The Royal College of Radiologists
Board of the Faculty of Clinical Radiology

The adoption of lossy image data compression for the purpose of clinical interpretation
This guidance forms part of a series on the developments in information technology in radiology. This is a fast-moving field and developments are occurring rapidly. Consequently, this guidance will be updated regularly and readers should check regularly that they are using the most up-to-date guidance available.
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1. Introduction

1.1 The objectives of this document are to develop an understanding of the main issues surrounding the management of the large volumes of data currently generated within a typical imaging department and more globally within the context of a larger (regional and national) image-sharing environment and to provide guidelines for the safe use of lossy image compression in the clinical environment.

1.2 The guidance provided within this document on the levels of image compression is based on a conservative approach to the currently available information and acknowledges the need for efficient image data management, while ensuring patient safety. The guidance is the current position statement by The Royal College of Radiologists (RCR) and as such is a live document available on the RCR website for reference purposes. The document is therefore subject to change as and when new information comes to light.

1.3 The guidance document supports the implementation of compression as a standard as part of the Connecting for Health national picture archiving and communications systems (PACS) solution, and in addition will facilitate the more efficient transmission of image data as part of locally agreed or larger specific teleradiology solutions.

2. Background

2.1 There has been an almost exponential increase in the volume of imaging data produced each year, ranging from multi-slice CT scanners with ever-increasing numbers of thinner slices to more sophisticated reconstruction techniques in magnetic resonance (MR) and computed tomography (CT) vascular imaging which require large volume data sets. This is against a background of increased demand and need for more access to all forms of diagnostic imaging, including the desire to transmit image data over considerable distances for the purposes of diagnosis.

2.2 With the advent of and subsequent almost universal adoption of PACS in the UK and in Europe, the effects of storing high volumes of data on the local hospital-based short-term storage and longer-term archive (which may be a regional storage facility) have been highlighted in terms of providing sufficient storage capacity and the associated increased costs associated with the management of the stored image data. Although the cost of storage media has fallen dramatically over the last few years, the costs of owning and operating the storage remain high, and because of this, any move to reduce the storage capacity requirements will result in significant savings for healthcare organisations.
2.3 As many of the local storage solutions have a fixed size, based on historical data volumes for perhaps just one year, then it is apparent that if working practices are not modified to reduce the data sent to storage and there is no adoption of image compression then the number of cases able to be stored in the short term will decrease significantly. As the majority of cases are reviewed again following the acquisition of the original image within one year, this limitation may have an impact on rapid prior image recall, with a greater dependence on retrieval from long-term archives.

3. **Image data compression**

3.1 Compression of image data at the time of acquisition in such a manner that does not affect the diagnostic quality of the image for primary interpretation purposes provides a potential solution for minimising storage costs, increases the potential number of cases stored online locally and for the purposes of teleradiology can result in a significant reduction in the required bandwidth and just as importantly reduce retrieval times.

4. **Types of image compression and methods of assessment**

4.1 A review of the literature with regard to the acceptability of different levels of compression in various modalities for the purposes of primary diagnostic reading reveals that different methods (algorithms) or types of image compression have been used and the methods of assessing them have varied between studies. Moreover, recent work (as yet unpublished) is suggesting that there may be advantages in using ‘older types’ of compression compared with Joint Photographic Experts Group (JPEG) 2000.

5. **Types of image compression**

5.1 Image compression can be broadly divided into two types; lossless or reversible and lossy or irreversible. Both have current roles in diagnostic imaging. Lossless image compression implies that the regenerated image following compression is identical to the original image, while with lossy compression the regenerated image is not guaranteed to be identical to the original image as certain image elements may have been removed when reducing the image size. Lossless image compression is frequently used within the internal processes of the majority of PACS installations.

5.2 The most familiar types of compression relevant to the current discussion come under the umbrella title of JPEG compression of which there are several distinct forms.
5.3 JPEG lossless uses a pulse code modulation (PCM) algorithm and is used internally in many PACS systems. Two varieties of this algorithm are defined in Digital Imaging and Communications in Medicine (DICOM) and achieve a level of lossless compression of about 2.5:1. JPEG lossless compression does not define different levels of quality or ratios of compression; the compression is dependent on the inherent nature of the image itself.

