Canadian Association of Radiologists

CAR Standards for Irreversible Compression in Digital Diagnostic Imaging within Radiology

The standards of the Canadian Association of Radiologists (CAR) are not rules, but are guidelines that attempt to define principles of practice that should generally produce radiological care. The physician and medical physicist may modify an existing standard as determined by the individual patient and available resources. Adherence to CAR standards will not assure a successful outcome in every situation. The standards should not be deemed inclusive of all proper methods of care or exclusive of other methods of care reasonably directed to obtaining the same results. The standards are not intended to establish a legal standard of care or conduct, and deviation from a standard does not, in and of itself, indicate or imply that such medical practice is below an acceptable level of care. The ultimate judgment regarding the propriety of any specific procedure or course of conduct must be made by the physician and medical physicist in light of all circumstances presented by the individual situation.

Approved: June 2011

These Standards, supported by Canada Health Infoway, were developed by radiologists from Sunnybrook Hospital, Toronto Ontario, Fraser Health Authority of British Columbia and the Medical Imaging Informatics Research Centre at McMaster University, Hamilton Ontario.

Table of Contents

I. INTRODUCTION

This standard validates the use of irreversible compression under certain defined circumstances and for specified examination types. The specific recommendations appear in section V.

A. Background

The increasing volume of data generated by new imaging modalities such as multi-slice computed tomography scanners and magnetic resonance imaging justifies the use of irreversible compression techniques to decrease the cost of storage and improve the efficiency of transmission over networks (1). The impact on storage and network bandwidth requirements is predicted to increase sharply when departments adopt digital technology in all modalities, especially digital mammography and CT scanners that are generating increasingly large numbers of images per study; and archiving of 3D volume renderings and other complex advanced image reformats of the original images.

While the cost of storage is falling, the savings are largely surpassed by the increasing volume of data being generated. In addition, the cost of operating a digital environment with high performance and resiliency is rising and is exacerbated by factors such as mandatory data migration and long or indefinite retention periods for digital images.

Access to imaging data is becoming more widespread as regions/nations implement Electronic Health Record (EHR) solutions. Expectations for accessibility are changing with physicians requiring access to images dating back many years, in near real-time. To satisfy these expectations, Canada Health Infoway is driving the deployment of imaging repositories that host data on-line for the legal retention period and, in some instances for the lifetime of the patient.

While local area network bandwidth within a hospital is adequate for timely access to imaging data, efficiently moving the data between institutions requires wide area network bandwidth, which has a limited availability at a national level. As such, EHR networks cannot support timely access and distribution of large medical images (2).

B. Compression

A solution to address data storage and transmission issues is the use of Irreversible Compression, provided there is no material loss of clinically relevant information. Irreversible compression allows a significant reduction in digital image file size with no significant visual quality loss or image degradation, and the severity of the degradation is strictly dependant on the compression ratio. JPEG is the most widely accepted compression algorithm, but it has been shown that the new JPEG-2000 algorithm (11) may provide higher compression levels than JPEG at an equivalent or higher image quality (3).

Current practice in radiology is to reduce digital image file sizes through reversible, or “lossless” compression, which offers up to a 3 times size reduction. Irreversible, or “Lossy” compression allows a far greater (between 8 and 25 times) size reduction with no significant material visual quality loss up to certain compression ratios. Leveraging irreversible compression in daily practice offers an opportunity to further reduce files sizes and, thereby, enable more cost effective and efficient management of medical imaging data.

C. Relevant Research

Two independent literature reviews, sponsored by Canada Health Infoway, were completed as a part of the study into the use of irreversible compression in Canada. The studies, which reviewed over 120 papers from clinical and technical journals, were completed by INSITE Consultancy Inc. (4), and Kirk Finis (5). Both reviews drew similar conclusions:

- Irreversible compression is a clinically acceptable option for the compression of medical images
- The extent of allowable irreversible compression is dependent on the modality of the image and the nature of the imaged pathology and anatomy

Two independent and comprehensive legal reviews, sponsored by Canada Health Infoway, were completed as a part of the broader study into the use of irreversible compression in Canada. The first study was completed by Bull, Houser and

Tupper (6) and the second study was completed by Mitchell McInnes (7) Faculty of Law, Ivey School. Both of these reviews concluded that the use of irreversible compression does not increase the legal liability of physicians and other practitioners if used and implemented appropriately.

Bull, Houser and Tupper completed a regulatory assessment as part of their legal review. This regulatory assessment considered the USA, Canada, the EU and Australia. The review found no statements preventing the use of irreversible compression.

