The Effect of Lossy Discrete Cosine Transform Compression on Subtle Bone Fractures

Morankinyo Oyewole Toney, Rodrigo Dominguez, Huu-Ninh Dao, and Gary Simmons

Extensive research efforts have been devoted to the feasibility of picture archiving and communication systems (PACS) in recent years. The advantages of PACS are numerous but mainly include reduced cost and improvement in the operational efficiency of a PACS-based radiology department. In digital radiography, images are viewed either in hard-copy or soft-copy format. Usually, these images are subsequently compressed and archived for future evaluation. There are various methods used in image compression. In this study, computed radiography images showing subtle pediatric bone fractures were compressed with the lossy method of image compression after they had been initially evaluated on workstation monitors. These studies were subsequently evaluated by observers, who were unaware of the interpretations of these images before compression, to determine if they could detect similar abnormalities. Our conclusion is that there is no difference in the interpretation of soft-copy computed radiographic images before or after lossy 10:1 compression in studies of subtle pediatric bone fractures.

This is a US government work. There are no restrictions on its use.

KEY WORDS: computed radiography, lossless and lossy compression, hard-copy, soft-copy, Friedman analysis of variance (ANOVA), Wilcoxon's signed ranked test.

IN RECENT YEARS, extensive research and development efforts have been devoted to the feasibility of picture archiving and communication systems (PACS) as a replacement for film-based radiography.¹⁻⁶ Unlike teleradiology in which images are transmitted to remote areas, PACS is used for local transmission of images, usually within the hospital and imaging centers.⁴ There are numerous advantages to the PACS in radiology. These include reduced storage space requirements, and film cost, expedient image transfer and display of radiographic images, and overall improvement in the operational efficiency of PACS-based radiology departments.⁵

Digital images are potentially available to radiologists in two viewing forms when using computed radiography (CR): hard-copy and soft-copy.⁷⁻⁹ In hard-copy viewing, digital data is used to modulate the intensity of a laser beam that exposes an analog film. Soft-copy viewing involves the conversion of digital data to an analog video signal that is viewed on a preview monitor or

multimonitor workstation in a stand-alone or networked situation. In this study, images were displayed in soft-copy on workstations incorporating four monitors each with a 1536×2048 pixel matrix.

There are several advantages to the use of image compression in CR. These include decreased short-term magnetic and long-term optical media requirements, increased speed of transmission, and decreased transmission cost in PACS and teleradiology. The goal of the study was to assess the efficacy of using soft-copy CR images in detection of subtle pediatric bone fractures before and after lossy 10:1 compression (Figs 1 and 2).

METHODS

A total of 67 pediatric plain CR images of the upper or lower extremities, such as the elbows, wrists, hands, or ankles, referred to the radiology department from the emergency room were evaluated on PACS workstations.

This study was conducted by using the Department of Defense's Medical Diagnostic Imaging Support (MDIS) PACS (Medical Imaging System Vantage PACS; Lockheed Martin, La Jolla, CA) at our institution. This system incorporates a CR subsystem (ST-V; Fuji, Kanagawa, Japan) with images displayed as soft-copy on workstations incorporating four monitors each with a 1536×2048 pixel matrix supported by Infodex (Model No. GMA-212; Wolcott, CT). These monitors allow the radiologists to digitally manipulate images using a mouse and keyboard commands. Images can be magnified, minified, the gray scale inverted, and the image contrast (window and level) adjusted as a minimum.

Initially, these digital soft-copy images were individually interpreted before compression by two radiologists with at least two years of experience with the functions of the PACS workstation. After the images were compressed with a 10:1 lossy compression technique, they were subsequently individually interpreted by two other experienced radiologists with at least one year of experience with the PACS workstation and who were unfamiliar with the previous interpretations.⁷ Thirty-two of

From the Department of Radiology, Brooke Army Medical Center, San Antonio, TX.

The opinions contained herein are those of the authors and do not reflect the views of the Army, the Department of Defense, or the United States Government.