5.4 JPEG lossy uses a discrete cosine transform (DCT) algorithm and can achieve much higher levels of image compression and here there is a trade-off between image quality and compression. The familiar characteristic appearance with this method is a block artefact at high levels of compression.

5.5 JPEG 2000 is a wavelet compression algorithm which can be used to achieve both lossless at low compression levels and lossy at higher levels. JPEG 2000 is the only standardised interoperable wavelet method, is part of the international ISO standard and like the other compression algorithms is also defined for use in DICOM. There is no consensus on whether JPEG or JPEG 2000 provides the better trade-off between quality and compression, but there have been some concerns expressed with regard to the type of artefacts produced with JPEG 2000 at high levels of compression, which tend to produce a smoothing effect and look 'natural' rather than the blocky artefacts of JPEG. A future advantage with JPEG 2000 is the ability to stream larger volumes of data. The JPEG2000 Interactive Protocol (JPIP) streaming protocol permits the client to download only the requested part of the image and allows for a quick view of the large image at low resolution and the ability to pull more data for higher resolution images or more detailed examination of a smaller part of an image. Moreover, the method reduces computer processes at both the server and client. Another possible advantage of JPEG 2000 (as yet unused outside research environments) is the ability to compress images as 3-dimensional blocks, rather than 'slice-by-slice', using the correlation between slices to improve compression efficiency.

6. The effect of image matrix size on the degree of applicable compression

6.1 It is well recognised that high matrix level images will tolerate greater levels of compression compared with low matrix images. A typical high matrix (large image) such as a chest radiograph has about 10 MB of data which will tolerate levels of compression above 20:1 without any appreciable visual differences. Moreover, very large images such as a mammogram (30 MB) have been recently shown to tolerate much higher levels of compression without any loss of diagnostic accuracy. Conversely, small images such as those from CT and MR are only able to tolerate lower levels of compression before detectable differences are seen.
7. **Methods of assessment**

7.1 The approach to assessing the effects of lossy image compression has varied between studies and over time since the early 1990s.

7.2 **Diagnostic accuracy**

Many studies have concentrated on the effects of varying levels of lossy compression on diagnostic accuracy assessing the reader’s performance in terms of sensitivity and specificity using the receiver operator characteristics (ROC) method, plotting true positives versus false-positives. This clinical method has shown in many instances for chest radiography (CR) and CT studies that diagnostic accuracy is not impaired until quite high levels of compression are reached.

7.3 **Image quality perception**

Other studies, especially in recent years, have focused on the threshold at which the reader can discern the difference between a compressed image and the original at different levels of compression. These studies have used the just noticeable difference (JND) method to determine where the visually lossless threshold lies, above which image quality is thought to be detrimental to the primary reading process. Adoption of a level of compression above the visually lossless threshold may have medico-legal implications if a lesion is missed by the reporting radiologist, even if studies show that higher levels of compression are acceptable in terms of diagnostic accuracy. This method is perhaps more rigorous in its approach in forcing the observer to make a choice as to the level of image quality. The technique has been used effectively in assessing the effects on image quality at different levels of compression; for example, comparing different slice thicknesses in CT,¹ or the effects of image compression on body parts, such as lung versus abdomen. It is clear that with the increasing use of multi-slice CT, the effects of thinner slices on image quality has to be taken further into consideration.

8. **Evidence supporting the use of lossy image compression in imaging**

8.1 In 2000, a paper by Erickson for the Society for Computer Applications in Radiology (now known as the Society for Imaging Informatics in Medicine; SIIM) concluded that some forms of lossy compression could be used without degradation of diagnostic value.²

8.2 At present, there are now a wide range of studies and reviews of the literature which support the safe use of lossy compression. In summary, papers and reviews up to 2004 have included the following modalities: digital radiography, CT, MR, ultrasound, mammography and digital angiography. Assessment of the
effects of various levels of compression in these modalities has been undertaken on different body parts such as CT cranium or CT abdomen.