The position of the American College of Radiology:

> *"Data compression may be performed to facilitate transmission and storage. The type of medical image, the modality, and the objective of the study will determine the degree of acceptable compression. Several methods, including both reversible and irreversible techniques (lossless and lossy are also common terms), may be used under the direction of a qualified physician or practitioner, with minimal if any reduction in clinical diagnostic image quality. If compression is used, algorithms recommended by the DICOM standard such as wavelet or JPEG-2000 compression methods should be used. The types and ratios of compression used for different imaging studies transmitted and stored by the system should be selected and periodically reviewed by the responsible physician to ensure appropriate clinical image quality. Regulatory bodies may require the compression ratio used to be indicated on the compressed image. The Food and Drug Administration (FDA) does not allow compression of digital mammograms at this time for retention, transmission, or final interpretation.." (8)*

The position of the United States' Food and Drug Administration:

> *"Data compression - If standard data compression schemes (e.g. differential pulse code modulation (DPCM), Huffman encoding) are utilized in communications or storage, they should be identified by name. If non-standard or proprietary methods are employed, the algorithms utilized should be described in detail and copies of any related technical publications provided. In either case the compression ratios to be employed should be specifically stated." (9)*

Finally, the Canadian Association of Radiologists sponsored two pan Canadian clinical evaluations on JPEG and JPEG-2000 irreversible compression in medical imaging. The first clinical evaluation was completed by a team at Sunnybrook Hospital and lead researcher Dr. David Koff (10). The objective of the evaluation study was to assess the impact of irreversible compression on visual quality with sufficient scale and rigour to stand up to scientific and clinical scrutiny. More specifically, the study:

- Evaluated the impact of JPEG and JPEG-2000 irreversible compression at "safe" compression ratios. These ratios were selected based on the evidence of the literature reviews
- Incorporated both diagnostic accuracy and subjective evaluation techniques:
  - Diagnostic accuracy with ROC analysis
  - Original Revealed Forced Choice Just Noticeable Difference
- Covered a broad scope
  - 5 modalities: CR/DR, CT (slice thickness ≥5mm), US, MR, NM
  - 7 radiological areas: Angiography, Body, Breast, Chest, Muscular Skeletal Imaging, Neuroradiology, Paediatrics

- Leveraged sufficient scale to support statistical "power"
  - 23 different sessions, with 3 reviewers for each
  - 100 radiologists from across Canada
  - Sample size of 60 to 80 images for each session

A subsequent clinical evaluation was completed by a team at the Medical Imaging Informatics Research Centre at McMaster University and lead researcher Dr. David Koff (13). The objective of the evaluation study was to extend the first clinical evaluation to CT images with thickness less than 5 millimeter (mm). More specifically, the study:

- Evaluated the impact of JPEG and JPEG-2000 irreversible compression at "safe" compression ratios. These ratios were selected based on the evidence of the literature reviews
- Incorporated both diagnostic accuracy and subjective evaluation techniques:
  - Diagnostic accuracy with ROC analysis
  - Original Revealed Forced Choice Just Noticeable Difference
- Covered a specific scope
  - CT modality: Slice thickness <5mm
  - 4 radiological areas: Abdomen (Body), Chest, Musculokeletal Imaging, Neuroradiology
- Leveraged sufficient scale to support statistical "power"
  - 4 different sessions, with 6 reviewers for each
  - 25 radiologists from across Canada
  - Sample size of 70 studies with 15 images per study for each session

The clinical evaluation studies demonstrated that the appropriate use of irreversible compression has no effect on diagnostic accuracy for all modalities and anatomy tested.

II. DEFINITIONS

There are 2 types of image compression: Reversible Compression and Irreversible compression.

A. Reversible Compression (Lossless):

Upon decompression, the image is perfectly reconstructed and numerically identical to the original (i.e. the original and decompressed are perfectly correlated). Run-length encoded (RLE), low-ratio JPEG and the new JPEG lossless compression standard (JPEG-LS) algorithms are examples of lossless compression.

B. Irreversible Compression (Lossy):

With irreversible compression, data are discarded during compression and cannot be recovered. Upon compression frequency content to which the human eye is insensitive is removed. Upon decompression, the discarded information cannot be recovered, resulting in some reconstruction interpretation. Consequently, the original image is not identical to the decompressed version. Wavelet and Irreversible JPEG are examples of irreversible compression. JPEG-2000 is a progressive lossless to lossy compression algorithm.

C. Compression Ratio:

A compression ratio is the average number of bits per pixel (bpp) before compression divided by the number of bits per pixel after compression. For example, if an 8 bit image is compressed and each pixel is then represented by 1 bit per pixel, the compression ratio = 8/1 = 8. Or equivalently for a 24 bit image, if the compression ratio = 18, the compressed image will have 24/18 = 1.33 bpp.

