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● *Original Contribution*

TEXTURE ANALYSIS IN DIGITALLY-ACQUIRED ECHOCARDIOGRAPHIC IMAGES: THE EFFECT OF JPEG COMPRESSION AND VIDEO STORAGE

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Abstract—The analysis of texture in video-stored echocardiographic images is an established method to characterize myocardial pathologies. We investigated whether or not texture parameters calculated from video-stored images and those derived from the joint photographic expert group (JPEG) format compressed data are equivalent to those calculated from uncompressed digital images. Texture parameters were calculated using uncompressed digital data, images stored on videotape, and three forms of compressed digital data (baseline JPEG, JPEG 2000 and lossless JPEG 2000). Video storage heavily affected most texture parameters. Although first-order texture parameters derived from JPEG-compressed images were generally equivalent to those derived from the uncompressed data, several second-order parameters differed significantly. We conclude that texture of video-stored images is not comparable to that of digitally-stored images and that JPEG compression changes important second-order texture parameters. This observation should be taken into account when analyzing texture of modern image data (uncompressed or compressed) and comparing the results with earlier studies utilizing video-stored data. (E-mail: karjer@usz.unizh.ch) © 2005 World Federation for Ultrasound in Medicine & Biology.

Key Words: **DICOM, JPG, Ultrasound, Image processing.**

INTRODUCTION

Ultrasound (US) devices use timing and intensity of sound waves reflected at the interfaces of two different media to generate an image. Myocardial texture is mainly caused by speckling, which results from the interaction of the US beam with tissue-particles that are small compared to the beam wavelength. Texture shows characteristic patterns, depending on the type of tissue being investigated. Several mathematical models exist to quantify its character. First-order statistics mainly describe the number of pixels having a certain grey level, independent of their location in the image. More complex texture parameters describe the relation of pixel intensities in the second dimension (second-order parameters). Run-length features (Chu et al. 1990; Galloway 1975) describe the distribution of pixels of the same or similar grey level, and parameters calculated from the co-occurrence matrix (Haralik et al. 1973; Pressman 1976) describe more complex interactions of pixels at a certain distance and in a certain direction. Several investigators have reported the successful use of texture analysis in various areas, including the diagnosis of amyloidosis (Pinamonti et al. 1989), myocarditis (Ferdeghini et al. 1991), the classification of myocardial hypertrophy (Di Bello et al. 1999) and the prognosis of dilated cardiomyopathy (Dagdeviren et al. 2002).

Most of the studies published on myocardial texture during the last 20 years used the mean grey level as well as its cyclic variation index. Some studies used skewness, kurtosis and first-order entropy. Others successfully used second-order statistics, including run-length parameters (long run emphasis, run-length nonuniformity, low and high grey-level run emphasis) and co-occurrence-matrix parameters (mean, variance, contrast, angular second moment, inverse difference moment, sum mean, sum variance coefficient of variance). To the best of our knowledge, all of these

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studies used image data digitized from images previously saved on videotapes. The emergence of the DICOM standard (digital imaging and communication in medicine, DICOM 2003; http://medical.nema.org) in the last years made the ability to store and transfer digitally-acquired medical images generally available. These high-quality images greatly facilitate off-line analysis of texture in US images by preventing the loss introduced by temporary storage on videotapes, as well as the use of frame-grabbers to convert the analog video data back into digital images.

Due to the high data volume of digital images and loops, the DICOM standard includes rules on how images may be compressed before they are saved on a storage unit. There are four types of compression approved by the DICOM committee for US images (DICOM 2003). Two of them, baseline joint photographic expert group (JPEG) and JPEG 2000, produce an irreversible loss of image information (lossy compression) The other two, run-length encoding and lossless JPEG 2000, do not produce loss of image information (lossless compression).

Baseline JPEG leads to typical blocky artefacts because image data are handled in blocks of 8 × 8 pixels. JPEG 2000 is not restricted to a fixed block size and might have less effect on texture. Lossless JPEG was investigated, even though it should not influence image quality because round-off errors in the encoding and decoding engines may affect texture features.

