Evaluation of Irreversible JPEG Compression for A Clinical Ultrasound Practice

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A prior ultrasound study indicated that images with low to moderate levels of JPEG and wavelet compression were acceptable for diagnostic purposes. The purpose of this study is to validate this prior finding using the Joint Photographic Experts Group (JPEG) baseline compression algorithm, at a compression ratio of approximately 10:1, on a sufficiently large number of grayscale and color ultrasound images to attain a statistically significant result. The practical goal of this study is to determine if it is feasible for radiologists to use irreversibly compressed images as an integral part of the day to day ultrasound practice (ie, perform primary diagnosis with, and store irreversibly compressed images in the ultrasound PACS archive). In this study, 5 Radiologists were asked to review 300 grayscale and color static ultrasound images selected from 4 major anatomic groups. Each image was compressed and decompressed using the JPEG baseline compression algorithm at a fixed quality factor resulting in an average compression ratio of approximately 9:1. The images were presented in pairs (original and compressed) in a blinded fashion on a PACS workstation in the ultrasound reading areas, and radiologists were asked to pick which image they preferred in terms of diagnostic utility and their degree of certainty (on a scale from 1 to 4). Of the 1,499 total readings, 50.17% (95% confidence intervals at 47.6%, and 52.7%) indicated a preference for the original image in the pair, and 49.83% (95% confidence intervals at 47.3%, and 52.0%) indicated a preference for the compressed image. These findings led the authors to conclude that static color and gray-scale ultrasound images compressed with JPEG at approximately 9:1 are statistically indistinguishable from the originals for primary diagnostic purposes. Based on the authors laboratory experience with compression and the results of this and other prior studies JPEG compression is now being applied to all ultrasound images in the authors radiology practice before reading. No image quality-related issues have been encountered after 12 months of operation (approximately 48,000 examinations).

KEY WORDS: Compression, Joint Photographic Experts Group, ultrasound, medical images, PACS, teleradiology, archive

With the rapidly dropping cost of digital storage and conservative use of standards-based irreversible (lossy) compression techniques, it is becoming practical to maintain large volumes of clinical images online, and distribute them efficiently over networks.

A prior ultrasound compression study was performed by our group to evaluate the effects of irreversible wavelet compression on ultrasound images and to determine how much compression can be applied, and still have the images be "acceptable for diagnostic purposes."¹ That study focused specifically on grayscale ultrasound images and considered a variety of factors including wavelet compression at several compression levels, different acquisition techniques (frame-grabbed v directly digitally acquired) and the effects of text that is "burned" into the image. To assess the relative performance of the wavelet compression technique, the images also were compressed and

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Table 1. Grayscale Ultrasound Images

Anatomic Region	Abdomen	Pelvis	Small Parts (Thyroid, Testicle, Breast)	Vascular
Number of grayscale images in the study	74	74	73	43
Maximum compression ratio (QF = 70)	12.3	12.8	11.2	11.6
Minimum compression ratio (QF = 70)	6.0	7.2	7.1	6.6
Average compression ratio (QF = 70)	8.6	9.3	9.1	8.4

Note. Grayscale images were compressed using the JPEG algorithm at a quality factor of 70. This resulted in compression ratios ranging from 6.0 to 12.8 with an average of approximately 9 to 1.

evaluated using the standard Joint Photographic Experts Group (JPEG) algorithm.² An unexpected finding from the prior study was that the radiologists consistently preferred the JPEG-compressed images over the wavelet-compressed images. Although the results were not statistically significant, 100% of the images compressed with JPEG at ratios of 15:1 or less were considered “acceptable for diagnostic purposes.” This was true in spite of the fact that viewing tools such as zoom easily showed the presence of artifacts in the 15:1 compressed images.

Based on that finding, it was decided that a second, more focused, compression study should be done using one compression algorithm at one compression level on a sufficient number of grayscale and color static ultrasound images to attain a statistically significant result. The purpose of this study is to formally validate the earlier preliminary finding. The practical goal of this study is to determine if it is feasible for radiologists to use irreversibly compressed images as an integral part of the day-to-day ultrasound practice (ie, perform primary diagnosis with, and store irreversibly compressed static images in the ultrasound PACS archive).