Address reprint requests to Col. Morankinyo Oyewole Toney, MC, Department of Radiology, Brooke Army Medical Center, San Antonio, TX 78234.

This is a US government work. There are no restrictions on its use.

0897-1889/97/1004-0004\$0.00/0

Fig 1. An example of a pediatric fracture seen on a computed radiograph before compression.

the 67 cases were reported as fractures, ie, torus, buckle, or Salter I fractures. Another 32 were reported as normal, and 3 studies were found technically inadequate for interpretation.

The radiographic diagnosis grading system used was as follows: (1) definite fracture, (2) no fracture, (3) probable fracture, and (4) indeterminate image for interpretation. Statistical analysis of the results of interpretation before and after application of lossy compression was performed by means of

Friedman nonparametric repeated analysis of variance (ANOVA) and Wilcoxon’s signed rank test statistical analysis.¹⁰ Using the data obtained, a power analysis was performed to estimate the power of this study to detect a difference between compressed and uncompressed images. The sensitivity of uncompressed images was estimated to be 90%. The methods of Kraemer and Thiesmann¹¹ and Fleiss¹² were used to estimate the number of subjects needed to detect a difference in sensitivity and specificity with a level of confidence of 95% and a power of 80%. Next, 1,000 iterations of Monte Carlo simulation were performed to determine the power using the estimated number. If the power was less than 80% or greater than 85%, the number was modified proportionately and the 1,000-run Monte Carlo simulation was reiterated until a power ranging from 80% to 85% was obtained. According to this method, 33 images were sufficient to detect a change in sensitivity from 0.90 to 0.55 with the desired level of confidence and power.

RESULTS

The Friedman nonparametric ANOVA showed that no significant difference exists between observers before and after compression of the images (Table 1). Also, the Wilcoxon’s signed ranked test showed no significant differences between observers before and after image compression (Table 2).

Five studies were initially classified as probable fracture by all observers. These were subsequently combined into the fracture group because the initial clinical management was similar and follow-up images in these 5 studies were consistent with fracture. The clinical management and course of these patients was the “gold standard” used to confirm a radiologist’s interpretation of fractures. Observers were not aware of the clinical outcome of cases until all images were interpreted (before or after compression). Combining definite fractures and probable fractures into one category, because the initial clinical management was similar, showed no statistical difference in classification relative to compression.

Table 1. Friedman Nonparametric Repeated ANOVA Measures in 67 Cases

Mean Rank	Compression	Observer
2.57	Before	1
2.57	Before	2
2.49	After	3
2.37	After	4

Note: Before, images interpreted by observers 1 and 2 before compression; After, images interpreted by observers 3 and 4 after compression.

* $P = .7573$, $\chi^2 = 1.1821$, $DF = 3$.

Fig 2. An example of a pediatric fracture seen on a computed radiograph after image compression.

Table 2. Wilcoxon's Signed Rank Test on Classification of Radiographs by Compression (Before, After) and Observer

Observers	After < Before	After > Before	After = Before	Significance (P)
3/1	3	0	64	.1088
4/1	9	2	56	.0619
3/2	3	0	64	.1088
4/2	9	2	56	.0619

Note: After < Before, number of images that were ranked lower after compression; After > Before, images that were ranked higher after compression; and After = Before, the number of images that were ranked the same by both observers.

DISCUSSION

CR is an essential part of the implementation of a highly filmless PACS-based radiology department because plain images and other projection radiographs are the most frequently requested diagnostic studies in clinical practice. However, a noncompressed digitized image contains an enormous amount of data that may overwhelm storage media capacities and communication links.¹³ Various methods are available for image compression in CR.¹⁴⁻¹⁶ One common method is based on a two-dimensional discrete cosine transform (DCT) technique recommended by the Joint Photographic Expert Group (JPEG).