It has been shown that the loss of image quality due to JPEG compression does not impose a drawback on its clinical use (Karson et al. 1995). However, the impact of JPEG compression on texture features has not been studied. To provide a pathway from texture studies based on video-stored data to future studies based on digitally-stored data, we aimed to investigate the quantitative effect of video storage and lossy as well as lossless JPEG compression on texture.

METHODS

Image acquisition

We prospectively recorded end systolic (contracted) and end diastolic (relaxed) 2-D US frames showing the heart in cross-section (short-axis view) of eight healthy students using an Acuson Sequoia® 256 (Acuson/Siemens, Mountain View, CA; http://www.siemens-ultrasound.com). The images were saved on the Acuson internal hard drive in DICOM format using the photometric interpretations YBR_FULL (color-system conversion into YCbCr followed by RLE compression). This format is lossless for images that do not contain color pixels.

The frames used to analyze the effect of video storage were digitally recorded, saved on videotape (Sony S-VHS medical videocassette recorder SVO 9500 MDP; http://www.sony.com, Maxell S-VHS ST-120; http://www.maxell.com), and then recaptured by the Acuson device and saved in digital format.

For further analysis, the DICOM studies were transferred to a workstation using the DICOM TCP/IP network connection.

JPEG compression

The acronym JPEG is an abbreviation for the developers of this compression format (Joint Photographic Expert Group, http://www.jpeg.org). Lossy JPEG compression involves steps that potentially lead to an irreversible loss of pixel information. These are color-system conversion (rounding errors), color subsampling and pixel compression. For grey-level images (such as black-and-white US images), only the compression step is relevant, and the other steps are fully reversible.

There is no direct measure of the degree of image distortion introduced by JPEG compression. We used the so-called "quality-levels" proposed by the independent JPEG group (http://www.ijg.org), extending from the highest (100) to the lowest quality (0), indicating the amount of scaling applied to the quantization tables used for compression. The quality level generally used for baseline compression is 75 (compression ratio ≈ 1:7).

Baseline JPEG compression was done using the Intel® JPEG library V. 1.51 (http://www.intel.com) and JPEG 2000 compression was done in Photoshop V 5.5 (Adobe Corp., http://www.adobe.com) using the J2K-Plugin (http://www.fnordware.com/j2k/). We investigated eight quality levels from 95 to 25 in steps of 10, as well as a video frame for each of the eight patients.

Texture analysis

Image analysis was performed on a personal computer equipped with an Intel® 1.7-GHz Pentium™ processor running Windows 2000 SP3 (Microsoft Corp., Redmond, WA; http://www.microsoft.com). The software used for image transfer to the workstation as well as for the texture-analysis is not yet a commercially available application (EchoAnalyzer V. 2.01) written in Visual Basic® 6.0 SP5 (Microsoft Corp.) by the first author of this study.

The software calculated 35 selected texture parameters of the regions-of-interest (ROIs) set by the operator and saved these values in a database for further statistical analysis.

The analysis was done for the original and video-stored image as well as for all the different JPEG-compressed images, leaving the ROIs at identical pixel

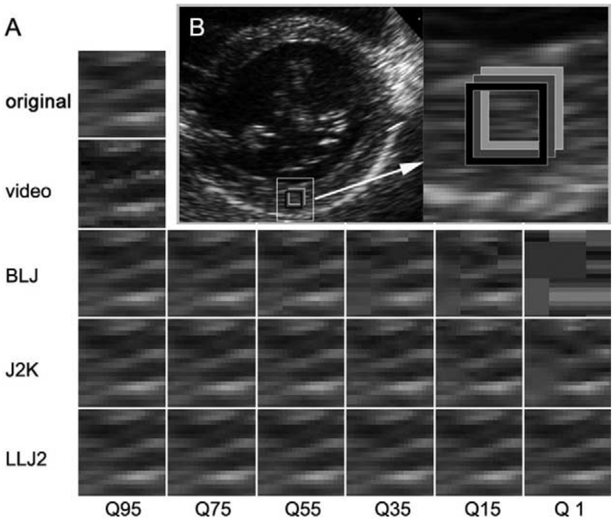

Fig. 1. (a) The enlarged regions are shown to illustrate the effect of different types of JPEG compression on visual image quality. Every block corresponds to one pixel. Lossless JPEG is not affected by quality levels; images are shown for comparison. (b) The inset demonstrates how the three ROIs were chosen within the posterior wall. BLJ = baseline JPEG; J2K = JPEG 2000; LLJ2 = lossless JPEG 2000; Q95–Q1 = quality level.

positions. We thereby assured that any change in value of a texture parameter was due solely to the effect of JPEG compression or video storage (Fig. 1a).