III. TECHNOLOGY

There are principally 2 types of irreversible digital compression methods used in medical imaging: DICOM JPEG and DICOM Wavelet (JPEG 2000).

A. DICOM JPEG

The Joint Photographic Experts Group (JPEG) created the JPEG standard for compression of digital images in 1983. The JPEG standard was adopted by both the International Standards Organization (ISO) and International Telegraph Union Telecommunications standards sector (ITU-T) as ISO/IEC 10918-1 and ITU-T Recommendation T.81 respectively. JPEG is the most commonly used method for compression of digital images. DICOM Version 3.0 supports the use of JPEG Image Compression through the Encapsulated Format.

JPEG reduces the size of an image by breaking it into 8x8 blocks and within each block, shifting and simplifying the colors so there is less information to encode. As pixels are changed only in relation to the other pixels within their block, two identical pixels that are next to each other, but in different blocks, could be transformed in different ways. When high compression ratios are used, the block boundaries become obvious, causing the 'blockiness' or 'blocking artifacts' frequently observed in common JPEG.

B. DICOM JPEG 2000

JPEG-2000 is a new image coding system that uses state-of-the-art compression techniques based on wavelet technology. The JPEG-2000 standard was adopted by ISO as ISO/IEC 15444-1 (JPEG 2000), for digital compression and coding of continuous-tone still images. JPEG-2000 was added to the DICOM Version 3.0 supplement 61 as an Encapsulation Format in 2002.

JPEG2000 is a wavelet-based compression algorithm that offers superior compression performance over JPEG at moderate compression ratios. The end result is a much better image quality. With DICOM JPEG-2000 there are no blocking artifacts as evident with JPEG, however at high levels of compression the image appears blurred.

C. DICOM JPEG and DICOM JPEG-2000 Comparison

JPEG-2000 offers many benefits over JPEG:

1. Efficient irreversible and reversible compression within a single unified coding framework.
2. Multiple resolutions within the same compressed image. This allows compressed images to be sent at the best resolution for a particular device without additional storage overhead.
3. Progressive transmission by pixel accuracy and resolution (progressive rendering). This allows for thumbnails and rapid image display at lower resolutions.
4. Superior image quality; broad range of image types.
5. Support for Region of Interest coding.
6. Support for continuous-tone and bi-level compression (BW and color).
7. Robustness to bit-errors.
8. JPEG-2000 supports 24 bit color, and 8, 12 and 16 bit grayscale image data and is the only 16-bit grayscale irreversible compression supported in DICOM.

IV. SCOPE AND CLINICAL APPLICATION OF IRREVERSIBLE COMPRESSION

A. Modalities in Scope for this Standard

Table 1: Anatomical Areas and Modalities in Scope below, shows the modalities and anatomical areas for which this standard can be applied. These five modalities and seven anatomical areas are those studied in the Pan Canadian Clinical Evaluation Study.

	CR/DR	CT ≥5mm	CT <5mm	US	MR	NM
Vascular		X			X	
Body	X	X	X	X	X	
Breast	X			X	X	
Chest	X	X	X			
Musculoskeletal	X	X	X	X	X	
Neuroradiology		X	X		X	
Paediatrics	X	X		X	X	
All NM						X

Table 1 : Anatomical Areas and Modalities in Scope

V. THE STANDARD

A. Algorithms

The standard algorithms for irreversible compression of Diagnostic Images in Radiology are ISO/IEC 15444-1 (DICOM JPEG-2000 part 1) and ISO 10918-1 (DICOM JPEG) at the compression ratios and for the imaging categories described in this standard.

DICOM JPEG-2000 part 1 has advantages over DICOM JPEG with respect to progressive transmission and bit depth support. It is recommended as the standard algorithm of choice.

B. Compression Ratios

Irreversible DICOM JPEG and JPEG-2000 compression must only be used at the compression ratios and for the modalities and anatomical areas shown below.

Irreversible DICOM JPEG must only be used on 8 and 12 bit images.

a. Computed Radiography / Digital Radiography (CR/DR)

The standard defines the following irreversible compression ratios for CR/DR imaging categories.