The DCT method is used to convert a matrix of pixel values from the spatial domain into the frequency domain.¹⁶ Briefly, there are two types of DCT technique resulting in lossless (nondestructive, reversible) or lossy (destructive; irreversible) image compression. Lossless compression returns the original image to exactly the same original pixel values after the decompression of the image data. Lossless compression may be performed by using a simple differential pulse code modulation scheme⁷ that compresses the original image, followed by a reversal of the compression algorithm that returns the image back to its original size. In

lossy image compression, the compressed image is not returned to its pixel values after compression as in lossless compression. However, artifacts are suppressed by blocking image differences and compression noise is suppressed and made imperceptible during workstation viewing without loss of perceptual quality.

The three basic steps involved in lossy image compression are (1) transform coding, (2) quantization, and (3) compression. Images are first transformed into a format which is more suitable for compression. There are different steps used in quantization as discussed by Gillepsy and Rowberg.¹⁶ The quantization technique, which is not used in the lossless method, and the use of greater compression ratios up to 100:1 (a typical lossless compression ratio is not greater than 3)¹⁷ are perhaps the most overwhelming advantages of lossy image compression over lossless compression technique. The clinical goal when using lossy compression therefore is to use a compression algorithm and compression ratio that returns an image containing the original diagnostic content. Thus, clinically, the image will appear unchanged to the clinical observer. The techniques involved in lossless and lossy compression have been adequately explained by other investigators.^{7,14}

This study clearly demonstrated the efficacy of lossy 10:1 compression in the evaluation of subtle pediatric bone fractures. Our null hypothesis at the beginning of the study was that there will be no difference in the interpretation of soft-copy CR images showing these fractures before or after 10:1 lossy compression. The results of this study using the Friedman nonparametric ANOVA and the Wilcoxon's signed ranked test analysis showed that there are no significant differences between radiologists' evaluation of subtle pediatric bone fractures before and after image compression. Different observers were used for the postcompression observations to eliminate the possibility that they would be biased by previous analysis of the uncompressed images. Although this added as a variable differences between observers, this was evaluated by comparing each precompression observer to each postcompression observer in the post hoc analysis. Unlike previous studies,¹⁸ we have used a radiological diagnosis grading system in our study: (1) no fracture, (2) indeterminate, (3) probable fracture and (4) definite fracture. Because this study involved repeated measures on an ordinal scale

Table 3. Distribution of Classifications by Compression and Observer

Compression	Observer	Fracture/ Probable Fracture	Indeterminate	No Fracture
Before	1	30	3	34
Before	2	30	3	34
After	3	27	3	37
After	4	23	3	41

Note: Before, images interpreted by observers 1 and 2 before compression; After, images interpreted by observers 3 and 4 after compression.

applied to the same image, we performed an ANOVA with the Friedman statistic before post hoc analysis using the Wilcoxon's signed rank test, as recommended for repeated measures on ordinal variables by Glantz.¹⁰

The images classified by the observers included 33 subtle fractures and 34 normal images. Five studies were classified as probable fractures by all observers. These were combined with the definite fracture group because the clinical management was the same and follow-up studies in these 5 studies were consistent with fracture. Observers 1 and 2, viewing uncompressed images, identified 30/33 fractures and 34/34 normal images correctly, corresponding to a sensitivity of 90.9% and a specificity of 100%. Three fracture images were found to be technically inadequate for interpretation. Observers 3 and 4, viewing compressed images had sensitivities of 81.8% and 63.6%, and specificities of 100% and 81.8% respectively. Although the difference in sensitivity is large enough to be clinically significant, the Friedman nonparametric ANOVA (Table 1) showed that there was no statistically significant difference between the combined factors of observer and compression ($P = .7573$) when the probable fracture and definite fracture categories were combined. This finding is supported by Wilcoxon's signed rank test ($P \geq .0619$) (Table 2). Observer number 4 has less experience with the PACS than the other observers. Training of technologists and physicians are impor-

tant quality control parameters in digital imaging systems and previous authors have adequately discussed methods of optimizing image quality and quality assurance in musculoskeletal digital radiography.^{19,20}

We realize the small number of images in this study may have resulted in a slight decrease in sensitivity during compression. However, there was no significant difference in observers in arriving at the same diagnosis before or after image compression. Wilcoxon's signed rank test (Table 2) shows lack of any significant trend before or after lossy 10:1 compression, indicating that the trends are parallel. Further image evaluation studies with larger numbers of images are needed. The small number of images used in this study may have resulted in clinically significant differences in sensitivity being statistically insignificant. There appears to be no clinical or statistically significant difference in specificity. Further image evaluation studies with larger numbers of images are needed. Assuming a sensitivity of 90%, 222 fracture images will be needed to detect a decrease in sensitivity to 80%, and 72 fracture images will be needed to detect a decrease to 70%. An equal number of normal images should be included in the study.