Run length was calculated in the horizontal direction using 256 bins. The co-occurrence matrix was generated for a distance of two pixels in the horizontal direction.

Texture values were calculated for systolic and diastolic images and, from these values, we calculated the cyclic variation index (CVI) defined as: $(\text{Value}_{\text{end-diastolic}} - \text{Value}_{\text{end-systolic}})/\text{Value}_{\text{end-diastolic}} \times 100$ (Lythall et al. 1992).

Statistical analysis

Due to the variable nature of texture in US images, texture values of ROIs in a homogeneous region will differ slightly (within-subject variability, WSV). If a texture value calculated from compressed or video-stored (= processed) images differs from the value calculated from uncompressed (= original) data, but this difference remains within the WSV of the original image, it is still called equivalent.

Using images from echocardiographies obtained in eight volunteers, we calculated the mean differences ± 95% confidence interval (CI) between the texture values of the uncompressed image and its processed version. This is a measure of the change caused by processing of the image. To assess the WSV for each texture parameter, we calculated the mean and SD of three ROIs shifted by two pixels to the left and to the top in the original image (Fig. 1b).

Texture values of processed data were defined to be equivalent to texture values of the original image, if their mean difference ± 95% CI remained within the WSV of the original image (Fig. 2). Using this approach, the probability of erroneous equivalence remains less than 5% ($p < 0.05$).

Statistical analysis was done using SAS (http://www.sas.com).

RESULTS

The effects of video storage and JPEG compression on digitally-stored image data are reported in Table 1. Video storage has a striking effect on texture of both the systolic and the diastolic images. Mean grey level was significantly lower (Fig. 2a), whereas contrast was higher in video-stored images (Fig. 2b).

When the cyclic variation index (CVI) was used for analysis instead of the value of the systolic or diastolic image alone, several texture parameters became equivalent to the original (first order: variance, kurtosis and entropy; run length: grey-level nonuni-

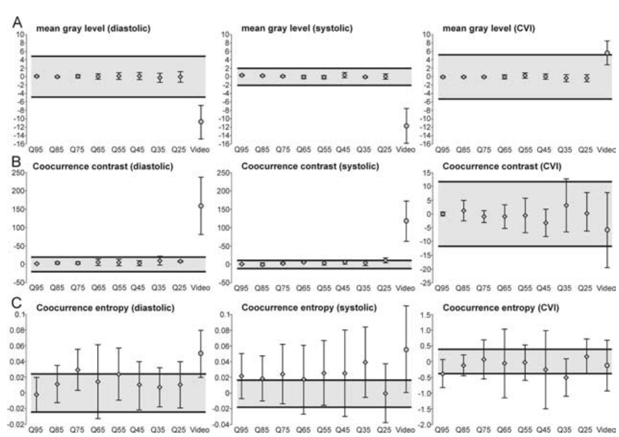

Fig. 2. (a) The first three graphs demonstrate a texture parameter (mean grey level) that remained equivalent in spite of JPEG compression. The mean ± 95% CI of the difference (circles with range indicators) between the texture value of the original and the compressed image remained fully within the within-subject variability of three measurements made in shifted ROIs of the original image (gray band). The last bar showing mean grey level in video-stored images ("Video") lays outside the shaded area. This denotes a significant effect on texture caused by video storage. For a more detailed definition of the term equivalence, see text. (b) Contrast was affected by JPEG compression at a quality level of 35 and less only, remaining equivalent at Q75, the level used in most US devices. Contrast was also affected by video storage. (c) Entropy was changed significantly by JPEG compression and video storage had a similar effect. Values are shown for systolic and diastolic images and for the CVI.

