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Abstract: We have examined the impact of a gain on contrast-enhanced ultrasound video (JPEG DICOM) and radiofrequency (RF) data. The gain is one of main acquisition parameters and therefore, its influence on a data analysis might be huge. The gain was set in a range of 10 to 50 dB. Imaging was performed with an ultrasound system Vevo 2100 and a linear array probe MS 250 with a transmit frequency of 18 MHz. A contrast agent used in this study was Sonovue (Bracco, Milan, Italy). Measurements were performed for two solutions with a different contrast agent concentration (a dilution factor of 1:4 and 1:16, a solvent is saline). The impact of the gain was evaluated using three parameters: the contrast to background ratio (CBR), the contrast to noise ratio (CNR) and the background to noise ratio (BNR). In RF data, an image intensity grows up continually with the increasing gain but in video data, saturation can occur at higher values of the gain. In terms of the CBR, CNR and BNR, the impact of the gain on RF data is negligible but on video data is substantial.

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Abstract *– We have examined the impact of a gain on contrast-enhanced ultrasound video (JPEG DICOM) and radiofrequency (RF) data. The gain is one of main acquisition parameters and therefore, its influence on a data analysis might be huge. The gain was set in a range of 10 to 50 dB. Imaging was performed with an ultrasound system Vevo 2100 and a linear array probe MS 250 with a transmit frequency of 18 MHz. A contrast agent used in this study was Sonovue (Bracco, Milan, Italy). Measurements were performed for two solutions with a different contrast agent concentration (a dilution factor of 1:4 and 1:16, a solvent is saline). The impact of the gain was evaluated using three parameters: the contrast to background ratio (CBR), the contrast to noise ratio (CNR) and the background to noise ratio (BNR). In RF data, an image intensity grows up continually with the increasing gain but in video data, saturation can occur at higher values of the gain. In terms of the CBR, CNR and BNR, the impact of the gain on RF data is negligible but on video data is substantial.*

1 Introduction

Ultrasonography is a low–cost non–invasive and non–ionizing technique. There was still not found that ultrasound (US) inflicts tissue damages at low power, which is commonly used in diagnostics. Consequently, ultrasonography became a worldwide spread diagnostic tool [1, 2]. However, due to physical properties of tissues (particularly acoustic impedance), US images do not provide a high contrast between adjacent structures and boundaries between them are generally very smooth. This drawback is partly overcome by using ultrasound contrast agents (UCA). The usage of UCA increases the contrast and the boundaries become sharper. This facilitates distinguishing the structures from themselves.

Nevertheless, the image quality (contrast, resolution, noise level...) is mainly given by acquisition parameters of an ultrasound system. The acquisition parameters are especially transmit power, a transmit frequency, a dynamic range and a gain. Although, settings of the transmit power and frequency play the main role, inconvenient settings of the dynamic range and gain may decrease the image quality and negatively influence a data analysis (e.g. a perfusion analysis) [3–6].

Ultrasound systems enable the exporting of data in different formats, such as JPEG or DICOM. Some ultrasound systems also enable the exporting of data in a raw radiofrequency (RF) format. Standard formats are preprocessed and reduced but the RF format is not preprocessed and even reduced. So, the RF format is the most appropriate format for any data analysis.

The objective of this study was to investigate the impact of the gain on video (JPEG DICOM) and RF data using a high frequency animal ultrasound scanner and a standard contrast agent, originally developed for human applications. The gain is one of more factors determining a resulting intensity of an image. This study deals with if and how much different the impact of the gain on the image intensity between video and RF images is. In addition to that, whether the gain setting can distort a data analysis and eventually to propose an interval of gain values, in which the data analysis is minimally or not distorted. The impact of the gain on the quality of the image was evaluated on the basis of three parameters: the contrast to background ratio, the contrast to noise ratio and the background to noise ratio (a detailed explanation in the section 2.3 Data analysis).

2 Materials and Methods

2.1 Static phantom

A phantom is formed by agarose gel, in which a plastic container with a contrast agent (SonoVue™ – Bracco, Milan, Italy) is placed. SonoVue™ is sulphur hexafluoride microbubbles with a phospholipid shell. The solution of SonoVue was prepared at two concentrations. The first solution (a high contrast agent concentration – HS) was diluted at a rate of 1:4 with saline and the second (a low contrast agent concentration – LS) in a rate of 1:16. These concentrations were chosen with regard to echo strength and attenuation. To keep the contrast agent (CA) concentration on the same level during measurements, solutions was mixed immediately before measurements and sealed in the container.