- **Body Imaging** – DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 30:1.
- **Breast Imaging**– DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 25:1.
- **Chest Imaging**– DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 30:1.
- Muscular Skeletal Imaging –
  - DICOM JPEG to a maximum compression ratio of 30:1
  - DICOM JPEG-2000 to a maximum compression ratio of 20:1.
- **Paediatric Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 30:1.

b. Computed Tomography (CT)

The standard defines the following irreversible compression ratios for CT imaging categories with a slice thickness of 5mm or greater

- Angiography - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 15:1.
- Body Imaging –
  - DICOM JPEG to a maximum compression ratio of 15:1
  - DICOM JPEG-2000 to a maximum compression ratio of 10:1.
- **Chest Imaging**– DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 15:1.
- **Muscular Skeletal Imaging** – DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 15:1.
- Neuroradiology –
  - DICOM JPEG to a maximum compression ratio of 12:1
  - DICOM JPEG-2000 to a maximum compression ratio of 8:1.
- **Paediatric Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 15:1.

The standard defines the following irreversible compression ratios for CT imaging categories with a slice thickness of less than 5mm.

- **Body Imaging –**
  - DICOM JPEG to a maximum compression ratio of 12:1
  - DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Chest Imaging–** DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Muscular Skeletal Imaging –** DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Neuroradiology –**
  - DICOM JPEG to a maximum compression ratio of 12:1
  - DICOM JPEG-2000 to a maximum compression ratio of 12:1.

c. Ultrasound (US)

The standard defines the following irreversible compression ratios for US imaging categories.

- **Body Imaging –** DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Breast Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Muscular Skeletal Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.
- **Paediatric Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 12:1.

d. Magnetic Resonance (MR)

The standard defines the following irreversible compression ratios for MR imaging categories.

- **Angiography** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.
- **Body Imaging** – DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.
- **Chest Imaging**– DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.
- **Breast Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.
- **Muscular Skeletal Imaging** – DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.

- **Neuroradiology** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.
- **Paediatric Imaging** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 24:1.

e. Nuclear Medicine (NM)

The standard defines the following irreversible compression ratios for NM imaging categories.

- **All anatomical regions** - DICOM JPEG and DICOM JPEG-2000 to a maximum compression ratio of 11:1.

C. Organizational Implementation

A bona fide exercise of discretion is required by the organisation who adopts the use of irreversible compression:

- The organization must consider whether to introduce irreversible compression, and that decision must be reasonable.
- The implementation must be tested prior to clinical use. Test images should be compressed and checked for accuracy. Additionally, mathematical checking must be done to ensure that the compression ratios are accurate.

D. Operational Implementation

There are significant operational components to the use of irreversible compression. While the decision to introduce irreversible compression can be characterized as a policy decision, the implementation of that decision will, in all its facets, be regarded as operational activity.

When irreversible compression is used the following standards apply:

- Irreversible compression, when used, must be considered part of image processing and, as such, the compressed images become the legal record.
- Irreversible compression can be applied to original images prior to reporting or interpretation, or at any time after reporting or interpretation.
- Compressed images are subject to the requirements for archival storage for the legal retention periods. There is no requirement to maintain raw or uncompressed images.
- Display systems must indicate to the user that irreversible compression has been applied and the type and ratio of compression.
- The adoption of irreversible compression by an organization or group of radiologists must be subject to the supervision of qualified radiologists who are satisfied with the image quality after compression has been applied.[1]
- The ratios of compression used for different image modalities must be periodically reviewed to ensure appropriate clinical image accuracy and consistency with the current findings in the scientific community.
- Images must not be recompressed and the capability to allow such recompression must not exist.
- Images captured from analog to digital conversion applications: frame grab images; must not be compressed and the capability to allow such compression must not exist.
- The compression of images to be used within post processing applications[2] : 3D reformatting and reconstruction, multi-planar reconstruction (MPR) and maximum intensity projection (MIP); are not covered by this standard

[1] Whereas all of the recommended maximum compression ratios have no effect on diagnostic accuracy, compression artefacts may be subjectively visible to individual practitioners for certain modalities. It is always up to the individual practitioner to decide what level of compression allows for the most comfortable and accurate interpretation of images as long as it remains less than or equal to the stated maximum.

- The compression of images to be used within a Computer Aided Diagnosis (CAD) application[2] are not covered by this standard.
- The irreversible compression ratios for MRI image modality, as defined in this standard, are not specific to all possible variations in examination technique, technical equipment and modality specifics such as pulse sequences. The irreversible compression ratios for MRI image modality, as defined in this standard are generally applicable.[1]

E. Quality Assurance

Ensuring the appropriate use of Irreversible Compression must be part of the departmental QA program.

