, but with smaller differences in 80:1 as shown in Fig 3B. Fig 3C by observer C tells another trends with definitely different agreement in case of 80:1.

The results of objective evaluation were shown in Table 1. There was a significant difference in random errors and systematic errors measured only between uncompressed image and compressed image at a ratio of 80:1.

DISCUSSION

Although the effect of lossy image compression on network transferring time and the cost for long-term storage is large, deterious effects on image quality occur. Optimized compression ratio should be studied carefully from many aspects.

Many studies that describe the effects of the lossy compression method, especially JPEG, for digital angiography have been reported.[3,7-13] They suggested that optimized compression ratio of JPEG for digital angiography was a range between 5:1 and 15:1. Mercel noted that the MPEG-coded angiography images look reasonably good at a ratio of 8.

Jeffrey et al[14] compared MPEG-1 digital video with sVHS videotape for diagnostic echocardiographic readings. They reported that MPEG-1 digital video is equivalent to sVHS videotape. Kirk et al[4] noted effects of MPEG compression on the quality and diagnostic accuracy of digital echocardiography studies with many levels of compression. They concluded that digital echocardiology loops compressed by MPEG-1 at a ratio of 200:1 show no degradation in endocardial visualization quality or diagnostic content.

However, in case of digital cine angiography image, more spatial resolution and density resolution than the case of echocardiography are required. Furthermore, MPEG-2 is available in more general purpose such as DVD (Digital Versatile Disk) than MPEG-1. Therefore, we report careful and quantitative results of the effect of MPEG-2 compression scheme on digital cine angiography.

MPEG-2 compression scheme is based on discrete cosine transform (DCT) with other compression techniques, such as motion compensation or predictive coding, which are inherent to the motion image.[5,15] Therefore, "block artifact" that is viewed as small blocks in the image tends to be seen in a compressed image at a higher degree of compression as shown in Fig 1. In addition, because the high spatial frequency component in the image was suppressed, a viewer would tend to perceive the image as a blurred image when a high degree of compression ratio was carried out. These effects are very similar to JPEG.

Table 1. Systematic Error and Random Error of the Measured Stenosis Ratio Using a Coronary Analysis Software

	Uncompressed	Compressed		
		20:1	40:1	80:1
Systematic error	1.644	0.346	1.053	4.379*
Random error	9.080	9.080	10.652	17.071*

Note. There were significant differences in both systematic error and random error of stenosis ratio between uncompressed image and compressed image at a ratio of 80:1.
$*P < 0.01$.

As shown in Fig 1, cardiologists have perceived the effects mentioned above when seeing the compressed image at a ratio of 40:1. From results of subjective evaluation, however, it is obvious that assessment of stenosis severity was affected in the compressed image at a compression ratio of 80:1 only. Differences between uncompressed image and compressed images at ratios of 40:1 and 20:1 were not significant. These results showed that subjective losses in image quality begin to occur before diagnostic quality is lost,[17,18] and it is reasonable to suppose that compressed image at a compression ratio up to 40:1 does not affect the accuracy of vessel stenosis diagnosis significantly. This is consistent with the results of objective evaluation. As shown in Table 1, both systematic error and random error were increased significantly in compressed images at 80:1. Consequently, MPEG-2 compression at 40:1 (1.5 Mbps) is sufficient to keep the accuracy of assessment of vessel stenosis severity. However, it should be noted that other coronary stenosis ratio measurement software may lead to other results.[16]

As a study limitation, we should argue several potential problems in the method we used. We used the correspondence between two sets of the coronary segment stenosis ratios as an index for diagnosis accuracy. Although there are many indices that should be diagnosed in the cardiac image, stenosis ratio of coronary vessel frequently is used in clinical evaluation and one of the representative diagnose indices for treatment of cardiac diseases such as angina pectoris. So, accuracy of assessment of stenosis ratio is important and should be studied primarily. However, we would not advocate that these results should be extended to every clinical environment even other than stenosis severity. Stenosis severity is only one piece of clinical information that one obtains from angiograms.