2.2 Data acquisition

Data were acquired by using a Vevo 2100 ultrasound imaging system and saved in 32 bit In–phase Quadrature (IQ) format data. 8 bit log–compressed grayscale JPEG DICOM and 32 bit RF images were extracted from the IQ data. Scanning the scene was performed in a nonlinear contrast mode (amplitude modulation) by a linear array probe MS 250 with a transmit frequency of 18 MHz and transmit power of 4 % to eliminate bubble destruction. No time gain compensation was included. A dynamic range of 40 dB was set up for JPEG DICOM data. Gain was increased from 10 to 50 dB with a step of 2 dB. For each gain change, a 50–frame image sequence was recorded.

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2.3 Data analysis

An analysis was performed using Matlab R2013a. Only images of 20 to 44 (25 frames) were included in the analysis because, at the beginning of each sequence, there are huge intensity changes in a contrast area. The two rectangular regions of interest (ROI) were selected manually for every image. One ROI (the white rectangle in Figure 1 center) represents the contrast area (CA) and the other rectangle (the dashed rectangle in Figure 1 center) represents the background (BG). For the correct analysis, the size and position of selected ROIs were very similar, especially the depth due to attenuation. Both ROIs were selected three times for every image to minimalize the irregularity of the manual selection. The manual selection of ROIs was necessary in order to avoid specific artefacts, which can appear in the scene (e.g. air bubbles). Figure 1 shows three frames of HS recorded for the gain of 16, 30 and 44 dB.

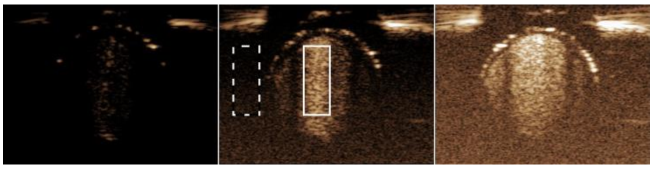

Figure 1: The images of HS recorded for the gain of 16 (left), 30 (center) and 44 dB (right)

The signal intensity in the ROI is calculated as median because data does not have the Gaussian distribution. The noise intensity in the ROI is expressed as standard deviation. Because three ROI selections were made in one image, the final intensities are given by averaging of three values. The below discussed shapes of curves are determined by using the calculation of their first difference. As aforementioned, the impact of the gain on the image quality was evaluated according to three parameters: the contrast to background ratio (CBR), the contrast to noise ratio (CNR) and the background to noise ratio (BNR). These ratios were computed as:

$$CBR = 20 \times \log_{10} \frac{CA\ signal\ intensity}{BG\ signal\ intensity}, \tag{1}$$

$$CNR = 20 \times \log_{10} \frac{CA\ signal\ intensity}{CA\ noise\ intensity}, \tag{2}$$

$$BNR = 20 \times \log_{10} \frac{BG\ signal\ intensity}{BG\ noise\ intensity}. \tag{3}$$

3 Results

We have investigated the impact of the gain on the signal and noise intensity in JPEG and RF images. The impact was evaluated on the basis of the contrast to background ratio, the contrast to noise ratio and the background to noise ratio.

The graph of the signal intensity against the gain for the contrast area and the background is illustrated in Figure 2.A (JPEG) and Figure 2.B (RF). In JPEG, the increase of the intensity for all three curves is linear from a certain gain value and for the HS curve we can see saturation around the gain of 44 dB for the higher UCA concentration. On the contrary, no saturation (in our gain interval) is observed in RF and moreover, the relation is quadratic. In JPEG, the intensity of the contrast areas and the background increases approximately the same way resulting in the decline of the CBR, as seen in Figure 3.A (the CBR cannot be calculated for the gain of 10–24 dB because of the zero intensity of the background). Unlike this, in RF, the intensity of the contrast areas and the background increases differently, HS and LS curves show considerably bigger growth than the BG curve. However, the growth is not so divergent to increase the CBR. The CBR oscillates around a specific value (Figure 3.B). As expected, the higher CBR is reached in the HS solution.