**Chest radiography**

Recent studies have shown that levels of compression as high as 50:1 are acceptable for image interpretation. A study by Sloan et al\(^3\) (2003) using JPEG lossy compression and analysis of the visually lossless threshold has shown that images were acceptable to the readers at 10:1 and 20:1, with no significant degradation of image quality. A clinical evaluation using ROC analysis of JPEG 2000 by Sung et al has shown that image compression up to 20:1 is acceptable without affecting lesion detection, and significant differences between the original and compressed images on CR were not discernable up to 50:1 compression.\(^4\)

**Skeletal radiography**

The most recent study to date on skeletal radiography by Uchida et al demonstrated that using compression ratios of up to 25:1 were acceptable using a subjective clinical analysis.\(^5\)

**Digital angiography**

Brennecke et al in 2001 demonstrated acceptable levels of compression were obtained clinically at 10:1 and 20:1 with wavelet compression and at 10:1 with JPEG for coronary angiography.\(^6\)

**Digital mammography**

Several studies have shown acceptable levels of compression up to 25:1 using various forms of compression techniques, including JPEG and JPEG 2000.\(^7,8\) A recent presentation at the European Congress of Radiology in 2007 by Dr Reinhard Loose,\(^9\) demonstrated that digital mammograms could be compressed by 100:1 using a standard wavelet compression algorithm without any deterioration in diagnostic quality. There was no statistically significant impact on quality or visible difference in images for compression rates up to 100. Such an outcome may have been expected when compressing a large matrix image such as a mammogram.

**MRI**

Compared with CT, relatively few studies have been undertaken with MRI. Terae et al have shown acceptable levels of compression up to 25:1 using a wavelet algorithm with a ROC analysis in lesion detection.\(^10\) However, some of the current issues arising from the compression of CT data may be relevant to current MR imaging (see section 8.2.8)
US
A study from 2002 using JPEG compression and subjective assessment showed that compression was acceptable up to 9:1 and reflected previous findings.  

CT
A wide range of studies have been undertaken with this modality, including cranium, lung and abdomen, mainly based on a clinical evaluation of diagnostic accuracy with ROC analysis. The results indicate a range of acceptable compression ratios, using mainly pre-JPEG 2000 algorithms ranging from 4:1 to 20:1.  

9. Acceptable levels of compression in CT
9.1 Evidence suggests that the body part being examined influences the level of acceptable compression that can be tolerated. For example, with the thorax, relatively high levels of compression may be expected to be tolerated without any loss of diagnostic accuracy or noticeable differences between the compressed image and the non-compressed image. This is due to the high contrast ratio between the lung structures and air, compared with a lower tolerance of compression in the mediastinum (in the absence of an intravenous contrast agent) where there is a low range of contrast. However, recent studies (see below) using the visually lossless threshold have suggested less tolerance to compression in CT of the lungs but there was no measurement of diagnostic accuracy. Furthermore, with the development of multi-slice CT producing thinner scan slices, it appears that these are less tolerant to compression compared with thicker slices. However, this could be a result of the differences in assessment of different compression levels as more recent studies have concentrated on JNDs in image appearances by observers comparing the compressed image with the non-compressed image. This technique is a more stringent one in determining possible unacceptable images but does not address whether diagnostic accuracy has been compromised.  

9.2 The conclusion that 10:1 compression can be applied to CT studies can probably only be safely applied to thick studies (≥5 mm section) and studies in which there are large contrast differences. The older referenced papers predate many of the studies using thinner slices from multi-slice CT.  

9.3 Recent papers by Lee et al 20 and by Woo et al 1 on JPEG 2000 compression on CT images of the abdomen have demonstrated differences in tolerance to compression between thick and thin section images (0.67 mm and 5 mm) at different levels of compression using the visually lossless threshold criteria. Thin-section abdominal CT images are less tolerant of compression, and a lower compression level should be used for the visually lossless threshold, which in this case was no more than 6:1 compression. There were significant differences at 10:1 and higher.
9.4 If there were a local policy of sending all thin slices to PACS from a multi-slice CT then caution would be required as to the level of compression used. The study did not comment on diagnostic accuracy.