Table 1. Effects of video storage and JPEG compression on digitally-stored image data

	Diastolic				Systolic				CVI			
Texture class parameter	BLJ	J2K	LLJ2	Video	BLJ	J2K	LLJ2	Video	BLJ	J2K	LLJ2	Video
First order grey level												
Mean grey level	*	*	*	†	*	*	*	†	*	*	*	†
Variance	*	*	*	†	*	*	*	†	*	*	*	*
Skewness	*	*	*	*	*	*	*	*	*	*	*	*
Kurtosis	*	*	*	*	*	*	*	†	*	*	*	*
Entropy	*	*	*	†	*	†	*	†	*	*	*	*
Run lengths												
Short-run emphasis	†	†	*	†	†	†	*	†	†	†	*	†
Long-run emphasis	†	†	*	†	†	†	*	†	†	†	*	†
Grey level nonuniformity	†	(†55)	*	†	(†25)	(†55)	*	†	(†55)	(†65)	*	*
Run length nonuniformity	†	†	*	†	†	†	*	†	†	†	*	†
Run percentages	†	†	*	†	†	†	*	†	†	†	*	†
Low grey-level emphasis	*	(†65)	*	†	*	(†45)	*	†	*	(†45)	*	†
High grey-level emphasis	*	*	*	†	*	*	*	†	*	*	*	†
Co-occurrence												
Mean	*	*	*	†	*	*	*	†	*	*	*	†
Variance	†	*	*	†	*	*	*	†	*	*	*	*
Contrast	(†35)	*	*	†	(†35)	(†25)	*	†	(†35)	*	*	†
Angular 2nd moment	†	†	*	†	†	†	*	†	†	†	*	†
Inverse diff. Moment	†	†	*	†	†	†	*	†	†	†	*	†
Entropy	†	†	*	†	†	†	*	†	†	†	*	†
Maximal probability	†	†	*	†	†	†	*	†	†	†	*	†
Correlation	*	*	*	†	(†35)	(†25)	*	†	*	*	*	†
Cluster shade	*	*	*	†	*	*	*	†	*	*	*	*
Cluster prominence	*	*	*	†	*	*	*	*	*	*	*	*
Sum average	*	*	*	†	*	*	*	†	*	*	*	†
Sum variance	*	*	*	†	*	*	*	†	*	*	*	*
Sum entropy	*	*	*	*	†	(†65)	*	†	*	*	*	*
Difference mean	*	*	*	†	*	*	*	†	*	*	*	†
Difference variance	*	*	*	†	*	*	*	†	*	*	*	*
Difference entropy	*	*	*	†	†	†	*	†	*	*	*	*
Measure of correlation I	*	*	*	*	(†25)	*	*	†	*	*	*	*
Measure of correlation II	*	*	*	*	*	*	*	*	*	*	*	†
Coefficient of variation	*	*	*	†	*	*	*	†	*	*	*	†
Diagonal variance	†	†	*	†	†	†	*	†	†	†	*	†
Diagonal moment	(†65)	*	*	†	†	†	*	†	*	*	*	†
Second diagonal moment	*	*	*	†	*	(†25)	*	†	*	*	*	†
Product moment	*	*	*	†	†	*	*	†	*	*	*	*

* Equivalent to the original; † not equivalent to the original. The numbers within parentheses denote the level on which equivalence was lost when this was true for a level below Q75, that used by commercial US devices. BLJ = baseline-JPEG; J2K = JPEG 2000; LLJ2 = lossless JPEG 2000; CVI = $[\text{Value}_{\text{end-diastolic}} - \text{Value}_{\text{end-systolic}}]/\text{Value}_{\text{end-diastolic}} \times 100$.

formity; co-occurrence: variance, cluster shade, difference variance, difference entropy and product moment). This, however, was not true for the mean grey level.

First-order grey-level statistics derived from JPEG-compressed images were largely equivalent to those calculated from uncompressed data. However, most run length parameters and some parameters calculated from the co-occurrence matrix (variance, angular second moment, inverse difference moment, entropy, maximal probability and diagonal variance) were affected by JPEG compression. This was due to the introduction of random variability and, for some parameters, to a shift of the mean value.

Contrary to our expectations, JPEG 2000 did not perform better than baseline JPEG. As expected, lossless JPEG 2000 had no effect on texture.