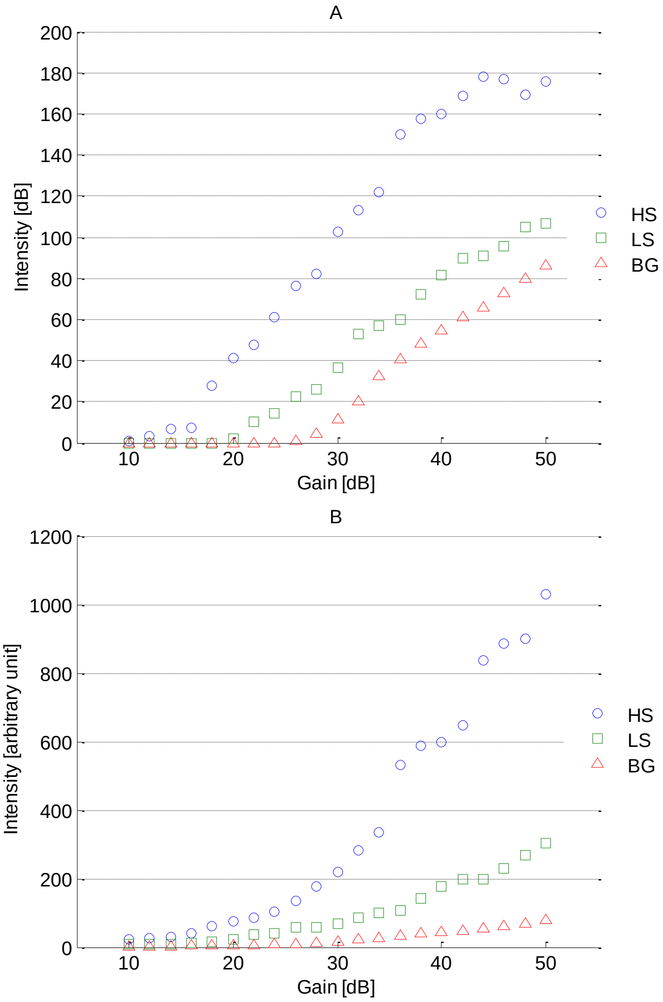

Figure 2: The intensity depicted against the gain for the contrast areas of HS and LS and the background. (A) JPEG image. (B) RF image

The level of noise in JPEG and RF images is depicted in Figure 4. The noise intensity in RF for HS, LS and BG seems to grow quadratically as well as the signal intensity in RF. Unlike this, the JPEG noise intensity does not correlate with the JPEG signal intensity. The level of the HS and LS noise stabilizes with the increasing gain. It is interesting that the noise levels of the HS and the LS are comparable in a steady part. The BG noise starts to grow from 20 dB and then it

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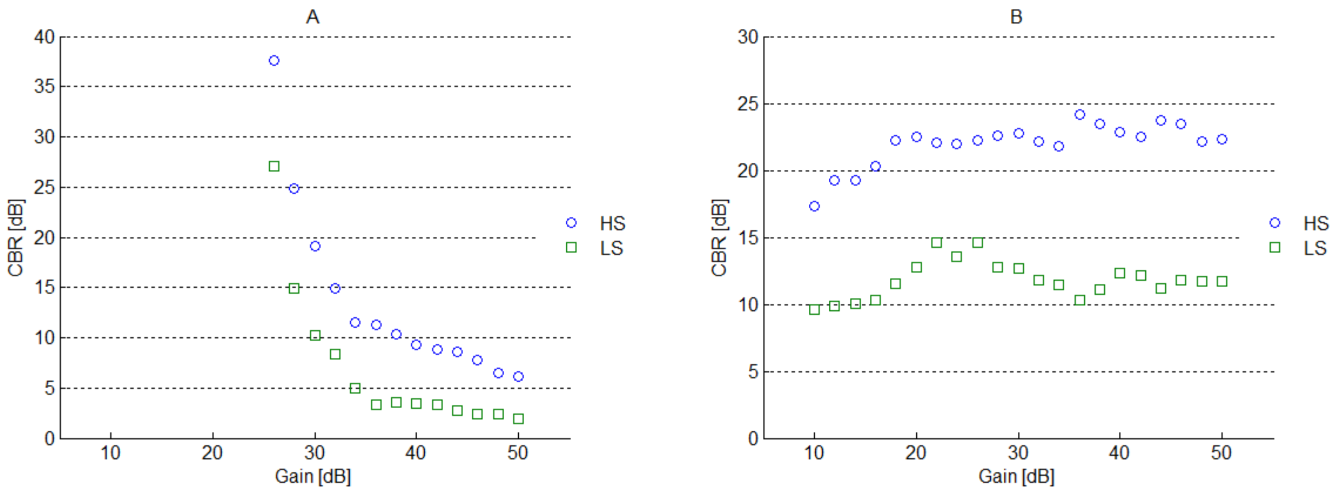

Figure 3: The contrast to background ratio of HS and LS depicted against the gain. (A) JPEG image. (B) RF image