9.5 A further paper by Ringl et al., using 3D-JPEG 2000 in the abdomen using 3 mm and 6 mm slices came to similar conclusions. Images compressed at ratios of 4:1 and 8:1 were visually indistinguishable and essentially indistinguishable, from the original images (p>.01 for all readers). For the 12:1 and 16:1 ratios, all readers definitively (p<.001) identified the original images. The highest 3D-JPEG 2000 compression ratio for abdominal CT scans, at which compressed images are essentially indistinguishable from the original, was 8:1.

9.6 An earlier study by Ringl et al., on JPEG 2000 compression of thin slice CT (1 mm) of the lungs using similar techniques concluded that the tolerance to compression was even less than previously found, 'The highest ratio that yielded visually lossless compression of thin-section CT images was 3:1. With the 5:1 ratio, there was minor image quality loss, while use of higher compression ratios (≥7:1) caused substantial degradation of image quality and potential loss of diagnostic information'. An assessment of any reduction in diagnostic accuracy was not undertaken but there is a presumed 'potential loss of diagnostic information'. It is interesting to compare the results of this study with a much earlier one by Li et al., on the use of JPEG and wavelet compression on low-dose CT in the detection of small lung cancers. They concluded that the clinical detection rate using ROC analysis of small lung cancers was not compromised at a ratio of 10:1. A lower diagnostic accuracy for detecting lung tumours between 6 and 10 mm was identified at 20:1 compression.

9.7 Clearly, the stricter the criteria are for the recording of JNDs between compressed and uncompressed images and the environment in which the studies were conducted such as clinical versus laboratory controlled conditions will push the outcomes towards lower levels of compression tolerance. Studies should include an assessment on diagnostic accuracy in addition to the visually lossless threshold criteria.

9.8 Two papers on computer-aided detection and volume assessment have indicated that CAD detection performance of solid lung nodules did not suffer until 48:1 lossy compression, and using JPEG 2000 compression at 20:1 caused undermeasurement of nodule volume compared with no significant difference at 10:1.
10. Compression of CT data sets used for 3D angiography reconstructions

10.1 There is, at present, no information with regard to performing angiographic reconstructions from compressed data sets. It is likely that current radiological practice will continue to process the full data from the modality before sending the reconstructed images to store in addition to selected axial scans.

11. Compression of CT radiotherapy objects

11.1 A number of factors can affect Hounsfield unit (HU) measurements. These include metallic artifacts, bowel gas and residual barium in bowel, size of patient and so on. These factors, in addition to CT scan voltage, patient support table top scattering and inhomogeneity of a lesion, can all affect treatment volume calculations. In addition, different CT reconstruction kernels can affect changes in HU probably more so than the effects of compression.

11.2 Currently, no reference can be found on the clinical effects of JPEG 2000 wavelet compression on radiotherapy planning CT scan HU measurements or homogeneity and thus any effect on treatment volume calculations.

11.3 Wavelet compression is known to introduce ‘grain of rice’ type texture effects, rather than ‘blockiness’ and thus it is clear that application of wavelet compression can affect both the homogeneity of a lesion and the perceived margins of lesions – this is basically the same issue as the perception of image differences in diagnostic CT when the contrast differences are small. Although there are detectable differences with regard to tissue homogeneity and margin conspicuity with increasing levels of lossy compression when using stringent comparison techniques, it is not known how these effects reflect on the accuracy in terms of radiotherapy planning.

