

# A Comparison of Wavelet and Joint Photographic Experts Group Lossy Compression Methods Applied to Medical Images

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**This presentation focuses on the quantitative comparison of three lossy compression methods applied to a variety of 12-bit medical images. One Joint Photographic Experts Group (JPEG) and two wavelet algorithms were used on a population of 60 images. The medical images were obtained in Digital Imaging and Communications in Medicine (DICOM) file format and ranged in matrix size from  $256 \times 256$  (magnetic resonance [MR]) to  $2,560 \times 2,048$  (computed radiography [CR], digital radiography [DR], etc). The algorithms were applied to each image at multiple levels of compression such that comparable compressed file sizes were obtained at each level. Each compressed image was then decompressed and quantitative analysis was performed to compare each compressed-then-decompressed image with its corresponding original image. The statistical measures computed were sum of absolute differences, sum of squared differences, and peak signal-to-noise ratio (PSNR). Our results verify other research studies which show that wavelet compression yields better compression quality at constant compressed file sizes compared with JPEG. The DICOM standard does not yet include wavelet as a recognized lossy compression standard. For implementers and users to adopt wavelet technology as part of their image management and communication installations, there has to be significant differences in quality and compressibility compared with JPEG to justify expensive software licenses and the introduction of proprietary elements in the standard. Our study shows that different wavelet implementations vary in their capacity to differentiate themselves from the old, established lossy JPEG.**

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**M**EDICAL IMAGES used for diagnosis today typically range in matrix sizes from  $256 \times 256$  (magnetic resonance [MR]) to  $2,560 \times 2,048$  (computed radiography [CR], digital radiography [DR], etc) or higher. These dimensions result in file sizes of 128 kb to 10 Mb or more, using 12 to 16 bit/pixel data. Various compression techniques have been developed to reduce file sizes significantly,

with ratios varying between 1.5:1 to 200:1. Lower ratios are obtained using "lossless" compression techniques,<sup>1,2</sup> resulting in unmodified copies of the original images once reconstructed. "Lossy" techniques allow higher compression ratios (10:1 and higher), but modify the original pixel data, explaining the reluctance of the medical community to adopt them as part of their everyday practice. Examples of lossy compression methods include several methods standardized by the Joint Photographic Experts Group (JPEG), and newer and more experimental techniques such as wavelet-based techniques and fractal compression, among others. Extensive research is needed before these techniques can be used confidently in medical practice for diagnostic purposes. This preliminary study, in preparation for a larger study comparing a greater number of methods with more elaborate analysis, focuses on the quantitative comparison of three lossy compression methods.

## MATERIAL AND METHODS

The study was based on a population of 60 medical images. These images were distributed as listed in Table 1. Images were obtained in Digital Imaging and Communications in Medicine (DICOM) file format from various vendors' modalities, representing a wide variety of organ system studies. Digitized studies were processed on a Lumisys 150 medical film digitizer (Lumisys, Sunnyvale, CA) and driven by proprietary software generating DICOM files.

Three compression algorithms were applied to each image, with a range of compression levels applied to each. The compression algorithms used were Pegasus wavelet, Aware wavelet, and Independent JPEG Group (IDG) JPEG (release 6b)—Penn State modification.

Each compression algorithm used a distinct compression factor. The Pegasus algorithm used a factor that ranged from 100 (minimum compression) to 0 (maximum compression). The Aware algorithm used a desired ratio factor. This factor indicated the desired compression ratio one would like. (The desired ratio would not yield a file that was exactly the requested ratio; but it was sometimes close.) Valid ratios ranged from 5.3:1 up to 100:1. The JPEG algorithm used a factor that ranged from 100 (minimum compression) to 1 (maximum compression).

Our methodology entailed a three-phase process. The first phase was to generate a Pegasus-compressed image, an Aware-compressed image, and a JPEG-compressed image that were comparable in file size for nine different levels. We applied the Pegasus algorithm first at the following levels: 70, 60, 50, 45, 40, 30, 25, 20, and 10. The other methods were then applied by software developed for the study to obtain comparable file sizes for both compression methods at each compression level. Each

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Table 1. Distribution of Image Types

Modality	No. of Images	Resolution
MR	15	256 × 256
CT	15	512 × 512
DR	15	2K × 2.5K
Digitized film	15	2K × 2.5K/1K × 1.5K

algorithm was applied in several iterations until a compressed image comparable in file size to its Pegasus counterpart was generated. The second phase was to reconstruct the compressed images. All compressed images were reconstructed to generate a set of nine images per technique and labeled appropriately.