To facilitate this evaluation, every attempt was made to use the same PACS hardware and software components that are used daily in the clinical ultrasound practice (UltraPACS; ALI Technologies, Vancouver, Canada). The JPEG compression algorithm was chosen because it is supported by the Digital Imaging and Communications in medicine (DICOM) standard, and because the images compressed with JPEG were preferred to those compressed with the wavelet algorithm used in the previous study. A compression ratio of approximately 10:1 was

conservatively targeted for this study based on findings from the prior study and the desire to minimize the presence of artifacts. A compression ratio of approximately 10:1 was judged to yield worthwhile benefits in terms of image storage and transmission efficiencies.

METHODS

A single frame-grabbed ultrasound image was selected from each of 300 patients by 2 of the authors during the course of their routine clinical practice. These images were evenly distributed among 4 general anatomic regions (abdomen, pelvis, small parts [thyroid, testicle, breast], and vascular). A total of 36 of the 300 images were color Doppler.

A combination of the JPEG quality factor and the image characteristics determine how much one image gets compressed. Applying one JPEG quality factor to a set of images will result in a range of compression ratios. To determine what JPEG quality factor would yield a compression ratio of approximately 10:1, a subset of 10 study images were compressed using various quality factors. Quality factors of 70 and 97 for the grayscale and color images, respectively, yielded an average compression ratio of slightly less than 10:1. The 300 images then were compressed and decompressed at these quality factors using the JPEG baseline standard implementation from ALI Technologies. The average compression ratio for all 300 images was approximately 9:1. Tables 1 and 2 show for grayscale and color images, respectively, the number of images in each anatomic group, and the maximum, minimum, and average compression ratios for each group.

Each compressed/decompressed image was paired randomly with its original, so that in 50% of the cases the original would appear on the left and in 50% of the cases on the right in a viewing pair. Each of 5 groups of 60 random image pairs were associated as a patient, and a DICOM header was added (or modified) to make each set of 60 pairs appear under one patient name, patient ID, and study on a DICOM workstation.

The images were then sent to a PACS workstation (UltraPACS) that is used routinely in the clinical practice, and displayed in a format that allowed the largest possible display of a pair of images on one screen. The same PACS workstation was used throughout the study. The worksta-

Table 2. Color Ultrasound Images

Anatomic Region	Abdomen	Pelvis	Small Parts (Thyroid, Testicle, Breast)	Vascular
Number of color images in the study	1	1	2	32
Maximum compression ratio (QF = 97)	8.2	8.6	9.1	10.9
Minimum compression ratio (QF = 97)	8.2	8.6	8.2	7.9
Average compression ratio (QF = 97)	8.2	8.6	8.7	9.3

Note. Color images were compressed using the JPEG algorithm at a quality factor of 97. This resulted in compression ratios ranging from 7.9 to 10.9 with an average of approximately 9 to 1.

tion was physically shipped between 3 sites that were involved in the study, and set up in a diagnostic reading room at each site. Care was taken to keep the workstation monitor luminance and ambient room illumination in tight control during all reading sessions.

Five radiologists, practicing in 3 different Mayo Radiology locations reviewed the full set of 300 images (for a total of 1,500 radiologist readings). Radiologists were asked to pick which image (right or left) was preferred in terms of diagnostic utility and their degree of certainty (on a scale from 1 to 4, where 1 = not sure and 4 = very sure) that there was a difference. The data from all 5 radiologists were pooled, and the rates at which the original and compressed images were preferred was computed.

The number of independent radiologist readings for the full set of color and grayscale images ($n = 1500$) was chosen to assure that the 95% confidence intervals of the preference rates (expressed in percent) were approximately 2.5% or less. A test of the (null) hypothesis that the preference rate for both the original and compressed images is 50% was made using a normal approximation for a one sample binomial proportion test with 2-sided $\alpha = 0.05$. The 95% confidence intervals for the radiologist preference rates were calculated and are included in the results.