- The radiologist must check visual accuracy for the modalities/body parts covered by compression.
- Qualification of Personnel: under the overall supervision of the imaging physician, technologists, bioengineers, image communications specialists, or image management system specialists on-site or as consultants must have the responsibility for implementation, evaluation and operation of the irreversible compression and the applicable quality assurance program.
- In remote sites, there must be a designated imaging physician responsible for the image compression aspect of the quality assurance program. Appropriate delegation of the operational aspects of the quality assurance processes at the site to a suitably qualified technologist is acceptable.
- Personnel involved in implementation and utilization of irreversible compression must stay current with recent developments in the scientific community concerning irreversible compression.
- As a part of a quality assurance program periodic testing must be undertaken to ensure the correct ratios are applied to the appropriate modality and anatomical areas.

F. Physician's Duty of Care

All physicians owe a duty of care to their patients. Any legal question raised by the introduction of irreversible compression will be whether radiologists meet the applicable standard of care if they rely on irreversible compressed digital images.

Specialists such as radiologists, who possess a special degree of skill and knowledge, must exercise the degree of skill of an average specialist in the field. Expert evidence permits a court to determine what the standard practice is in the field, which will often provide the basis for the standard of care (12).

[2] The impact of compressing raw images on post processing applications and CAD has not been evaluated at the time of writing. When such evaluation is completed, the Standard will be updated accordingly.

VI. GLOSSARY

ACR/NEMA - the American College of Radiology and the National Electrical Manufacturers Association

Bit (Binary Digit) - the smallest piece of digital information that a computing device handles. It represents off or on (O or 1). All data in computing devices are processed as bits or strings of bits.

Data Compression - methods to reduce the data volume by encoding it in a more efficient manner, thus reducing the image processing and transmission times and the storage space required.

DICOM (Digital Imaging Communications in Medicine) - a standard for interconnection of medical digital imaging devices, developed by the ACR/NEMA committee.

Digitize - the process by which analog (continuous wave) information is converted into digital (discrete value) information. This process is a necessary function for computer imaging applications because visual information is inherently in analog format and most computers use only digital information.

Gray Scale - the number of different shades or levels of gray that can be stored and displayed by a computer system. The number of gray levels is directly related to the number of bits in each pixel: 6 bits = 64 gray levels, 7 bits = 129 gray levels, 8 bits = 256 gray levels, 10 bits = 1024 gray levels and 12 bits = 4096 gray levels.

Lossless - no loss of the original digital information upon reconstruction of the digital image

PACS – Picture Archival and Communication System

Resolution - the ability of an imaging system to differentiate between objects

VII. REFERENCES

1. Koff, D., Shulman, Harry, An Overview of Digital Compression of Medical Images: Can We Use Lossy Image Compression in Radiology?, CARJ vol 57, No 4, October 2006
2. Bak, P. Will the use of irreversible compression become a standard of practice? SCAR News 2006; 18(1): 10.
3. Iyriboz T. A., Zukoski M. J., Hopper, K. D., and Stagg, P. L. *A comparison of Wavelet and JPEG lossy compression methods applied to medical images.* J. of Digital Imaging 1999; 12(2) suppl 1: 14-17.
4. INSITE Consultancy Inc. Irreversible Compression in Digital Radiology – A Literature Review, August 2004.
5. Finnis K. A Review and Comparison of Medical Image Compression, August 2004.
6. Bull, Housser and Tupper LLP *Lossy Compression Study: Legal Assessment*, December 2004.
7. Mitchell McInnes, *Digital Compression of Medical Images: an Assessment of Legal Risk*, Faculty of Law, University of Western Ontario.
8. *ACR Technical Standard for Electronic Practice of Medical Imaging* – American College of Radiology (ACR) Practice Guideline, United States. 2007 (Res. 13)
9. Guidance for the Submission of Premarket Notifications for Medical Imaging Management Devices, Food and Drugs Administration (FDA) July 27, 2000.
10. Koff, David, Bak, P., Brownrigg, P., Pan-Canadian Evaluation of Lossy Compression Ratios for Development of National Guidelines, Presentation at SIIM 2007 Providence RI
11. Brislawn, C. M., and Quirk M.D. Image compression with the JPEG-2000 standard. In: Encyclopedia of Optical Engineering. Driggers, R.D., eds, New York: Marcel Dekker; 2003 pp 780-785.
12. Cranwill v. James (1994), 164 A.R. 241 (Q.B.) at 254, and Leadbetter v. Brand (1980), 37 N.S.R. 2d 581 (SC)
13. David Koff, Peter Bak, André Matos and Geoff Norman: *Evaluation of Irreversible Compression Ratios for Medical Images Thin Slice CT & Update of the Canadian Association of Radiologists (CAR) Standards*. Report to the Canadian Association of Radiologists, December 2009