12. JPEG 2000 versus JPEG lossy (DCT)

12.1 Current work in progress suggests that JPEG 2000 compressed images are more sensitive to discernable differences in image quality in some body areas and JPEG performs better. The Canada Health Infoway (Infoway) organisation responsible for the development of the Pan-Canadian Electronic Health Care Record has concluded through the commissioning of two independent reviews examining image quality and diagnostic quality that lossy compression is a clinically acceptable option for the compression of medical images and the extent of permissible compression is dependent upon the modality. Both literature reviews consider papers up to mid-2004. Presently, the results of the total study are incomplete but a substantial body of outcomes has been sent for evaluation by the Canadian Association of Radiologists and it is now anticipated that guidance on levels of image compression in different imaging circumstances will be produced during 2008.
12.2 Some of the outcomes from the Canadian studies have indicated the preference of readers in terms of image quality for JPEG (lossy DCT) compared with JPEG 2000 at higher levels of compression studied in areas such as the brain and musculoskeletal imaging. CT of the cranium revealed a significant difference between types of compression, with a greater proportion of readers choosing unacceptable to intermediate image quality for JPEG 2000.

12.3 In terms of diagnostic accuracy, with a neuro CT JPEG was found to be more sensitive in detecting abnormalities compared with JPEG 2000. In musculoskeletal CR, statistical differences were found in abnormality detection for the level of compression with JPEG compared with JPEG 2000 at 25:1 (0.91 vs. 0.80) and at 30:1 (0.97 vs. 0.85).

12.4 Although clearly further analysis and understanding of the emerging data is required, particularly with regard to the differences between JPEG and JPEG 2000 at higher compression levels in terms of diagnostic accuracy (sensitivity) and perceived image quality, it has so far been concluded that the current position is that at the lowest levels of compression tested (for example, 10:1 for CT and 20:1 for CR), there is no loss of diagnostic accuracy and there are no differences between JPEG and JPEG 2000 in terms of image quality at the lowest compression levels tested. The formal deliberation of these studies is awaited.

13. Discussion

13.1 Relevant to the forgoing discussion is an important paper by Kalyanpur et al., which describes the effects of JPEG (lossy) and wavelet compression on images of inherently low contrast. Wavelet compression (such as JPEG 2000) performs worse than JPEG in this regard. At 20:1 compression compared with 10:1 compression, wavelet compression performs worse than JPEG in terms of low-contrast resolution, which may have the consequence of failing to detect an enhancing renal lesion (increase of 10 HU). Clearly, further studies are required to elaborate on these observations – both in terms of image quality and to assess the potential for reduced diagnostic accuracy.

13.2 It is increasingly apparent that there are differences in performance between JPEG lossy (DCT algorithm) and JPEG 2000 (wavelet-based technique), the latter appearing to affect image quality in inherently low contrast areas or those with a high noise level. Caution, therefore, has to be exercised in adopting high levels of compression. Furthermore, with increased storage of larger numbers and thinner slices from CT, the temptation to heavily compress these must be resisted due to a greater degradation of image quality.
14. **Recommendations**

14.1 On the basis of the above discussion, a conservative approach to the levels of compression is recommended, particularly with the issues raised around the loss of low-contrast resolution at high compression levels with JPEG 2000 and the increasing output of thinner scan slices from CT.

14.2 As the aim of this paper is to provide evidence for the safe use of the recommended levels of compression for different modalities for the purposes of primary diagnosis then it follows that image compression could take place at the time of image acquisition before committing information to the local short-term data store or the longer term archive to derive the benefits of increased short- and long-term storage capacity and more efficient use of the network bandwidth. A practice that may be adopted locally is the reading of images uncompressed and then committing compressed images to store. However, as the primary reading of the images may well take place outside the organisation where the images were obtained and the retrieval of the images may be dependant on data stores where the images are compressed, then there is an argument for compressing images after their acquisition and before sending to short- and long-term storage provided that the images are of diagnostic quality as various studies have demonstrated. The decision to use image compression should be a local one based on the evidence now clearly available as to the advantages and safety of the process and, most importantly, all PACS configurations should allow the choice to compress images after acquisition.