RESULTS

Figures 1, 2 and 3 summarize the results of the 5 radiologists readings. Figure 1 provides a summary of the results for grayscale and color images for each radiologist (300 readings each) as well as for all radiologists. There were 1,499 readings (instead of 1,500) because one radiologist failed to indicate a preference for one of the grayscale image pairs on the data collection sheet. For all 1,499 readings, 752 of 1,499 or 50.17% (95% confidence intervals at 47.6%, and 52.7%) indicated a preference for the original image in the pair, and 747 of 1,499 or 49.83% (95% confidence intervals at 47.3%, and 52.0%) indicated a preference for the compressed image. Because the hypothesized preference rate (50%) is well within the 95% confidence interval of the measured rate, the measured preference rate is not statistically different from 50% ($p = 0.90$).

**Chart #1: % of Preference by Radiologist for Original or Compressed
(out of 300 grayscale and color image pairs)**

Fig 1. For grayscale and color images (300 pairs per radiologist), the percent of image pairs where the original image was preferred, and the percent of image pairs where the compressed image was preferred.

Fig 2. For only grayscale images (264 pairs per radiologist), the percent of image pairs where the original image was preferred, and the percent of image pairs where the compressed image was preferred.

Figure 2 provides a summary of the radiologist readings for grayscale images for each radiologist (264 readings each) as well as for all radiologists. (There were 1,319 grayscale readings, and, as mentioned above, 1 radiologist failed to indicate a preference for one of the grayscale image pairs on the data collection sheet). For all 1,319 readings, 666 of 1,319 or 50.49% (95% confidence intervals at 47.8%, and 53.2%) indicated a preference for the original image in the pair, and 653 of 1,319 or 49.51%

(95% confidence intervals at 46.8%, and 52.2%) indicated a preference for the compressed image. Because the hypothesized preference rate (50%) is well within the 95% CI of the measured rate, the measured preference rate is not statistically different from 50% ($p = 0.72$).

Figure 3 provides a summary of the radiologist readings for color images for each radiologist (36 readings each) as well as for all radiologists (180 readings total). For all 180 readings, 86 of 180 or 47.78% (95% confidence

Fig 3. For only color images (36 pairs per radiologist), the percent of image pairs where the original image was preferred, and the percent of image pairs where the compressed image was preferred.

intervals at 40.1%, and 55.5%) indicated a preference for the original image in the pair, and 94 of 180 or 52.22% (95% confidence intervals at 44.7%, and 59.7%) indicated a preference for the compressed image. The 95% CI and p value for the color image set suffer from the substantially lower number of color readings, as compared with the full set of grayscale and color images. A 1 sample test for proportion did not reject the (null) hypothesis that the preference rate was 50% ($p = 0.55$).

Preference rates also were computed based on the weighted results (where the radiologist indicated degree of certainty that there was an actual difference between the 2 images). These weighted preference rates were not substantially different from the nonweighted results presented above, and did not alter the statistical results.

DISCUSSION

The results of this study indicate that color and grayscale ultrasound images compressed with the JPEG at approximately 9:1 were indistinguishable from the originals. Because it is supported by the DICOM standard, images compressed with the JPEG baseline standard can be stored by and sent to compatible DICOM devices making it possible to utilize irreversible compression for primary diagnostic purposes on standards-based PAC systems.

One important consideration regarding our study and findings involves the display device and display mode that were used. The images were presented on a color computer display in a manner consistent with the clinical practice. Because zoom tools rarely were used when interpreting ultrasound cases on the PACS, they were not used by radiologists during the study viewing sessions. It is possible that if zoom tools (or a higher fidelity display device) were used, subtle differences between the original and compressed images might have been seen. Our results suggest that these observed differences would not be important clinically. However, they may affect radiologist preference for, and confidence in, the compressed images.

Another consideration concerning the display device was the preference rates for images presented on the right versus the left of each image

pair. Our data indicated that the image presented on the left was preferred 87.2% of the time, compared with 12.8% for the image presented on the right. This is because of the well-known fact that image sharpness and luminance are often greater toward the center of a Cathode Ray Tube (CRT) display than near the edges.^{3,4} The PACS workstation user interface was such that the image on the left side of each pair was close to the center of the CRT, whereas the image on the right was near the CRT edge. This is a "bias" that is overcome on a daily basis by radiologists when interpreting examinations on the PACS. The fact that this effect completely overshadowed any effects introduced by irreversible compression, further supports the conclusion that the use of irreversible compression is a relatively benign factor in the overall imaging chain.