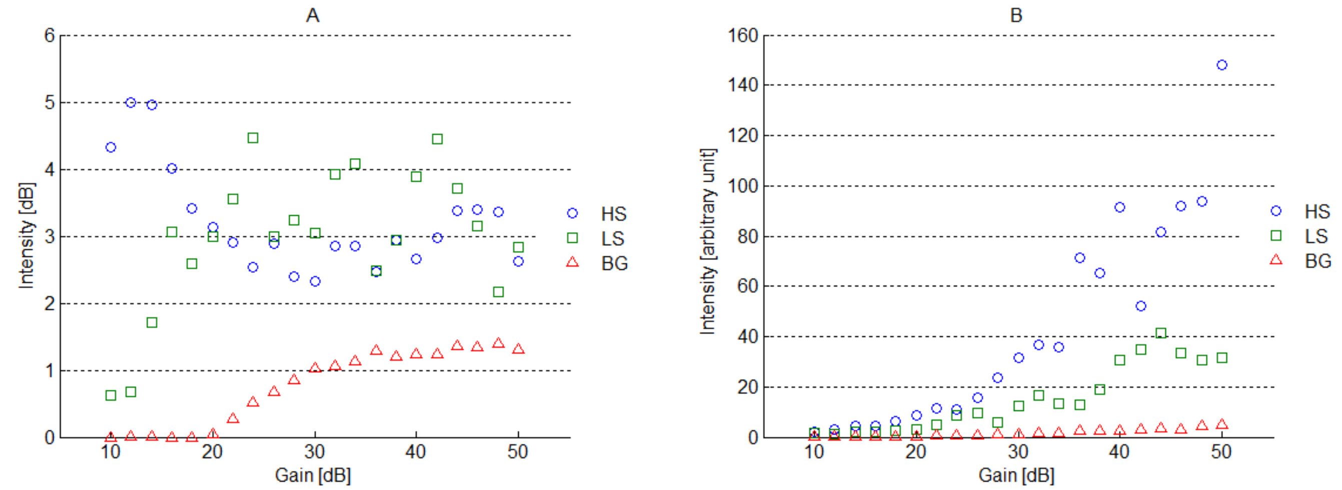

Figure 4: The noise intensity depicted against the gain for the contrast areas of HS and LS and the background. (A) JPEG image. (B) RF image

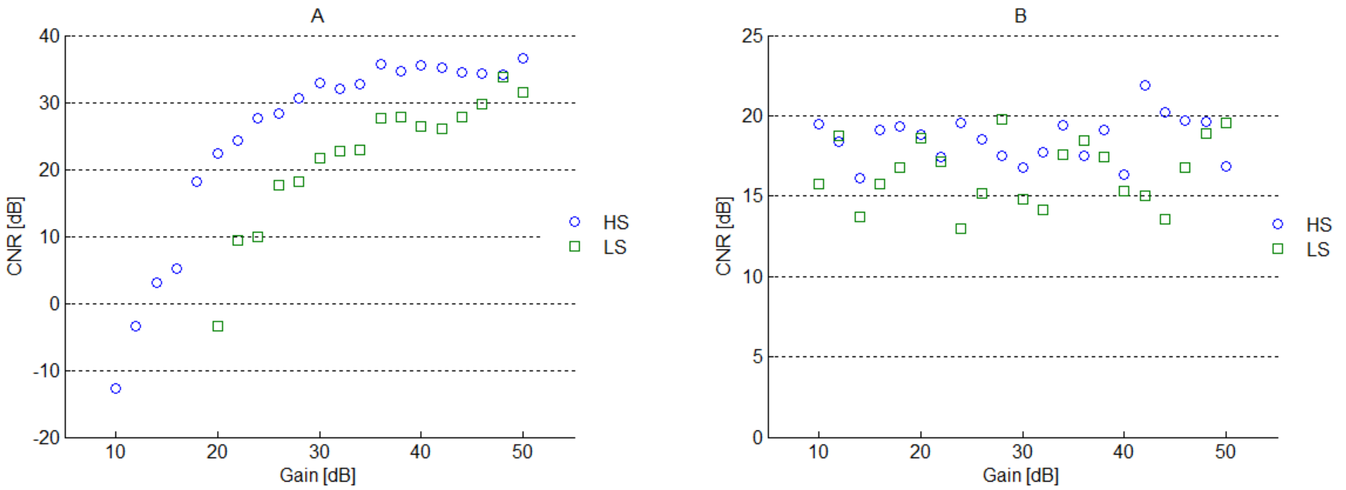

Figure 5: The contrast to noise ratio of HS and LS depicted against the gain. (A) JPEG image. (B) RF image

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stabilizes as well.