It turned out that the Pegasus algorithm gave the widest range of compressibility for all images. We had initially planned to use Pegasus compression factors of 100, 90, 80 . . . , down to 0; and then generate Aware- and JPEG-compressed files that were comparable in size to their Pegasus counterparts. However, we could not generate Aware and JPEG images of comparable file sizes. After analysis, the common range of compression between Aware and Pegasus was found to be between Pegasus factors of 70 through 10, and the common range of compression between JPEG, Pegasus and Aware was found to be between Pegasus factors of 70 through 30.

The final phase was to perform quantitative statistical analysis that compared each compressed-then-reconstructed image with its original image counterpart. Three numbers were computed. The first number was the sum of the absolute value of differences between each pixel in the original image and its corresponding pixel in the compressed-then-decompressed image.

$$m_1 = \sum_{x,y} |A_{x,y} - B_{x,y}|$$

The second number was the sum of squared differences between each pixel in the original image and its corresponding pixel in the compressed-then-decompressed image.

$$m_2 = \sum_{x,y} (A_{x,y} - B_{x,y})^2$$

The third number computed was the peak signal-to-noise ratio

(PSNR), which is another measure to indicate how “close” one image is to another. PSNR is defined as:

$$m_3 = PSNR = 10 \log_{10} \frac{(2^{\# \text{ of bits}})^2}{\frac{1}{\# \text{ of pixels}} \sum_{x,y} (A_{x,y} - B_{x,y})^2}$$

where the number of bits is 12, x is the width of the image, y is the height of the image, A is the original image, B is the compressed-then-decompressed image, and the summation in the denominator is simply the second measure described earlier,  $m_2$ . So the equation is reduced to:

$$m_3 = PSNR = 10 \log_{10} \frac{W * H * 4096^2}{m_2}$$

Higher values of PSNR indicate that the reconstructed image is closer to the original image than those images with lower PSNR values. If the compressed-then-decompressed image is identical to the original image, then the PSNR is equal to infinity, since  $m_2$  would be zero. Table 2 is an extract of the findings displaying a subset of the collected and calculated data and the statistical measures for these two images.

RESULTS

Both Aware wavelet and Pegasus wavelet were able to compress images on all nine predefined levels, allowing the use of the full range of 550 measurements to compare these two techniques. To evaluate JPEG in a paired manner against the other two techniques, we had to reduce the population of measurements to the six common levels achievable by all three techniques, and performed statistical comparisons on a limited population of 360 measurements.