Numerous other studies have shown that the use of low to moderate levels of irreversible compression does not result in diagnostic outcomes that are statistically different.^{5,6} Although image quality is the primary consideration, a risk versus benefit analysis should consider other factors as well when deciding whether to use irreversible compression in clinical practice. The following additional factors should be considered:

1. For legal reasons, in our opinion, image data that are identical to that used for primary interpretation should be stored. If softcopy images are read in uncompressed format, the image data should be maintained in an uncompressed or reversibly compressed format in the archive.
2. When DICOM connections (associations) are established between 2 pieces of DICOM equipment, a negotiation process takes place whereby the 2 devices agree on the protocol (transfer syntax) they will use to communicate to accomplish a given task (eg, store an ultrasound image). Use of compression algorithms that are supported by a DICOM transfer syntax will allow greater interoperability with other DICOM equipment to be maintained, while providing reduced transmission times with any compatible DICOM equipment that also supports the same DICOM irreversible compression transfer syntax. Use of a proprietary compression algorithm (not supported by DICOM) re-

- quires that the receiving device be proprietary (to know the decompression algorithm), or that the data be decompressed by the sending device before it is transferred.
3. To maintain interoperability with other DICOM equipment, if data are stored in an irreversibly compressed form, the archive should be able to decompress it and send it to other DICOM devices that do not support the DICOM compression transfer syntax.
 4. If the data will be used for research purposes, there may be a requirement to store the original uncompressed or reversibly compressed dataset. Irreversible compression causes minor alterations to the original data values that, although they may not be observable to the human eye, could potentially affect software algorithms that attempt to identify structures within images.
 5. Recompressing data that have been compressed previously can result in a greater alteration of information depending on the algorithms used and how they are applied. For example, if data are stored in an archive today using an irreversible JPEG compression algorithm and migrated in the future to an archive that utilizes an irreversible wavelet compression algorithm, there will be additional alteration from the original dataset than if only the JPEG, or only the wavelet algorithm were applied. Recompression of a dataset using the same compression algorithm can also introduce additional alteration, depending on the compression algorithm used and the compression ratio chosen each time.
 6. Although extremely rare, errors can be introduced by a compression algorithm that may not be discovered until the file is needed at a later time and cannot be decompressed. Compression adds another step in the imaging chain, and every step has the potential to go wrong.
 7. Improved computer monitors, and image processing algorithms may reveal artifacts that were not evident in the past. This likely will have little practical clinical impact, however.

Based on the results of this study, our ultrasound practice decided to implement irreversible JPEG compression. Compression, at the quality factors used in this study, is applied to

all ultrasound images immediately after they are transferred from the ultrasound scanner to the PACS and before the images are read by the radiologist. To satisfy the Food and Drug Administration (FDA) requirements, when displaying each image, the viewstation adds a small text field indicating that the image was compressed irreversibly, and the level to which it was compressed. The same compressed images that are read by the radiologist are stored in the archive.

Our experience, after using irreversible compression in the clinical practice for all ultrasound examinations performed during the past 12 months confirms the results of this study. (Approximately 48,000 ultrasound examinations have been read during this period.) Experienced ultrasound radiologists who had been using the PAC system daily for several years before turning on compression, have not indicated any problems or concerns with the image quality since compression was turned on. The only complaint that was voiced initially was that the text added to each image (to meet the FDA requirement to indicate that irreversible compression was used) was too large and should be displayed in a smaller, less distracting font.

CONCLUSIONS

The results of this study indicate that color and grayscale ultrasound images compressed with JPEG at approximately 9:1 are statistically indistinguishable from the originals for primary diagnostic purposes. Because it is supported by the DICOM standard, images compressed with the JPEG baseline standard can be stored by and sent to conforming DICOM devices making it possible to utilize irreversible compression for primary diagnostic purposes on standards-based PAC systems.

Based on our laboratory experience with compression, and the results of this and other studies, JPEG compression with quality factors of 70 and 97 for grayscale and color images, respectively, is now being applied to all ultrasound images in the radiology practice before reading. No image quality-related issues have been encountered after 12 months of operation (approximately 48,000 examinations). Table 2

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