14.3 The compression ratio recommendations are as follows.

<table>
<thead>
<tr>
<th>MODALITY</th>
<th>COMPRESSION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiography</td>
<td>10:1</td>
</tr>
<tr>
<td>Skeletal radiography</td>
<td>10:1</td>
</tr>
<tr>
<td>CT (all areas)</td>
<td>5:1</td>
</tr>
<tr>
<td>Mammography</td>
<td>20:1</td>
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<tr>
<td>MR</td>
<td>5:1</td>
</tr>
<tr>
<td>US</td>
<td>10:1</td>
</tr>
<tr>
<td>Digital angiography</td>
<td>10:1</td>
</tr>
<tr>
<td>Radiotherapy CT</td>
<td>No compression</td>
</tr>
</tbody>
</table>
15. **Deciding which images to send to PACS**

15.1 With regard to multi-slice CT, the approach as to which images are sent to PACS will depend on whether the intention is to archive selected data:

a) For review purposes only once the report has been generated

b) When the images are sent to PACS for the purposes of primary interpretation.

Option A would imply that the primary diagnostic reads are performed on the modality (CT) workstation prior to selecting images to send to PACS. The selection of the images to send to PACS would be guided by local policy and may include sending thicker slices than used for the primary read or angiogram reconstructions only and not the original thin slice data set from which they were constructed. The guidance here therefore is to send to PACS what was previously archived on film. The thin slice data sets may well be stored for a defined time period on the modality storage drive should further image manipulations be required.

15.2 In Option B, which now clearly pertains to the majority of practice, all primary diagnostic reporting with some exceptions is performed on PACS and this may be done at the site of image acquisition or remotely with images accessed through a central data store. For example, with regard to CT, the slice thickness should be acceptable for diagnostic purposes and tolerate the recommended levels of compression without loss of diagnostic quality. In situations where reformatted slices (coronal CT reconstructions) are sent to PACS for interpretation, then these should be of diagnostic quality under the levels of compression applied and there should be no need to send the original thin slice data set. Often there is an automated send profile from the modality to PACS that includes reformatted images. The key message is that the image quality should be that required for diagnostic interpretation.

15.3 For diagnostic CT angiography, it would be exceptional to send all the data sets to PACS because of the high volume of data and it is likely that the thin CT slices would not tolerate high levels of compression. The reconstructed images fit for primary interpretation are sent to PACS and the usual practice would be to generate the report using the modality workstation at the time of the reconstructions. However, in circumstances where reconstructions (angiography) and other forms of multi-planar reconstruction are undertaken on the PACS itself using MPR software packages at the time of first reading or in a multidisciplinary team meeting, then current information suggests that all the acquired data (slices) is sent to PACS without lossy compression. (There is no information available to suggest that lossy compression does not affect the quality of the reconstructed image.)
16. Conclusion

16.1 The current guidance on the levels of image compression is based on a conservative approach to the currently available information and acknowledges the need for efficient image data management while ensuring patient safety.

There are several areas where further study is required particularly with regard to the use of the JPEG 2000 standard in body CT and neuro CT in terms of diagnostic accuracy as well as JNDs in areas of low tissue contrast and with regard to thin (<3 mm) slices. Further studies should not just look at the levels of visually lossless thresholds, but include the impact on diagnostic accuracy directly rather than inferring reduced accuracy from the former technique. Moreover, the effects of compression on radiotherapy CT planning have not been investigated in terms of the effects on treatment volume calculations. Studies are also required to establish the effects of compression on thin sliced data that is used for reconstructions, such as CT angiography.

16.2 Overall, there is scope for further study and the RCR and the PACS and Teleradiology Interest group could sponsor and co-ordinate such studies.

17. Current regulations and medico-legal implications of lossy compression

17.1 The main regulatory bodies in the UK, EU, USA, Canada and Australia neither prevent nor endorse lossy compression for medical images. This risk of using lossy compression is no more than in conventional practice provided that the diagnostic quality of the image is not reduced and that the decision to use lossy compression was made at an institutional level as a matter of public policy and resource allocation and there was support from at least a respectable minority of radiologists.

Acknowledgements

The College wishes to thank Dr Laurence Sutton for his help in producing this guidance; Dr Keith Foord, for research of radiotherapy CT and CT angiography and Dr David Harvey, Medical Connections Ltd for technical advice.

Approved by the Board of the Faculty of Clinical Radiology 29 February 2008
References


27. Koff DA, personal communication.