Table 2. Sample of Measurement Data From the Image Population

Image	Width	Height	Original Size	Pegasus Size	Pegasus Quality	Aware Size	Aware Ratio	JPEG Size	JPEG Quality	m2 for Pegasus	m2 for Aware	m2 for JPEG	Pegasus PSNR	Aware PSNR	JPEG PSNR
Image 1	2048	2560	10,485,760	855,455	70	899,667	9.2	863,142	35	633,216,300	1,089,709,000	1,416,584,000	51.43	49.07	47.93
Image 1	2048	2560	10,485,760	595,008	60	596,788	13.6	597,146	21	1,208,950,000	2,016,753,000	2,078,591,000	48.62	46.39	46.26
Image 1	2048	2560	10,485,760	412,071	50	413,791	19.7	419,285	13	1,902,018,000	2,869,363,000	2,748,402,000	46.65	44.86	45.05
Image 1	2048	2560	10,485,760	340,809	45	341,769	23.6	346,114	10	2,280,039,000	3,250,603,000	3,060,090,000	45.86	44.32	44.58
Image 1	2048	2560	10,485,760	282,815	40	282,917	27.8	294,795	8	2,644,325,000	3,613,050,000	3,334,901,000	45.22	43.86	44.21
Image 1	2048	2560	10,485,760	196,031	30	191,049	42.3	206,316	5	3,329,412,000	4,492,868,000	4,049,073,000	44.22	42.92	43.37
Image 1	2048	2560	10,485,760	164,853	25	164,415	48.7	176,129	4	3,637,088,000	4,912,996,000		43.83	42.53	
Image 1	2048	2560	10,485,760	140,556	20	140,425	55.6	147,970	3	3,908,114,000	5,860,305,000		43.52	41.76	
Image 1	2048	2560	10,485,760	106,663	10	106,325	76.6	132,967	1	4,382,403,000	7,421,507,000		43.02	40.74	
Image 2	512	512	524,288	10,481	70	10,512	20.6	21,130	14	21,515,335	28,422,174	32,399,340	53.10	51.89	51.33
Image 2	512	512	524,288	7,856	60	7,816	26.5	15,526	9	30,680,337	40,632,208	44,518,960	51.56	50.34	49.95
Image 2	512	512	524,288	6,348	50	6,308	33.0	13,084	7	40,225,394	52,377,181	62,411,560	50.39	49.24	48.48
Image 2	512	512	524,288	5,794	45	5,797	36.0	11,854	6	45,444,246	57,751,481	72,356,220	49.86	48.81	47.84
Image 2	512	512	524,288	5,289	40	5,277	40.0	10,576	5	51,376,260	65,476,767	72,356,220	49.32	48.27	47.84
Image 2	512	512	524,288	4,482	30	4,486	47.1	9,254	4	64,318,771	81,030,537	106,014,300	48.35	47.34	46.18
Image 2	512	512	524,288	4,156	25	4,160	50.6	7,976	3	71,391,914	89,494,609		47.89	46.91	
Image 2	512	512	524,288	3,863	20	3,865	54.6	7,976	3	79,450,441	98,573,310		47.43	46.49	
Image 2	512	512	524,288	3,308	10	3,310	64.0	7,246	1	100,243,919	124,001,482		46.42	45.50	
Image 2										152,740,782	192,718,726		44.59	43.58	

*Comparison of Two Wavelet Techniques:  
550 Measurements*

Comparison of the absolute sum of pixel differences and PSNR values measured on 550 compression instances showed statistically significant differences of image quality at similar compression levels between the two wavelet implementations (Fig 1).

Paired *t* test comparison of both measurements on the larger population of 550 instances showed the Pegasus implementation to yield significantly better measurements at similar compressed image sizes. JPEG was not included in this comparison, as its compressibility did not cover the three lower compression levels.

*Comparison of All Compression Techniques:  
360 Measurements*

Comparison of the absolute sum of pixel differences measured on 360 compression instances showed statistically significant differences of image quality at similar compression levels between the two wavelet implementations (Fig 2), and

between Pegasus wavelet and JPEG, but not between Aware wavelet and JPEG.

Comparison of the PSNR differences measured on 360 compression instances showed statistically significant differences of image quality at similar compression levels between all three compression techniques, although data distribution for Aware wavelet remained closer to JPEG, rather than to Pegasus wavelet. Paired *t* test comparison of measurements showed Pegasus wavelet compression to yield significantly better results for both measurements when compared with the other methods. A ware wavelet's measurements were close enough to JPEG to be statistically similar to it for absolute sum of pixel differences.

DISCUSSION AND CONCLUSION

Wavelet compression has already been shown to give better compression quality at constant compressed file sizes compared with JPEG.<sup>2-6</sup> The DICOM standard does not yet include wavelet as a recognized lossy compression standard. For imple-