The memory effect should be considered carefully in subjective evaluation such as used in this study. We used 44 cases, and all motion images including both uncompressed, and compressed images were viewed in a relatively short time. The memory effect would not be small; in spite of that; viewers were asked to classify stenosis severity without utilizing their memory of stenosis classification that they evaluated previously on the same case at a different compression ratio. Therefore, the result would be an artifactually large kappa value, and it would be masking disagreement by the effect of compression. In addition, the method that we used in the subjective study does not guarantee the equivalence between images. This shows that if there is difference among images, we may have not been able to detect differences.

In this study, we provided a baseline for further studies using other diagnosis indices, expanded the number of cases, provided a longer interval between viewing session or narrower range of compression ratios. Further detailed studies must be carried out to clarify the effect of compression and to establish criteria for acceptable levels of image compression that do not affect the diagnostic accuracy.

ACKNOWLEDGMENTS

The authors thank K. Kinjo, MD, Y. Sakata, MD, and N. Nishikawa, MD, for participating in this subjective study and for useful suggestion of clinical issues. This work was supported in part by a grant from Ministry of Health and Welfare of JAPAN, 9-si-1, 1997–1999.

REFERENCES

1. The Cardiac and Vascular Information Working Group: Digital Cardiac Imaging in the 21st Century: A Primer American College of Cardiology, Bethesda, MD, 1997

2. Gillespy 3rd T, Rowberg AH: Displaying radiologic images on personal computers: Image storage and compression. Part 1. J Digit Imaging 6:197-204, 1993

3. Tuinenburg JC, Koning G, Hekking E, et al: American College of Cardiology/European Society of Cardiology International Study of Angiographic Data Compression Phase II, The Effects of Varying JPEG Data Compression Levels on the Quantitative Assessment of the Degree of Stenosis in Digital Coronary Angiography. JACC 35:1380-1387, 2000

4. Spencer K, Solomon L, Mor-Avi V, et al: Effects of MPEG compression on the quality and diagnostic accuracy of digital echocardiography studies. J Am Soc Echocardiol 13:51-57, 2000

5. Le Gall D: MPEG: A video compression standard for multimedia applications. Communications of the ACM 34:47-58, 1991

6. Landis JR, Koch GG: The measurement of observer agreement for categorical data. Biometrics 33:159-174, 1977

7. Breeuwer M, Heusdens R, Gunnewiek RK, et al: Data compression of x-ray cardio-angiographic image series. Int J Cardiac Imaging 11:179-186, 1995 (suppl 3)

8. Elion JL, Whiting JS: Clinical use of lossy image compression in digital angiography. Am J Cardiol 78:219-220, 1996

9. Baker WA, Hearne SE, Spero LA, et al: Lossy (15:1) JPEG compression of digital coronary angiograms does not limit detection of subtle morphological features. Circulation 96:1157-1164, 1997

10. Koning G, Beretta P, Zwart P, et al: Effect of Lossy Data Compression on Quantitative Coronary Measurements. Int J Cardiac Imaging 13:261-270, 1997

11. Silber S, Dorr R, Zindler G, et al: Impact of various compression rates on interpretation of digital coronary angiograms. Int J Cardiol 60:195-200, 1997

12. Kerensky RA, Cusma JT, Kubilis P, et al: American College of Cardiology/European Society of Cardiology International Study of Angiographic Data Compression Phase I: The effects of lossy data compression on recognition of diagnostic features in digital coronary Angiography. JACC 35:1370-1379, 2000

13. Brennecke R, Burgel U, Simon R, et al: American College of Cardiology/European Society of Cardiology International Study of Angiographic Data Compression Phase I: The effects of lossy data compression on recognition of diagnostic features in digital coronary angiography. JACC 35:1388-1397, 2000

14. Soble JS, Yurow G, Brar R, et al: Comparison of MPEG digital video with super VHS tape for diagnostic echocardiographic readings. J Am Soc Echocardiography 11:819-825, 1998

15. Wallace GK: The JPEG still picture compression standard. Communications of the ACM 34:30-44, 1991

16. Dietz U, Rupprecht H-J, Brennecke R, et al: Comparison of QCA systems. Int J Cardiac Imaging 13:271-280, 1997

17. Terae S, Miyasaka K, Kudoh K, et al: Wavelet compression on detection of brain lesions with magnetic resonance imaging. J Digital Imaging 13:178-190, 2000

18. Uchida K, Watanabe H, Aoki T, et al: Clinical evaluation of irreversible data compression for computed radiography of the hand. J Digit Imaging 11:121-125, 1998