A graphic representation of the effect of JPEG compression and video storage on three texture parameters is given in Fig. 2. Mean grey level remained equivalent in spite of JPEG compression because its mean ± 95% CI of the difference between the texture value of the original and the compressed image remained within the ± 1SD of the texture values in the three ROIs (shaded area). In contrast, video storage had a major effect on the mean grey level. Figure 2b shows a parameter (co-occurrence contrast) for which we could not demonstrate equivalence from a quality level of 35 or lower and, again, video storage had a much larger effect. Co-occurrence entropy (Fig. 2c) was clearly affected by JPEG compression; the effect of video storage was similar in magnitude.

DISCUSSION

The equivalence of texture in compressed and uncompressed images is visually difficult to recognize. In the present study, we defined texture in a region of a compressed or video-stored image to be equivalent to texture in the corresponding region of the original image, if the difference of their texture parameter values did not exceed a SD of the region of the original image and two more overlapping regions chosen in a visually homogeneous region. The three regions chosen in the original image shared 64% of their pixels and so their texture values lay within a relatively small band. Although this definition may seem to be strict, a looser definition would not allow us positively to identify texture parameters that are unaffected by video storage or JPEG compression.

Our study demonstrates that texture in video images is not comparable to that of digitally-stored images. In particular, mean grey level was significantly affected by video storage. To a lesser extent, the same applies for the mean grey-level CVI. Because most of the studies published on texture thus far used video images, caution is warranted when comparing new findings with earlier studies.

The observation that some texture parameters (such as skewness) remained equivalent in spite of video storage does not necessarily imply that they should be used to compare the texture of digital images with that of video-stored images, because texture depends on the video recorder and tape used. Therefore, different devices may affect different parameters and some devices might affect skewness but other parameters could be unaffected.

With the exception of the systolic entropy value, JPEG compression did not affect first-order texture parameters. Conversely, most run-length parameters, as well as some of the parameters calculated from the co-occurrence matrix (*e.g.*, inverse difference moment, angular second moment and entropy), were significantly affected by image compression. The finding that these parameters were affected by lossy JPEG compression (in both its forms) emphasizes their sensibility to changes in texture.

Parameters such as the mean grey level that remain equivalent in spite of JPEG compression may be used for the analysis of JPEG-compressed images and also for a comparison of texture in uncompressed and JPEG-compressed images.

When trying to use texture for clinical decision-making, one will usually compare two different patient groups and attempt to identify a statistically significant difference in texture parameters. Our study shows that several texture parameters are affected by video storage and JPEG compression. However, the difference in texture existing between two study groups may remain unaffected. A lack of equivalence can be due to two causes. Storage or compression can cause a consistent change in texture value, causing the mean difference from the original texture value to lie outside the expected band ($\pm$ 1 SD) (as caused to the mean grey level of video data; see Fig. 2a) or it can broaden the spectrum of texture values obtained, leading to a broader confidence interval (Fig. 1c).

Video storage mainly affects the mean grey level by causing a large shift in mean values, so there will probably also exist a statistically significant difference when comparing two digital images. On the other hand, JPEG compression affects second-order parameters by a progressively broader confidence interval caused by the introduction of a random variability. This makes it likely that the power to detect a difference between two groups will be decreased.

The CVI was introduced as an additional parameter that is less sensitive to bias because it is not an absolute measure, but a measure of change in texture from diastole to systole. Being a ratio, it is less sensitive to device settings, systematic measurement errors and to image distortion affecting both images (systolic and diastolic). Its great potential can be estimated by the fact that the CVIs of 13 texture parameters were equivalent to the original, in spite of a significant effect of video storage or JPEG compression on the systolic and/or diastolic image. In our opinion, the CVI has great potential to simplify the clinical use of texture analysis and to create reproducible study results.

CONCLUSION

Video storage markedly affects most of the texture parameters investigated. Scientists planning to study myocardial texture in digitally-stored images should be aware that results may differ from earlier studies based on video-stored images.

JPEG-compressed images can be used in studies using first-order texture parameters, but some of the most often used second-order parameters are affected by JPEG compression.

We recommend the use of uncompressed or lossless compressed digital images in future studies involving texture analysis. The use of the CVI may be the key to optimal comparability among texture studies.

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