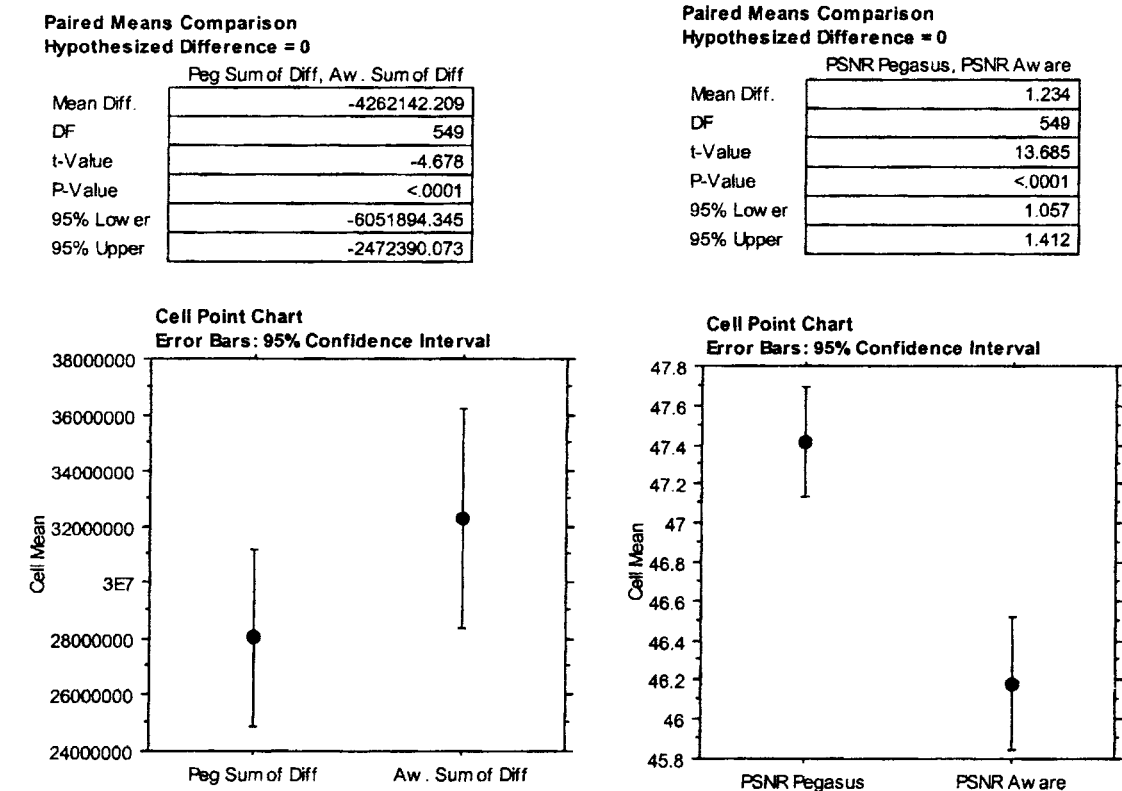


Fig 1. Comparison of the Aware and Pegasus wavelet implementations over 550 measurements.

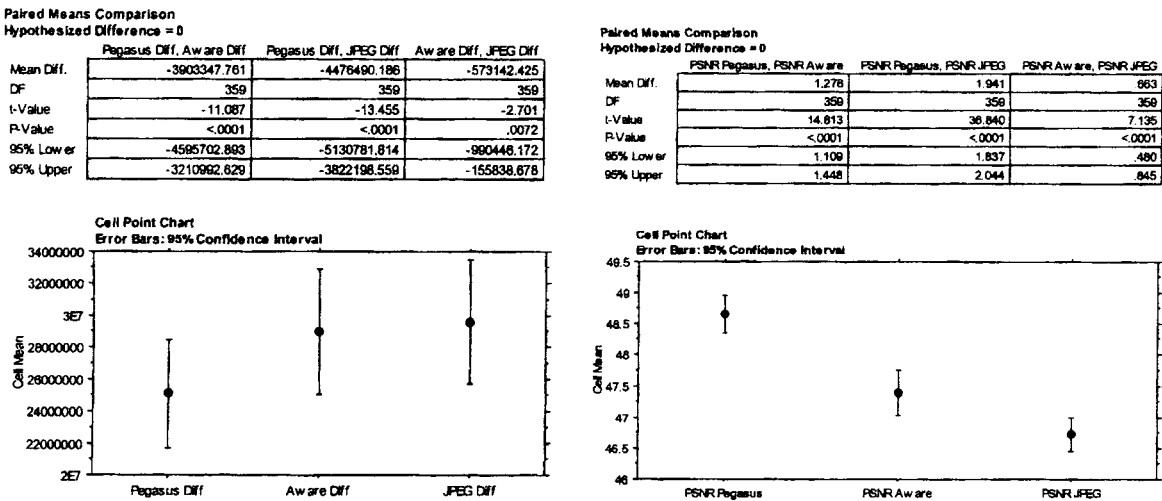


Fig 2. Comparison of all compression implementations over 360 measurements.

menters and users to adopt wavelet technology as part of their image management and communication installations, there has to be significant differences in quality and compressibility compared with JPEG, in order to justify expensive software licenses and the introduction of proprietary elements in the standard. As this short study shows, different

wavelet implementations vary in their capacity to differentiate themselves from the old, established lossy JPEG. Further studies including other commercial flavors of wavelet with a larger series of images and subjective analysis need to be performed to determine the best compression technologies available from vendors.

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