ACKNOWLEDGMENT

The authors thank Michael Cawthon, COL, MC, Program Director, Department of Radiology, Brooke Army Medical Center, San Antonio, TX for reviewing this article.

REFERENCES

- Huang HK, Andriole K, Bazzill T, et al: Design and implementation of a picture archiving and communication system: The second time. *J Digit Imaging* 9:47-59, 1996
- Mosser H, Urban M, Hruby W, et al: Filmless digital radiology-feasibility and 20 month experience in clinical routine. *Medical Informatics* 192:149-159, 1994
- Razavi M, Sayre J, Taira RK, et al: Receiver-operating characteristic study of chest radiographs in children: Digital hard-copy film vs 2K $\times$ Soft-copy images. *AJR Am J Roentgenol* 158:443-448, 1992
- Taira RK, Manovich NJ, Boechat MI, et al: Design and implementation of a picture archiving and communication system for pediatric radiology. *AJR Am J Roentgenol* 150:1117-1121, 1988
- Arenson RL, Seshardi SB, Kundel HL, et al: Clinical evaluation of a medical image management system for chest images. *AJR Am J Roentgenol* 150:55-59, 1988
- Bushberg JT, Siebert JA, Leidholdt EM, et al: *The Essential Physics Of Medical Imaging*. Baltimore, MD, William & Wilkins, 1994, p 159
- Wilson, DL: Compressed radiologic images and workstation. *J Digit Imaging* 5:168-175, 1992
- Mori T, Nakata H: Irreversible data compression in chest imaging using computed radiography: An evaluation. *J Thoracic Imaging* 9:23-30, 1994
- Smith DV, Smith S, Bender GN, et al: Evaluation of the medical diagnostic imaging support system based on 2 years of clinical experience. *J Digit Imaging* 8:75-87, 1995
- Glantz SA: *Primer of Biostatistics* (ed 2). New York, NY: McGraw-Hill, 1987
- Kraemer HC, Theismann S: How many subjects? *Statistical Power Analysis in Research*. Newbury Park, CA, Sage, 1988
- Fleiss JL: *Statistical Method of Rates and Proportions*. New York, NY, Wiley, 1973
- Huang HK, Mankovich NJ, Cho PS, et al: Picture archiving and communication systems in Japan. *AJR Am J Roentgenol* 148:421-429, 1987
- Gray R, Olshen R, Sayre J, et al: *Proceedings of The Digitized Radiographic Images: Challenges and Opportunities (workshop)*. National Library of Medicine, Bethesda, MD, June 2-3, 1993
- Honeyman JC, Frost MM, Huda W, et al: Picture archiving and communications system [PACS]. *Curr Probl Diagn Radiol* 234:101-158, 1994

16. Gillepsy T, Rowberg AH: *Displaying radiologic images on personal computers: Image storage and compression-Part 2*. J Digit Imaging 7:1-12, 1994
17. Moura L, Furie SS, Gutierrez MA, et al: *Lossy compression techniques, medical images, and the clinician*. MD Comput. 13:155-159, 1996
18. Cosman PC, Davidson HC, Bergin CJ, et al: *Thoracic CT images: Effect of lossy image compression on diagnostic accuracy*. Radiology 190:517-524, 1994
19. Freedman M, Stellar D: *Digital radiography of musculoskeletal system: The optimal image*. J Digit Imaging 8:37-42, 1995
20. Peterson H: *Digital skeletal radiography*. J Digit Imaging 8:43-44, 1995