In JPEG, the CNR opposite the CBR increases logarithmically with the gain and for the higher gain, we can observe a saturation state (mainly at HS), as illustrated in Figure 5.A (some LS CNR values are not calculated due to zero intensities for some gain values). In RF, the CNR as well as the CBR oscillates around a specific value (Figure 5.B). And again, it was found out the higher CNR at the higher UCA concentration solution.

Figure 6 shows the BNR against the gain for JPEG and RF images. The BNR curves (JPEG BNR values are not calculated in whole interval because of the zero intensities of the background) have similar waveforms as the particular CNR curves in Figure 5.A and 5.B.

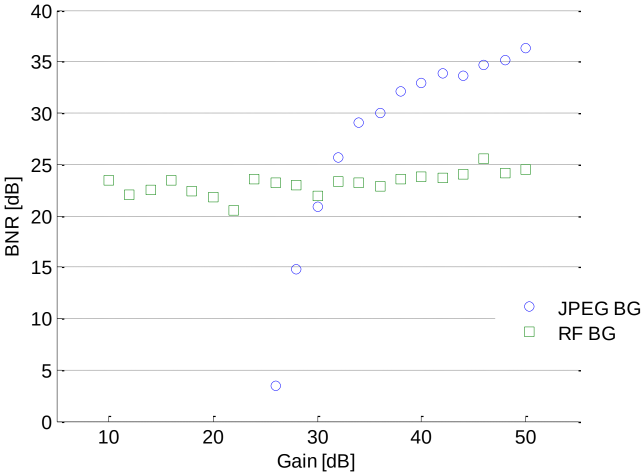

Figure 6: The background to noise ratio depicted against the gain for JPEG and RF image

4 Discussion

The gain influences JPEG and RF contrast–enhanced ultrasound images quite differently. The signal intensity increases with the gain quadratically in RF, whereas linearly in JPEG (in a given part). Furthermore, the signal intensity increase in RF seems to be infinite unlike that in JPEG where saturation occurs. The noise intensity in RF increases with the gain quadratically infinitely again but in JPEG keeps a particular level for higher gain values. The different influence of the gain can be clearly seen in the CBR, the CNR and the BNR. These ratios are not practically influenced by the gain in RF, whereas they reveal the large impact of the gain on JPEG images.

Gain values lower than about 26 dB are not very convenient because a contrast signal is too weak, as seen in Figure 1 and 2. Thus, it is not possible to determine exactly the margins of contrast areas and also in cases of the very low gain (lower than 20 dB) to detect entire contrast areas. On the other hand, only in JPEG, higher gain values can result in the saturation (Fig. 2.A – HS curve). Similar results were reported in [7].

The very weak signal and the saturation complicate contrast agent concentration estimation, which is very significant for a perfusion analysis. So, in JPEG, we have to choose the gain very carefully to be able to differentiate various levels of UCA concentrations. In RF, we are not limited by the saturation and moreover, intensity differences between UCA concentrations increase with the growing gain. Thus, concentration estimation is more accurate for higher values of the gain.

In the study [5] there was found that the gain influences visualization depth. The deeper structures become more visible with the higher gain. Sanne A. E. Peters et al. has found the major impact of the gain on echolucency measurements of the far wall common carotid intima-media in video data [6].

The gain setting is a more difficult task in JPEG than in RF. The gain value should be set up with the regard to three main factors: the contrast signal intensity, the CBR and the CNR (these two ratios represent the background and noise intensities). These factors determine the quality of a contrast-enhanced US image. In JPEG, the CBR drops with the gain unlike the CNR that grows with the gain. So, finding the compromise between the CBR and the CNR is important. Similarly, it is important to find trade-off between the contrast intensity and the CBR and the CNR as well. In RF, the CBR and the CNR behave the same way, so it is not necessary to compromise between them. As aforementioned, the contrast intensity must be sufficient to visualize structures.

5 Conclusions

The impact of the gain on RF images is negligible according to the CBR, CNR and BNR, whereas it is substantial in JPEG images. Even if, the CBR, CNR and BNR in RF are practically constant in the whole measured range, the gain lower than about 20 dB is not appropriate because of the very low signal intensity. For the higher gain (in the measured range), the signal intensity is sufficient and therefore, the settings of the gain are not limited.

The gain setting in JPEG depends on more parameters than that in RF. The signal intensity is too weak at the low gain and on the other hand, the high gain causes saturation. Moreover, the low or high gain is not suitable with regard to the CBR and CNR. Thus, middle values of gain are required. Gain values can be higher for low contrast agent concentration solutions.

Acknowledgements

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